Australian Society of Exploration Geophysicists

OCTOBER 2020 • ISSUE 208
ABN 71 000 876 040 ISSN 1443-2471

PREVIEW

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FRONT COVER

Installing a seismometer station in the SWAN network. See report by the Geological Survey of Western Australia for more information.

Preview is available online at
https://www.tandfonline.com/toc/texp20/current
ISSN: 1443-2471 eISSN: 1836-084X

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Editor's desk

In this issue our "best of" series, marking the 50th anniversary of the establishment of the Australian Society of Exploration Geophysicists, continues with a selection made by Dr Annetts, the current President of the ASEG. David's selection is the penultimate selection in this series that I, for one, have found most intriguing. We also have a second feature in which Roger Henderson muses about the life and times of Pierre Bouguer – a man whose name is pretty much constantly on the lips on anyone working with gravity data.

One of our Corporate Plus sponsors, Total Seismic, has accepted our standing invitation to tell ASEG Members more about the services they provide. Their article focuses on onshore seismic data acquisition and reviews some of the recent advances in the field. These advances have resulted in the cost of data acquisition falling at the same time as the speed of data acquisition is increasing. Partly as a consequence of these trends, Total Seismic reports that its client base is diversifying and now includes engineers and environmental managers.

The apparent growth in the application of geophysics to engineering and environmental problems is particularly welcome at a time when petroleum exploration is in decline as the supply of oil overwhelms demand, and some of our colleagues are finding that they need to consider new markets for their geophysical skills.

Our Geological Surveys continue to outdo themselves in terms providing both new and re-worked geophysical survey data. Every issue of *Preview* presents a feast in that regard and, as most the data is freely available, there is no excuse for idle hands!

As well as updating us on Canberra politics, David Denham (*Canberra observed*) wonders whether oil is headed the same way as coal. Terry Harvey (*Mineral geophysics*) reviews gravity data corrections, incidentally reminding us of the importance of Bouguer. Mick Micenko (*Seismic window*) introduces work being done by CSIRO, including our own Marina Pervukhina, on automatic facies classification for seismic inversion. Tim Keeping (*Data trends*) has a crack at wavelet transforms, and Ian James (*Webwaves*) pokes his nose into the IT initialisms.

Enjoy!

Lisa Worrall
Preview Editor
previeweditor@aseg.org.au

The Editor getting up close and personal with granites that have intruded the Hodgkinson Formation in the Hodgkinson Province in far North Queensland.

Vale: Patrick Hillsdon

'Pat' as he was better known to all his colleagues and friends, was a good mate to them all. Already news of his sudden passing, at home in Bowral on 11 September, is generating fond memories from many of us.

Pat was a great supporter of the functions of the ASEG from its early days and in particular in helping to organise the conferences. In his happier times he enjoyed the social events associated with them. He was always helpful to others with his better knowledge and experience.

A full obituary is in preparation and contributions will be welcomed. Contact Roger Henderson at rogah@tpg.com.au.

President’s piece

At the time of writing, Australia is about six months into the COVID-19 pandemic. Electronic meetings have become commonplace, replacing physical meetings and associated travel. Lockdowns have been imposed, then relaxed, then reimposed as localised cases increase. We have not resumed business as usual and, although there are encouraging signs, no clear date can be set as to when normality will be restored or what normality will look like when it is.

In preparing this column, I could not help recalling a Microsoft Conference in which the then CEO, Steve Ballmer, opened his presentation by bouncing around the stage screaming "developers" at least 14 times in an effort to impress upon the audience the target market of the Windows 2K operating system that Microsoft was introducing at the event. Copies can be found on YouTube, and it remains an extreme example of the passion exhibited by a famously passionate individual. At its core, the ASEG is not about developers. The ASEG, as with this *President’s piece* is fundamentally about Members.

The COVID-19 pandemic forced a rethink of the strategy and planning day that immediately follows the AGM. In 2020, instead of devoting single day to planning over a number of topics, three longer more focussed sessions were held, and all covered aspects of the ASEG membership including structure, conditions, finances and education. Suzanne Haydon, our current Memberships Chair, has been central to focusing and orienting membership classes and conditions for the future. Several actions resulting from these discussions will be implemented between the time of writing and publication, and Members are encouraged to monitor their inbox as the early-bird renewal period opens about a month earlier than previously.

Pending normality, the ASEG will continue to offer webinars to the membership and a wider audience as a replacement for the technical meetings and as an effort to include the International Members that comprise roughly 15% of the ASEG. These webinars may be viewed live or at leisure on the ASEG’s YouTube channel, which was reviewed in depth by Ian James, our current webmaster, in the last issue of *Preview*. Figure 1 plots the number of views received by each webinar as a function of days after posting. For those undecided as to whether or not to present a webinar or wait until a face-face meeting, I can offer the following. Technical webinars have been attended by a large proportion of ASEG Members, mostly from Australia as expected, but with significant representation from South Africa, India, USA, Canada and New Zealand. Videos subsequently posted on the ASEG’s YouTube channel generally acquire between one view every two days and one view each week. As with pre-COVID technical nights, there is some variability with numbers over each webinar. Although median attendance is around 50, similar to a better-attended technical night in WA, it is particularly interesting that there is no general correlation between webinar attendance and YouTube views. This suggests that, unlike technical nights and conferences, webinar presentations can target different time zones addressing an engaged and motivated Australian and international audience, especially when combined with promotion through social media. Webinars are a cost-effective method of introducing your work to a wide, and growing, motivated audience. Either the ASEG’s President Elect, Kate Robertson (president-elect@aseg.org.au), the president of your local state branch (*president@aseg.org.au where * is one of act, nsw, vic, qld, sa, tas or wa), or I would welcome inquiries about presenting a webinar.

By my count, that makes nine references to Members in this *President’s piece*. Although around half as many as Steve Ballmer’s "developers", ASEG Members are no less important, and, in any case, it was never a competition.

David Annetts
ASEG President
president@aseg.org.au

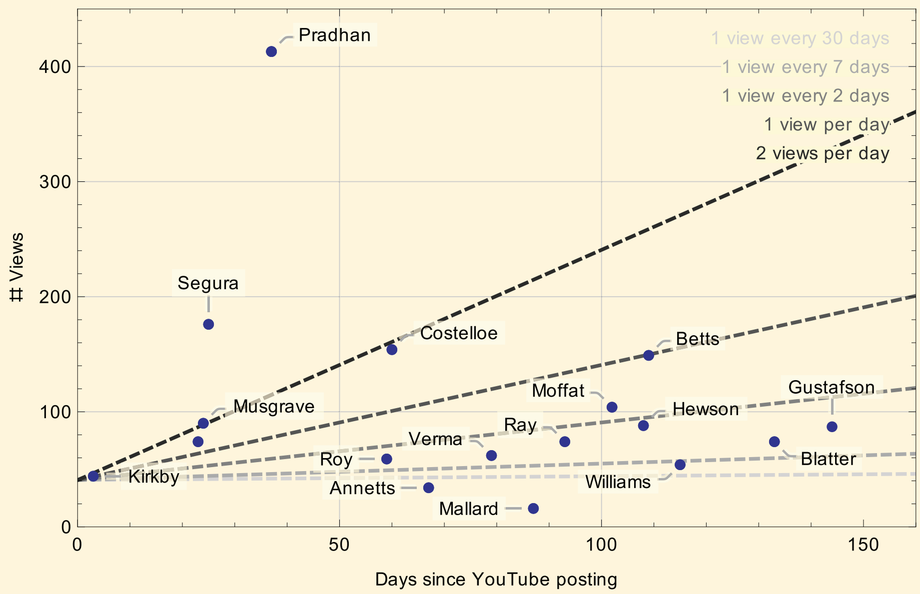

Figure 1. *Views of ASEG webinars as a function of days after posting on the ASEG’s YouTube Channel on 12 September, 2020. Most webinars acquire an extra view every two - three days. There are a few exceptions. The large number of views of webinars by Pradhan and Segura appears to be a function of promotion on social media networks.*

Executive brief

The Federal Executive of the ASEG is the governing body of the ASEG. It meets once a month via teleconference to deal with the administration of the Society. In the normal course of events, the newly elected committee meets for a strategic planning day immediately after the AGM, to determine the strategic focus for the coming year. Due to the restrictions surrounding COVID-19, the usual strategy day was not able to be held as a face-to-face meeting in 2020. The committee has, instead, held three online meetings to discuss the important issues currently facing the Society. The three areas of discussion centred around membership, financials and education, with the focus being on innovative ways to attract and retain members and students, and to develop a sustainable society into the future in an ever-changing world.

A key part of the discussions centred around virtual and online access to information, education, publications and conferences, which has come to the fore more than ever during the events of 2020. The committee agreed that some form of virtual aspect is required in all key areas of the Society, and supports the development of virtual/hybrid models for future events and conferences. All the while, maintaining the underlying mission of the Society to provide an environment for the science of applied geophysics to grow for the benefit of its Members and the wider community.

This following brief reports on the monthly meeting that was held in September 2020. If there is anything you wish to know more about, please contact Leslie at fedsec@aseg.org.au.

Finances

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

Year to date income: $169 881

Year to date expenditure: $154 122

Net assets: $1 091 344

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

Membership

As at 4 September, the Society had 867 financial Members, compared to 927 at this time last year. The ASEG currently has six Corporate Members, including three Corporate Plus Members. A huge thanks to all our Corporate Members for your continued support in 2020. Don't forget to have a look for our Corporate Members on the contents page of *Preview* and support them as much as you can. Our state branches also have additional local sponsors, and these are shown at all branch meetings and at the beginning of all webinars.

It is great to see our Society's Members also taking advantage of the savings gained with the 5-year membership options. Please remember early and mid-career Members can join the ASEG Young Professionals Network at www.aseg.or.au/about-aseg/aseg-youngprofessionals.

I would like to take this opportunity to thank Archimedes Financial Planning for their long-standing support of the ASEG as a Corporate Member. Noll Moriarty, Principal of Archimedes, has decided to retire after 30 years in the industry. Noll was a Board Member of the ASEG Federal Executive from 1996-98 and was elected President in 1998. Noll will now have more time to pursue his love of Spanish, but assures us we will still see his smiling face at future conferences.

Social media

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

Online events

Face-to-to face meetings continue to be challenging in many states, so the ASEG has continued with the webinar series with some interesting talks that have been very well supported by Members. These have been coordinated and run at both state and federal level. The sessions are all recorded and available for viewing at the ASEG website or on our YouTube Channel. The Federal Executive is still looking at the possibilities for returning to face-to-face meetings in those states where it is safe to do so. Keep a look out for notifications from your state branches to see what is coming soon, and get out there and reconnect with your colleagues.

With 2020 marking ASEG's 50th year, the committee has lots of interesting events and promotions planned for the year ahead. The SA/NT branch has finalised the 2020 ASEG Wine offer, and some special wines are available, so look for the flyer in this issue or in your in-box.

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

Leslie Atkinson
ASEG Secretary
fedsec@aseg.org.au

Welcome to new Members

The ASEG extends a warm welcome to 24 new Members approved by the Federal Executive at its August and September meetings (see Table).

First name	Last name	Organisation	State	Country	Membership type
Alya	Arief Azali	University of Adelaide	SA/NT	Australia	Student
Niesha	Baker	University of Adelaide	SA/NT	Australia	Student
Finnegan	Birch	University of Adelaide	SA/NT	Australia	Student
Elyse	Bosch	University of Adelaide	SA/NT	Australia	Student
James	Browne	University of Adelaide	SA/NT	Australia	Student
Thomas	Burke	University of Adelaide	SA/NT	Australia	Student
Dana	Imbrogno	University of Adelaide	SA/NT	Australia	Student
Richard	Lachapelle	Scintrex	Ontario	Canada	Active
Daniel	Lake	University of Adelaide	SA/NT	Australia	Student
Emily	Lewis	University of Adelaide	SA/NT	Australia	Student
Darby	Liersch	Australian National University	ACT	Australia	Student
Mark	Lowe	Seequent APAC	WA	Australia	Active
Cristian	Moreno	Curtin University	WA	Australia	Student
John Paul	Mubita	Geological Survey of Namibia		Namibia	Active
Brooke	North	University of Adelaide	SA/NT	Australia	Student
Josiah	Park	University of Adelaide	SA/NT	Australia	Student
Lauren	Peters	University of Adelaide	SA/NT	Australia	Student
Carmel	Plati	Curtin University	WA	Australia	Student
Samuel	Rasch	University of Adelaide	SA/NT	Australia	Student
Aidan	Spilsbury	University of Adelaide	SA/NT	Australia	Student
Jimmy	Ting	CGG	Kuala Lumpur	Malaysia	Active
Dick	West	University of Adelaide	BC	Canada	Retired
Zara	Woolston	University of Adelaide	SA/NT	Australia	Student
Jannet	Zeta	Newmont		Peru	Active

Free subscription to *Preview* online

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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.*

ASEG Honours and Awards: ASEG Gold Medal awarded to Brian Spies in 2020

Brian Spies

ASEG Gold Medal Award citation

The ASEG Gold Medal is awarded from time to time for exceptional and highly distinguished contributions to the science and practice of geophysics by an ASEG Member, resulting in wide recognition within the geoscientific community. The ASEG President has announced that a special award of the ASEG Gold Medal is being made in 2020 in recognition of Dr Brian Spies. Sadly this award is made posthumously as Brian passed away in Sydney on February 8 2020, after a courageous two-year battle with cancer.

This award specifically recognises Brian's exceptional and distinguished contributions to the profession, both in Australia and internationally, as a most eminent and visionary research exploration geophysicist, an accomplished national and international science leader, inspiring geoscience innovator, inventor and research collaborator, science mentor and advocate, and a great science educator.

Brian gained a BSc from the University of New South Wales in 1971, double-majoring in geology and physics, and went on to earn a Post-Graduate Diploma in Applied Geophysics from UNSW in 1972, supported by a Graduate Cadetship from the Australian Bureau of Mineral Resources (BMR), where he undertook applied research throughout the 1970s with a broad range of geophysical techniques in the Australian outback.

In particular, during these early years with BMR, Brian enthusiastically led the field trials of the relatively unknown transient electromagnetic (TEM) method over the Elura and the Woodlawn orebodies and followed with new interpretative scale model studies. This BMR research under Brian's leadership helped to further establish TEM as a practical exploration method for metallic ore deposits in Australia's conductive terrains. Brian was personally responsible for a number of developments in the TEM technique in Australia, which was transferred to the minerals exploration industry in a campaign of field demonstrations, presentations and publications. TEM is now an indispensable geophysical technique in Australian mineral exploration.

In 1976 Brian received the first SEG Foundation scholarship given in the southern hemisphere. This scholarship, and an Australian Public Service Board award, allowed him to commence his PhD studies at Macquarie University, under the supervision of the late Professor Keeva Vozoff. Brian completed his doctoral studies in 1980 and was awarded a PhD for an outstanding thesis "The application of the transient electromagnetic method in Australian conditions: field examples and model studies", which still has relevance to today's exploration geophysicists.

Brian's international geoscience and leadership roles began in the USA in 1980, when he joined Exploration Data Consultants in Denver as Senior Geophysicist. In 1981, he moved to California to join Electromagnetic Surveys Inc. as Vice President and Director.

In 1984 he joined the ARCO Oil and Gas Research Center in Texas as Senior Principal Research Geophysicist, where he developed a new non-destructive testing technology for oil pipelines. The method was commercialised by a large multinational engineering organisation and is now used worldwide.
In 1989 Brian was awarded ARCO's highest technical award, the Outstanding Technical Achievement Award in Research, for development of the Transient Electromagnetic Probing (TEMP) corrosion detection technique.

In 1990 Brian joined Schlumberger-Doll Research where he led the Deep Electromagnetics research program, involving theoretical and experimental investigations of new borehole electromagnetic and electrical techniques. Fundamental to these studies was the integration of geophysical, geological and engineering data, and large-scale computer modelling of complex, realistic geological sequences. He led the team that developed a new generation of deep-imaging electromagnetic tools for the oil well environment, based on a three-component digital cross-well system capable of generating accurate 2-D images of reservoirs between boreholes.

During the period of Brian's commercial research in North America, he authored eleven patents covering some highly innovative applications of transient electromagnetics. Brian also took on university Adjunct Professor teaching and post-grad student supervision during his time in the US.

In 1996 Brian returned to Australia to take over the role of Director of the Co-operative Research Centre for Australian Mineral Exploration Technologies (CRC AMET), appointed as part of the Corporate Executive of CSIRO Exploration and Mining. CRC AMET was a collaborative joint venture of government, academic and industry partners, developing a new generation of geophysical exploration technologies for Australian conditions of deep and varied weathered cover. The research programmes involved all aspects of airborne and ground electromagnetic exploration, instrumentation, processing, modelling and geological interpretation.

Brian successfully integrated the research programmes and participants to achieve the CRC objectives, particularly commercialisation and knowledge transfer. Brian's leadership of the research partnerships delivered a new generation of broadband high-resolution airborne electromagnetic exploration techniques optimised for Australian conditions.

Following the successful delivery of the outcomes from the CRC AMET, Brian was appointed in 2000 as Director of the Physics Division of the Australian Nuclear Science Technology Organisation (ANSTO).

In 2003, Brian took on the role of Chief Research Scientist, CSIRO Exploration and Mining, with major contributions to Australia's strategy and policy for the "Mineral Exploration Action Agenda". Brian was co-leader for targeted R&D funding for mineral exploration and lead writer for the education and training programs, including increased support for science and technology in secondary and tertiary education.

Brian's leadership positions in ANSTO and then CSIRO Exploration & Mining, provided the platforms for his passion for advocacy of great science influencing good government policy outcomes.

A great example of Brian's contribution to leading strong science evidence, informing national science debate and influencing good policy outcomes was his co-leadership of the Project Review Team on "Review of Salinity Mapping Methods in the Australian Context", which evaluated a range of methods, including airborne and ground EM systems, for mapping the extent and severity of dryland salinity.

In 2004 Brian was appointed Science Manager and later Principal Scientist, Sustainability and Climate Change, in the Sydney Catchment Authority. It was during his time in SCA that Brian began working in climate science.

In Brian's later career he was highly respected as a science advocate for the broader integration of science-technology-engineering and mathematics in modern research, education, and formulation of government policy. His co-authorship in 2012 of a major report on "Sustainable Water Management – Securing Australia's Future in a Green Economy" produced a visionary roadmap for Australia's future water management.

During this period Brian also made huge contributions through the Australian Academy of Technology and Engineering (ATSE) and was elected as Fellow of ATSE (FTSE) in 1998. In 2003 he was awarded the Australian Centenary Medal for his contributions to Geoscience. Brian also made substantial science contributions in environmental and climate science through the Royal Society of New South Wales and was elected as Fellow (FRSN) in 2016.

Above all else, Brian's most important legacy to geoscience and to successful exploration and discovery has been through his forty eminent and well-cited scholarly papers in refereed geoscience journals, many book chapters and over thirty other papers and articles in geoscience publications and conference proceedings. In addition, Brian's inspiring initiatives and leadership in establishing over 30 national and international workshops at the fore-front of research and the application in geophysical exploration technology, environmental geophysics, reservoir characterisation and trends in science management, has produced ground-breaking conference proceedings and workshop publications that have formed a core part of the industry's reference works on electrical and electromagnetic exploration geophysics.

Throughout his professional life, Brian remained a strong supporter of the ASEG, which he joined as a student in 1970. His active participation in the Society culminated in his distinguished service as ASEG President in 1999-2000, using his position at that time as Director of CRC AMET and his international expert standing in TEM to promote Australia's innovations and breakthroughs in the science of mineral exploration geophysics.

Brian joined the Society of Exploration Geophysicists (SEG) in 1972 and was acknowledged for his outstanding service in many capacities, including a term as 1st Vice President (2003-2004) and Secretary-Treasurer (1996-1997) with the award of SEG Life Membership in 1996.

Brian's geoscience career and his innovations and contributions to exploration geophysics, particularly as one of the pioneers of Transient Electromagnetics (TEM) as well as his contributions to other areas of science, have been brilliant and transformative. He remained an active geoscience collaborator and advocate for the importance of science in our modern society, with significant late-career contributions in the field of environmental and climate science, until a few months before he died.

Brian was greatly admired for his achievements both in Australia and internationally by his peers and colleagues. He leaves an extraordinary legacy of achievement beyond the science of exploration geophysics. His Australian and international science partners, friends and colleagues all speak of him with the highest praise and with reverence for his achievements and contributions and his inclusiveness and openness sharing new ideas and knowledge.

It is especially pleasing to be able make an award of the ASEG Gold Medal in the ASEG's 50th year to one of the Society's longest-serving and committed Members, who was also a distinguished contributor throughout his life to the science and practice of geophysics.

Nominations open for the 2021 ASEG Honours & Awards

A reminder to all Members that nominations are open for the 2021 ASEG awards, to be presented in conjunction with the AEGC 2021, 15-20 September 2021, Brisbane, Australia.

All ASEG Members as well as State and Federal executives are invited to nominate those they consider deserving of these awards. Award categories include:

- Outstanding contributions to the geophysical profession
- Outstanding contributions and service to the ASEG
- Recognition of innovative technological developments
- Promotion of geophysics to the wider community
- Significant achievements by younger ASEG Members

Lists of previous awardees, award criteria and nomination guidelines can be found on the ASEG website at: https://aseg.org.au/honours-and-awards

For further information, preliminary expressions of potential nominations, and submission of nominations, please contact:

Andrew Mutton
ASEG Honours and Awards Committee Chair
awards@aseg.org.au

ASEG Research Foundation: Projects supported in 2020

As advised in the June issue of *Preview* (PV 206), four applications for ASEG Research Foundation grants were successful in 2020. One was for honours, one for masters and two for PhD degrees. The total amount committed in this year's round was $46 220. The four successful grant applications are summarised below.

RF20M02

University of WA

Supervisor: Professor Mike Dentith

Student: Natalia Delgado

Grant: $2220, 1 year, MSc

Title: Geophysics in precision agriculture: Mapping soil properties to guide amelioration practices in the WA Wheatbelt

Summary: Geophysics is increasingly used in precision agriculture to map soil properties to facilitate optimal economic and environmental management of the land. New and existing geophysical data from a test site near Badgingarra, WA will be used to map soil properties in 3D. Methods that will be used include radiometrics, frequency-domain EM and GPR. The primary aims of the research are to determine how to best map clay content and depth to hard horizons. This information is crucial for determining which areas will benefit from tillage to counter water repellency of the top soil and compaction of the sub-soil.

RF20M03

Curtin University

Supervisor: Professor Brett Harris

Student: Fionnuala Campbell

Grant: $4000, 1 year, BSc

Title: Comparison, evaluation, and optimisation of the portable near surface Loupe TEM system for underground Nickel sulphide detection

Summary: The project aims to determine the Loupe Electromagnetic (EM) System's ability to detect and accurately map nickel sulphides in an underground mine environment. The Loupe EM System will be directly compared to a conventional fluxgate-surface loop EM survey. The comparison will be primarily based on resulting 1D conductivity models. An in-depth evaluation of the Loupe EM System in a new and potentially high-value environment has a potential high value for industry. If successful, the Loupe System could reduce the cost, time and personnel required for conventional EM surveys. The Loupe EM System is expected to accurately detect the underground sulfides to a comparable or better quality than conventional fluxgate surface loop EM survey methods.

RF20P01

University of Adelaide

Supervisors: Assoc Professor Simon Holford, Assoc Professor Ros King and Dr Mark Bunch

Student: Monica Jimenez Lloreda

Grant: $17 500, 2 Years, PhD

Title: Controls on gravity-driven normal fault geometry and growth in stacked deltaic settings

Summary: The Ceduna Sub-basin is a superb natural laboratory for studying the evolution of normal faults in stacked deltaic settings with multiple detachments. This project aims to increase our understanding of normal fault growth in deltaic continental margin successions, and more clearly define the role played by faults in determining trap configuration within the Ceduna Sub-basin. Through detailed interpretation of extensive 3D seismic data, the expected outcomes of this project include new models for fault growth and the evolution of structural domains, associated workflows for the interpretation of syn-kinematic listric faults, and the identification of trapping structures within the Ceduna sub-basin that might be at risk of reactivation.

RF20E03

Flinders University

Supervisor: Dr Ian Moffat

Student: Andrew Frost

Grant: $22 500, 3 years, PhD

Title: Assessing a multi-modal approach in the location of unmarked graves under various seasonal conditions

Summary: Australia is a dry continent. As such, the soil tends to be dry, and this affects the suitability and effectiveness of common geophysical techniques in the location of unmarked graves. This research will focus on the role that soil grain structure and moisture levels play. The suitability of the Schmidt (2017) precipitation ratio will be assessed for translation to the dryer Australian conditions, along with grain size and composition being assessed by using X-Ray diffraction, and soil permittivity will be explored. Three test sites have been identified, with one test site containing graves that were dug by the researcher in the late 1980s, this is believed to be a world first.

Doug Roberts
ASEG Research Foundation
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ASEG Branch news

Australian Capital Territory

The "Canberra Bubble" has kept our ACT-fold COVID-free for several months now, and we trust that all ASEG Members are also virus free. Frosts, fogs and sub-zero mornings are making way for spring blossom across the Capital. All is looking up!

August saw one of our ACT colleagues, Dr **Alison Kirkby**, provide an update on AusLAMP results and interpretation across the Tasmanides (the data were acquired as the result of a collaboration between GA, GSNSW, GSV and GSSA).

While privy to the significance of these investigations in my team at GA, it is great to see what were previously often considered to be adjunctive solid-earth geophysics datasets now being utilised as key drivers for mineral systems understanding. As with airborne magnetic or ground gravity coverage, GA and the State collaborative partners are committed to seeing the detailed continental coverage of AusLAMP completed.

In September, **Rod Paterson** of Intrepid Geophysics presented the background to 2.5D AEM inversion, with the advantages over 1D inversion eloquently illustrated through several case studies from iron ore to base metal deposits throughout Australia. The work of his team highlights the pitfalls of making interpretations from the basic inversions often provided by contractors. Rod also highlighted common inversion difficulties associated with IP effects, superparamagnetic material (SPM), and sharp resistivity contrasts. Note that, due to a minor technical hitch, the presentation was delivered and recorded in draft mode. However, Rod has very kindly offered to re-record it in full-screen 'animation' given the amount of interest created.

Many thanks to our local and guest speakers for sharing their work with us, and we look forward to a packed presentation schedule leading up to Christmas

Marina Costelloe
actpresident@aseg.org.au

New South Wales

We trust all ASEG Members are virus free and finding heaps to do as we all wait for the "new normal" to happen ….. although, as we type this, the borders between NSW and Victoria and NSW and Queensland are *still* closed (depending on which direction you are travelling) …. so who knows when that will be.

Over the last couple of months we have had one speaker who gave their presentation via Zoom. **Bob Musgrave,** from Geological Survey of NSW, gave a talk called "State of the Arc: Long-wavelength geophysics and Macquarie Arc basement". Bob walked us through his understanding of the basement of the Ordovician Macquarie Arc, which hosts world-class Cu-Au mineralisation. Bob discussed long-wavelength magnetic, gravity, MT and seismic features, noting that understanding those data is key to reconciling tectonic models, geochemistry, and geochronology of the arc. Many questions were asked and answered.

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Stephanie Kovach
nswsecretary@aseg.org.au

Queensland

The Queensland ASEG would like to share our support for all Members in Queensland and other states that continue to be devastated by the effects of the COVID-19 pandemic.

Plans are underway to resurrect the Queensland Cross-Industry Mentoring Programme, a joint initiative between the QLD ASEG and an alphabet soup of like-minded industry groups, including FESQ, PESA, QUPEX and SPE. Like so many other events and initiatives this year, more information will be sent out when there can be more certainty around timing for the launch event.

The Queensland Branch also hopes to restart face-to-face events in October with a delayed Trivia Night – keep an eye out for more details.

Ron Palmer
qldpresident@aseg.org.au

South Australia & Northern Territory

With the restrictions slowly easing in SA, the local branch has been coming out of hibernation. The various ASEG webinars on offer either live or from the 'ASEG Videos' YouTube channel have, however, kept us all entertained during lockdown

The ASEG SA/NT Branch was happy to sponsor the Science Student Networking Night on the August 20 at the Belgium Beer Café. Over 50 science students and

ASEG President Elect Kate Robertson speaking at the SA/NT Science Student Networking Night.

The SA/NT Science Student Networking Night in full swing.

eight ASEG Members attended. Our very own ASEG President Elect, **Kate Robertson,** gave a presentation on her career as a geophysicist, followed by a Q&A panel discussion with questions from the students. The night was a huge success, with the local ASEG Members actively promoting careers in geophysics to the undergraduate science students.

On the August 28 the SA/NT Branch hosted our annual wine tasting night. The wine selection was as good as it has ever been, with clear winners in the red and white categories. The winning selections are now on offer to all ASEG Members as part of the 2020 Annual ASEG Wine Offer. More details of the wine offer can be found in this issue or at www.aseg.org.au/2020-aseg-wine-offer. A massive thank you to the SA wineries that participated in the wine selection this year!

Your committee members are currently searching for topics of interest for our pub-night technical talks, which will be starting up again soon and hopefully televised (or added later to the YouTube channel) for the benefit of all Members.

On November 3 the local branch will be hosting our annual Melbourne Cup Luncheon, this year combined with a celebration of the ASEG's first 50 years. The venue is TBC, but join us for a fun day with prizes for best dressed, and the Calcutta sweep.

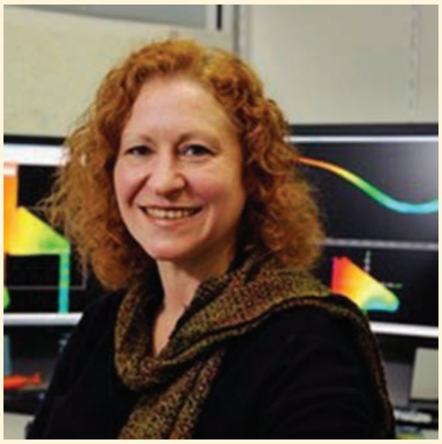
We couldn't host these fantastic events without the valued support of our sponsors. The SA/NT Branch is sponsored by **Beach Energy**, **Oz Minerals**, **Vintage Energy**, **Minotaur Exploration** and **Heathgate Resources**.

Ben Kay
sa-ntpresident@aseg.org.au

Tasmania

In late-breaking news, the Tasmanian Branch will be holding a dinner celebrating the 50th anniversary of the ASEG, on Friday 20 November 2020. The featured speaker, Dr **Tara Martin**, Research Group Leader at CSIRO Hobart and formerly of the British Antarctic Survey, will regale us with geophysical tales in between three delicious courses, served at the University Club in Sandy Bay.

Complete details are yet to be finalised at the time of writing, however all Tasmanian Members will receive an invitation including these details in short order. Anyone else who might be able to join us for what will be a great evening should get in touch with me at *taspresident@aseg.org.au*



Tara Martin, guest speaker at the Tasmanian Branch 50th anniversary dinner to be held in November (photo courtesy of Tara Martin).

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

Mark Duffett
taspresident@aseg.org.au

The Victorian quarantine diaries

Day 42

I greeted the day with a double Irish coffee at sunrise … minus the coffee. To be honest, I have not been to bed since the day before yesterday. Still, I cannot remember the last time I watched a sunrise. Today's viewing was special as over the past week the days appear to have effortlessly morphed into one very long subdued confrontation. The sun, in an astronomical attempt to deplete its supply of hydrogen by fusing itself into helium, ejects photonic packets of energy that take 8 minutes and 19 seconds to travel through the vast emptiness of interplanetary space before arriving here. The least I could do was make myself available for irradiation by its primordial light. It was very overwhelming. It was also providence that I had not bothered to replace the bedsheets after washing them the other day, otherwise I would not be sitting here on the front veranda at sunrise writing of my enlightenment.

This second lockdown has been bitterly confronting. The nightly curfew from 8 pm is eerie. The streets are frighteningly quiet as if as though 4.97 million inhabitants have suddenly, in unison, vanished from the city. I feel as if an unearthly supernatural presence pervades our city every night. Not even sounds from animals can be heard. It is as if they too are bound by this restriction. If anyone has been to Adelaide, and I will assume most of you have, then you will understand my misgivings. Adelaide has had an 8 pm to 5 am curfew for the past 184 years, so I probably shouldn't complain so much ☺

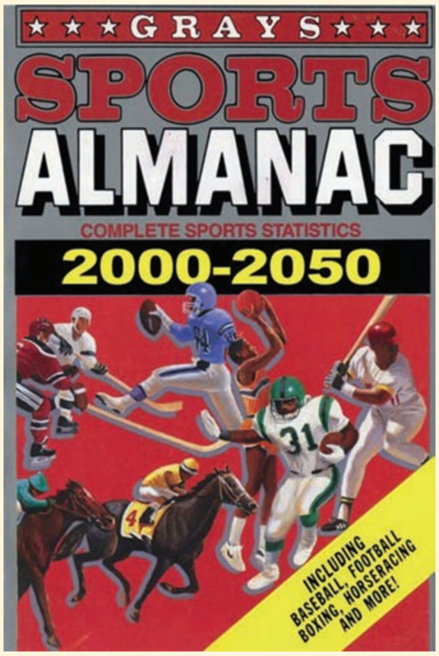
Every day in lockdown usually plays out the same. I can leave the house for one hour each day to exercise. I can leave the house for one hour each day to go on a supply run. If I undertake each privilege in sequence, I can make it feel like half the day is gone. But that is all. My ankle has been hurting today, which is not a sign of COVID, but it does not make me less paranoid. I am tempted to leave the house to seek medical attention, but I hastily reach for the whisky instead.

Ah, that's better. I am humbled at the thought that something which is one-billionth our size is beating us, and it is winning … for now. Admittedly, all those years of being a withdrawn, reclusive introvert with no social life and very few friends have prepared me well for this second lockdown.

I am building a time-machine, if you must know. I plan on taking the inaugural flight to the future, to the year 2050 to be exact, just like Biff Tannen did in *Back to the Future II*, where in a stroke of genius, he purchased a copy of *Grays Sports Almanac* to bring with him from the year 2000 back to 1955. Of course, I will use it to help the Victorian branch fund the next group of inspirational speakers I intend to bring to our technical meeting nights when all this is over, whenever that may be.

In the meantime, I take pleasure in welcoming Dr **Nathan Gardiner** to the Victorian ASEG committee as your new branch secretary. I may have to plead guilty to perjury in getting him to agree to sit on the committee. This is not a paying position, Nathan. I am sorry it had to be this way. But I will let you in on a sports tip – Port Adelaide will win the 2020 AFL grand final – much to everyone's disappointment.

Great scott! Oh, this will be heavy.



Thong Huynh
vicpresident@aseg.org.au

Western Australia

Due to the low COVID-19 cases in WA, ASEG WA is pleased to announce that a key mentoring programme is now restarting. Registration for the 2020/2021 Joint Industry Mentoring Programme has now (re)opened. If you previously applied to be a mentor / mentee in 2020, there is no need to reapply - we'll get in touch.

For those not yet involved, please do go ahead and sign up to be a part of this excellent programme, which enriches both the mentee and the mentor and often forms rewarding long lasting bonds and relationships. Contributions from mentors and mentees alike can have an enormous impact on the development of professionals and by extension create a legacy to our industry.

For the first time, the Joint Industry Mentoring initiative is offering various sponsorship packages for the 2020 programme. Full details about available options are on our website.

The WA ASEG-PESA annual Golf Tournament is also on this year. This year is the fourth year of our partnership with the Parkerville Children & Youth Care charity, which is a great cause. More information about the Parkerville charity follows this edition of Branch news. This year's event will be held on November 13, which means there is still plenty of time to register.

WA was proud to provide a webinar by **Ankita Singh** on October 1. The talk is entitled "Grayscale representative elementary volumes: An innovative approach to investigate pore-scale REVs from raw micro-CT images". It was a very good talk and very well received.

WA is also happy to report that our local Shearwater manager has promised us an interesting talk in November. Watch your email and our website for details.

Lastly, I'm really pleased to announce that **Darren Hunt** will be taking on the role of Treasurer in WA next year. And a very big thanks to the out-going treasurer, **Matthew Cooper**, who has time and again provided solid support for the WA team!

Stay safe!

Todd Mojesky
wapresident@aseg.org.au

ASEG national calendar

Date	Branch	Event	Presenter	Time	Venue
ASEG Branch face-to-face meetings have resumed in SA, WA and Tasmania. All other State Branch meetings are on hold till further notice. Most branches are still hosting webinars. Registration is open to Members and non-members alike, and corporate partners and sponsors of state branches are acknowledged before each session. Recorded webinars are uploaded to the ASEG's website (https://www.aseg.org.au/aseg-videos), as well as to the ASEG's YouTube channel (https://bit.ly/2ZNgIaZ). Please monitor the Events page on the ASEG website for information about upcoming webinars and other on-line events					
03 Nov	SA/NT	Melbourne Cup Lunch		TBA	TBA
13 Nov	WA	ASEG-PESA Annual Golf Classic		TBA	Secret Harbour, Perth
20 Nov	TAS	ASEG 50th Anniversary Dinner	Tara Martin	TBA	University Club, Sandy Bay, Hobart

TBA, to be advised

WA ASEG-PESA Annual Golf Classic

The 33rd West Australian ASEG-PESA Annual Golf Classic is being held at the Secret Harbour Golf Course on Friday 13 November 2020. The event is one of the most pleasant and well-attended resource exploration industry golf tournaments held in WA, with recent years enjoying attendances of 100 plus players. It is a day of fun, frivolity, and camaraderie with competitions, prizes, auctions and raffles. There is still plenty of time to register although, sadly, given current border restrictions only Western Australians can attend.

This year, for the fourth year, the WA ASEG-PESA Annual Golf Classic will be partnering with **Parkerville Children and Youth Care**. Last year the tournament raised $3000 for this charity, the equivalent to providing therapeutic support for 12 months to a child who has experienced trauma from abuse. And, we aim to do better this year.

Parkerville Children and Youth Care (www.parkerville.org.au) advocate for, and provide specialist care and services to, those most vulnerable in the WA community, including children, young people and families who have experienced trauma. They would be unable to carry out this incredibly important work without the support of a generous community of donors and supporters.

Parkerville Children and Youth Care began as an orphanage in 1903, and continues to deliver therapeutic out of home care, foster care, clinical and therapeutic services, family support, early intervention and prevention, specialist child advocacy services, and services to support young people. Last year they provided services to some 10 000 children, young people and their families in metropolitan and regional WA.

In particular Parkerville Children and Youth Care support the WA community by providing:

- Safe, nurturing and healing homes for children and young people who are unable to live with their families;
- Specialist mental health services for children, young people and adults who have experienced trauma;
- Reparative experiences with trusting and safe relationships that allow children, young people and families to heal from the harmful impacts of trauma;
- Multiagency integrated services to support children, young people and their families from first disclosures of trauma until such time as our services are no longer required;
- A specialist education and employment program for young people who find mainstream schooling challenging;
- Support to help families find their strengths, connect with family, community and culture so they can thrive and stay safe together;
- Education and early intervention to the community so they can be better informed and help their children develop their full potential and stay safe;
- Specialist services to young people who are experiencing homelessness;
- High-quality education for professionals on the prevention, impacts and treatment of complex trauma.

These services are delivered by a large team of specialised psychologists and social workers but, without funding, these services would not exist and children would be unable to receive the proper care and treatment they deserve.

In September 2020, Parkerville launched their latest campaign 'Stand with Us' to provide vital funding for their Child Advocacy and Therapeutic Services in WA. They ask everyone in community to 'Stand with Us', behind all children, especially those who have experienced trauma from abuse. If you would like to support the children Parkerville serve, then please contact their Fundraising and Philanthropy Manager, **Jessica Cook**, at jcook@parkerville.org.au or on 08 9235 7030.

Parkerville Children and Youth Care are grateful to the ASEG-PESA Annual Golf Classic organising committee for raising awareness and funds for their cause. In particular they thank **Helen Debenham**, **Kelly Arnett**, **Andrew Fitzpatrick** and **Scott Moore**. Parkerville Children and Youth Care would also like to take this opportunity to thank the very generous sponsors and raffle prize donators that also help make the annual tournament such a successful event. Specifically, they would like to acknowledge the continued support of Platinum and Gold sponsors; **DUG**, **Wireline Services Group**, **HiSeis** and **Searcher Seismic**.

Participants in the 2017 ASEG-PESA Annual Golf Classic

2020 ASEG Wine Offer

2020 ASEG WINE OFFER *orders close Friday 30th of October*

The ASEG SA/NT Branch is pleased to be able to present the following wines to ASEG members. These wines were found by the tasting panel to be enjoyable drinking and excellent value. The price of each wine includes GST and bulk delivery to a distribution point in each capital city in early December. Stocks of these wines are limited and orders will be filled on a first-come, first-served basis.

Please note that this is a non-profit activity carried out by the ASEG SA/NT Branch committee only for ASEG members. The prices have been specially negotiated with the wineries and are not available through commercial outlets. Compare prices if you wish but you must not disclose them to commercial outlets.

Chain of Ponds 2020 Black Thursday Sauvignon Blanc

Sourced from 5 vineyards in the southern Adelaide Hills and carefully blended. With colour of a very pale green straw, green hue with brilliant clarity. An intensely aromatic bouquet of gooseberry, lychee and paw paw with lifted hints of lemon meringue pie with passionfruit, all integrated with subtle hints of fresh pea pods and nuances of cucumber. The 2020 Black Thursday is lively and vibrant with an intense fruit driven palate of citrus, gooseberry and tropical notes are supported by subtle grassiness. Balanced focused acidity with a soft voluptuous mouthfeel, and subtle fruit sweetness. The Chain of Ponds 2020 Black Thursday Sauvignon Blanc has exceptional length and intensity made for enjoying young. Perfectly suited to a lazy afternoon in the sun.

ASEG PRICE $125/dozen (RRP $240)

Maxwell Wines Little Demon Envious N.V. Sparkling

Named after the Scottish physicist James Maxwell's hypothetical intelligent gatekeeper, the 'Little Demon', illustrated in the thought experiment about the possibility of violating the second law of thermodynamics. Combined with a simple play on words 'Envious' to represent this NV Sparkling, or 'NVS' for short. This NVS has a composition of Chardonnay and Pinot Noir fruit which provides this Sparkling wine with citrus flavours that illuminates the palate and provides the wine with freshness. A bright pale straw colour with aromas of fresh green apple and citrus effervesce. Delicate creamy yeast characters which bring style and complexity, while a subtle melon note plays in the background. The Maxwell Wines Little Demon NVS has good length with a pleasantly dry finish and is wine made for celebration, to be enjoyed now.

ASEG PRICE $145/dozen (RRP $240)

Nietschke 2018 Jack Shiraz

The 2018 vintage was superb, a true classical Barossa vintage. Great Uncle Jack would be proud as this is a modern Shiraz with a twist. There's a little something extra with a dash of Petite Sirah added for complexity. The Nietschke 2018 Jack Shiraz is a deep red colour with purple hues, that's very uplifting with inviting aromas of chocolate cake, plum, cinnamon, roses and a hint of toasty mocha oak. The palate is full-bodied with rich dark fruits. It is generous, mouth-filling and beautifully balanced. Along with red and black fruits are subtle oak barrel notes giving complexity and dimension. Tannins are mild and well-integrated adding structure without obtrusion. A lengthy finish completes this wine. This is a fine Barossa Shiraz that will cellar gracefully in the medium term.

ASEG PRICE $155/dozen (RRP $252)

Please order online at www.aseg.org.au and pay by credit card, or fill in the order form below

Name: ________________ Phone # ____________ Email address: ____________________________

Address: ____ Capital city for collection: ____________

I would like to pay by: [ ] Cheque - payable to ASEG SA/NT Wine Offer (enclosed)
[ ] Visa/Mastercard - please call the Secretariat to process your payment

Number of orders	Wine	Price	Total
	Chain of Ponds 2020 Black Thursday Sauvignon Blanc	$125 per dozen	
	Maxwell Wines Little Demon Envious N.V. Sparkling	$145 per dozen	
	Nietschke 2018 Jack Shiraz	$155 per dozen	
		TOTAL	

Order and payment by mail or fax to:

ASEG Wine Offer, c/o. ASEG Secretariat, PO Box 576, Crows Nest, NSW 1585
T: (02) 9431 8622 F: (02) 9431 8677 email: secretary@aseg.org.au

(please follow up any faxes with a phone call to ensure the form has been received)

The growing role of onshore seismic data in Australia

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Total Seismic is an ASEG Corporate Plus Sponsor. The ASEG gratefully acknowledges their sponsorship, and has invited them to inform ASEG Members, via the pages of Preview, *about some of the services they provide*

Introduction

Total Seismic has provided integrated geophysics, project delivery and capability improvement services to the petroleum, coal, minerals and renewables sectors since forming in 2016. One of the most rewarding aspects of this work has been our involvement in the innovation and implementation of new technologies. While we also specialise in non-seismic geophysics and marine seismic services, a current highlight, which we discuss in this article, is the recent advancement in land seismic technology.

Overview

There are many reasons to be optimistic about the future of Australia's onshore exploration sector. Current infrastructure and long-term market outlooks are strong for Australia's petroleum, metallurgical coal, minerals and renewable industries, and the Government is continuing to assist industry by investing hundreds of millions of dollars exploring for new Tier 1 resources in Australia's frontier regions. Additionally, recent land seismic technology developments are transforming the value of onshore seismic data and its importance for all sectors.

Twenty years of intensive political debate has failed to deliver a clear message on national energy policy, although one thing that has become clear is that natural gas will have to play a critical role in providing baseload power, should the country continue in transitioning away from thermal coal. The good news for explorers is that natural gas is plentiful in Australia, and that there is a comprehensive and expanding nationwide pipeline network. The domestic demand for gas is already high due to export commitments, and a number of independent gas supply models show that a domestic gas shortage is on the horizon. This setting provides natural gas exploration and production operators with significant opportunities to be rewarded for their investments. Importantly, for the land seismic sector, Australia's onshore gas basins are underexplored relative to other western countries.

Australia's current market conditions and infrastructure for metallurgical coal and a range of key minerals – including gold, iron ore and battery metals - are also strong. Mining has provided strength to the Australian economy through times of depressed gas export revenue and COVID-19. The mining sector has also spearheaded the implementation of new seismic technology in recent years, and is currently acquiring far more seismic data than the petroleum sector. More than half of Total Seismic's work scope to date has been from the mining sector.

High quality land seismic imaging is likely to be important in the future for other subsurface applications including CO_2 sequestration, groundwater mapping and the imaging shallow geology for civil and environmental applications (Figure 1). Most States are undertaking CO_2 sequestration research, some related to ambitious energy initiatives such as Victoria's hydrogen export project. Seismic data is also expected to be important for future advances in tunnelling technology. There is an increasing use of passive seismic techniques including Total Seismic's Pre-emptive Mine Geohazard Location (PMGL) technology, which provides practical, whole-of-mine, life-of-mine geohazard event detection years ahead of mining. Geoscience Australia's incredibly diverse nationwide *Exploring for the Future* programme also has positive long-term implications for the land seismic sector.

Lightweight nodal receivers

In addition to this promising backdrop, one recent development in land seismic technology is transforming the value of seismic data: the arrival of lightweight nodal receivers (Figure 2). These were brought to Australia in 2017, and now a number of domestic seismic crews are each able to provide over 20 000 nodes. Whilst nodal receivers have been around for a decade or so, the latest nodes are much smaller and lighter, largely due to developments in battery technology. Importantly for

Figure 1. *The cost of onshore seismic has reduced significantly in Australia in recent years, resulting in a diversification of seismic applications.*

Figure 2. *Lightweight nodes (left) are replacing heavy cable systems (right).*

Australian seismic crews – which are constrained to a relatively small number of people for logistic reasons - the lightweight nodes enable receivers to be moved at more than double the rate of cable systems and heavy nodes. Higher receiver productivity means that simultaneous vibroseis sweep operations have become practical in Australia and this has major implications for productivity, data density and cost/value.

Total Seismic has been at the forefront of the movement to use lightweight nodes to make onshore seismic exploration more productive, more cost effective and of higher value. In our co-authored AEGC 2019 paper (Battig *et al*. 2019), we describe our work with BHP Coal over six 3D surveys to improve vibroseis source productivity five-fold, using iterative improvements to survey design, sweep parameters and simultaneous sweep rules (Figure 3). During the last five years we have been involved in around twenty high production surveys and our survey designs and acquisition plans have evolved significantly to optimise overall data acquisition productivity. Our bespoke project optimisation techniques have been highly effective, dramatically increasing productivity relative to flip-flop seismic data acquisition. The productivity benefits open up exciting strategic options for explorers. Do you bank the savings? Or invest these in expanding the survey area? Or do you acquire higher trace density, richer azimuth-offset data in the pursuit of more sophisticated geoscience information like geological inversion, small fault resolution, fracture orientation and fluid properties?

Data value optimisation and risk mitigation

We are already seeing how the step-change in onshore seismic data value is changing the land seismic scene in Australia. Applications of seismic surveys that were considered commercially marginal or unviable are becoming mainstream, such as for open cut coal mines and the structural imaging of gold, nickel sulphide and mineral sand deposits. There is the potential for the petroleum sector to gain significant value from both low cost seismic data and quantitative interpretation, to improve drilling success, field development and gas recovery. We believe there is scope for the value of seismic data to continue to improve with changes to nodes, and that field logistics and seismic projects will keep diversifying into time-lapse seismic, passive seismic, micro-seismic and CO_2 sequestration applications.

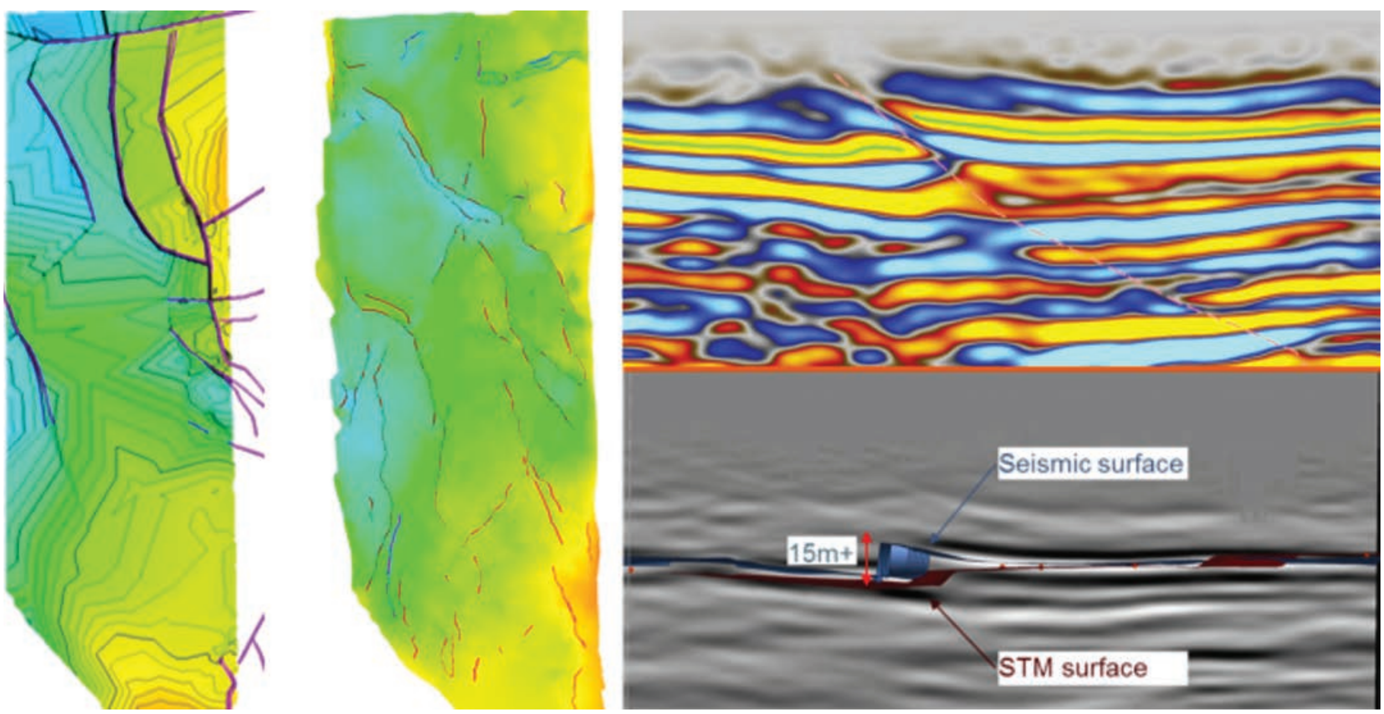

Figure 3. *From left to right: a shallow coal surface mapped from drilling information only; shallow coal surface mapped using 3D seismic data; example showing the difference in fault characterisation using seismic data (top) and only drilling information (bottom) (Battig* et al.*, 2019). Lightweight nodes and simultaneous vibroseis sweep operations have been used to transform the data quality and cost of shallow seismic data in recent years.*

There are, however, major strategic risks with high production reflection seismic surveys. Lightweight node and simultaneous sweep technology make the design and acquisition of a land seismic survey far more complex. Project planning has become a careful balancing act involving receiver movement logistics, deciding whether to surface plant or bury receivers, when and how to 'roll' spread without harvesting, choosing the right numbers of people, receivers and sources, designing sweeps and simultaneous sweep parameters, careful selection of micro-parameters including point spacing, choosing macro-parameters that reduce pressure on the line crew and a number of other operational and contractual factors. These are all inter-related and getting the balance wrong can lead to severe consequences for project feasibility, data quality and cost. The introduction of concepts such as compressive sensing and full waveform inversion add further complexity, opportunities and risks to the modern onshore seismic project.

To control all of these risks and maximise opportunities and value for a land seismic project, it is critical to have the technical expertise, software and project delivery experience for modern seismic data acquisition. At Total Seismic we use our 'Titan' suite of geophysics software to customise survey design, data analysis/processing and equipment assurance to get the most out of the modern seismic operation. We have worked hard to understand and optimise specific issues that can each have a major impact on data value, such as developing software to improve receiver productivity by 20%, understanding where, when and how to surface plant or bury nodes, examining legacy data to get point spacing exactly right, and vibroseis source expertise following extensive sweep and simultaneous sweep parameter testing (Figure 4). We have developed a series of geophysics workflows to ensure that we understand the *possible and required* data quality of a new project and that we obtain the optimal data as productively and cost-effectively as possible. We track and control data quality, productivity, schedule and cost through the life of the project to ensure that the project is delivered with high performance.

Figure 4. *Simultaneous vibroseis sweep seismic data acquisition is now standard in Australia.*

The results of Total Seismic's leading work to maximise the value of modern land reflection seismic projects speak for themselves. We have helped coal clients to achieve more than 400 vibration points per hour. We have designed cost-optimised, rich azimuth-offset, super-high data density surveys for petroleum clients to acquire data for reservoir characterisation and direct hydrocarbon indication. We have used innovative nodal survey designs around mine infrastructure to image complex mineral geology. For many projects that Total Seismic are involved in, we have designed or delivered surveys which achieve high quality data at less than half of the production cost expected by our client. The combination of new nodal technology and Total Seismic's technical expertise, project delivery experience and custom tools is providing a step-change in the value of Australia's land seismic data.

Looking to the future

So where do we go from here? For Total Seismic, the achievements to date are just the start: our team of specialists are working hard on a number of new research and development projects that aim to further increase the value of seismic and non-seismic data. For Operator companies, it is vital to realise the extent of the step-change in onshore seismic data value, to understand the greater diversity of seismic applications which are now possible, and to take full advantage with aggressive exploration and resource mapping strategies.

Our clients' engagement of our services and willingness to take on new ideas has helped the step-change in value of land seismic data to be maximised, and we are thankful to our clients for their continued work. For those who we have not yet supported, we encourage you to get in contact to discuss how to take most advantage of cutting edge seismic and non-seismic exploration. Our website www.totalseismic.com has more information about Total Seismic, including a detailed description of our services, the industry sectors we support, some of our research and development projects, examples of past work, client testimonials and other general content.

Here's to new technology, innovation and a bright future for the Australian exploration geophysics sector!

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Geoscience Australia: GADDS release, Kidson Sub-basin 2D seismic survey and new AusLAMP results

In collaboration with our State Agency partners of Western Australia, South Australia, Northern Territory, Queensland, New South Wales, Victoria and Tasmania, FY21 geophysical surveying has kicked off and/or is in the final throes of planning. This includes AusAEM20 AEM surveying across southern Western Australia (6000 line km completed as of 10 September), the Mundi AEM survey programme (contractor being chosen), the Tasmania Tiers magnetic/radiometric survey (25 000 line km to be acquired as a combination of rotary and fixed-wing platforms) and a high resolution 46 000 line km magnetic/radiometric survey planned for the Cobar District of NSW later in the year. Further details are presented in Figure 1 and in the tables that follow.

2020 GADDS Release: October update

We didn't quite make the public release of GA's Geophysical Archive and Data Delivery System (GADDS) for this month's *Preview*. We have, however, received very good feedback from a group of dedicated public beta testers, including:

- More than 60% of the users saying that the new GADDS system was intuitive for a first-time user and easy to navigate. The average overall experience rating provided by testers online was almost 4 out of 5.
- Many of the testers mentioning that the GADDS 2.0 system is much quicker to search and download data. This is no doubt a function of the more efficient NETCDF archiving and file formatting sitting behind it
- Nearly 69% of the beta testers saying that they came across few issues in searching and downloading the data. Well done to the various GA informatics and data scientists that have laboured over the new system for the last 12 months.

Whilst reiterating from last issue of *Preview*, the new GADDS will bring:

- An improved graphical/GIS – based interface, facilitating the choice of dataset
- Superior data selection criteria and data extraction speeds
- Enhanced pre-delivery filtering including data age, grid spacing, re-gridding algorithm, survey location and data type, to name just a few

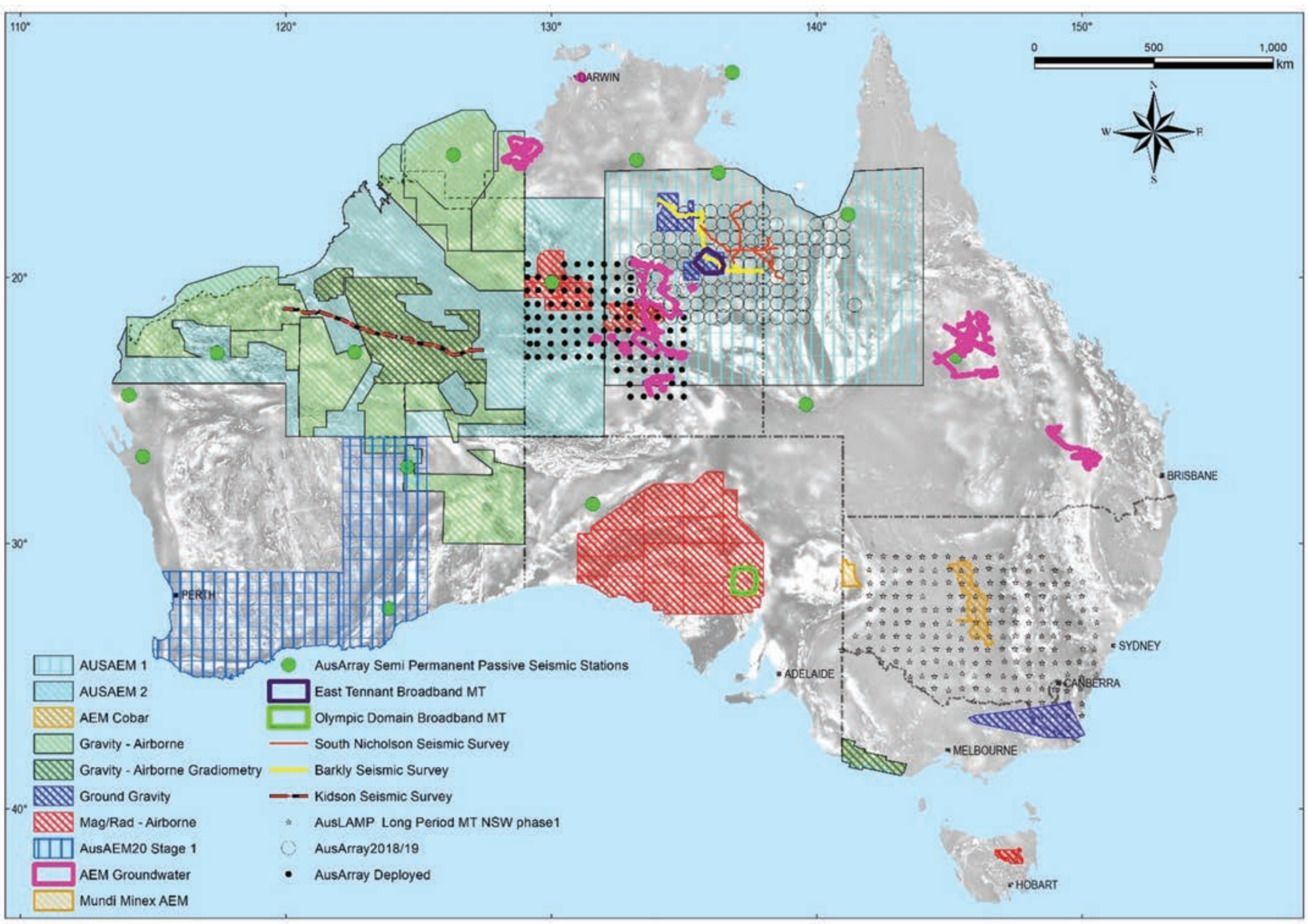

Figure 1. *2018 -2021 geophysical surveys – completed, in progress or planned by Geoscience Australia in collaboration with State and Territory agencies, including the proposed airborne gravity survey area, Victoria. Editor's note: For more information about this proposed airborne gravity survey see the article by the Geological Survey of Victoria elsewhere in this issue.*

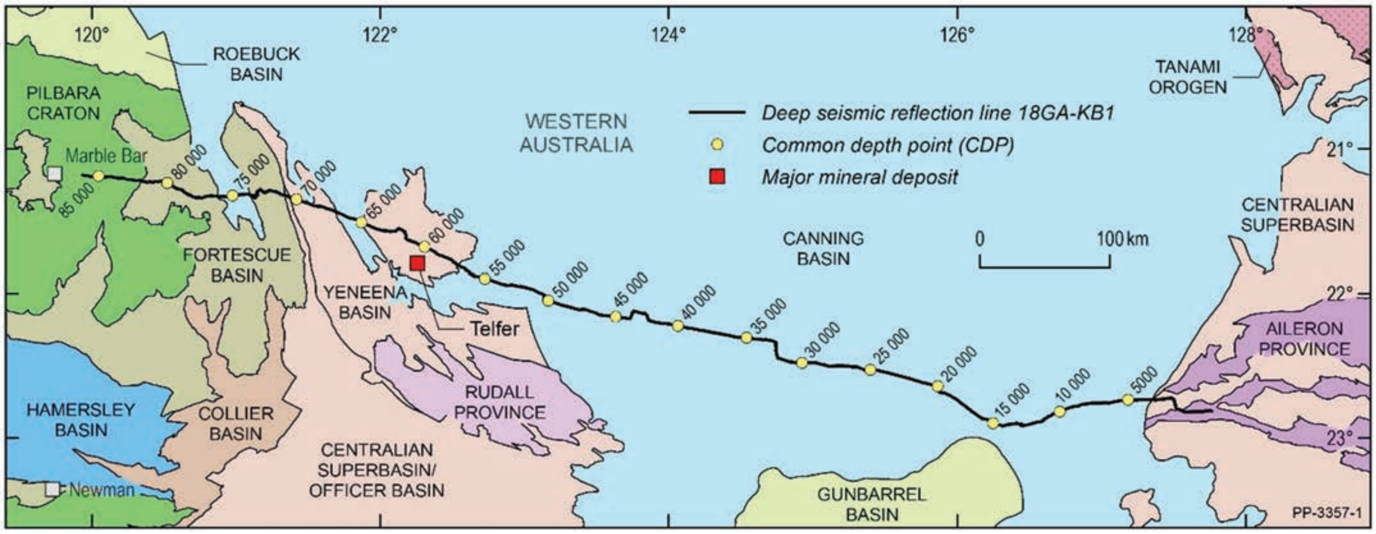

Figure 2. *Map showing the location of the Kidson seismic line that extends from the Aileron Province in the east to the Pilbara craton in the west.*

- Access via the primary GA portal so that most of the other GA-delivered datasets can be easily viewed and extracted

With further development, the capacity to deliver n-dimensional and time-series data sets including AEM and airborne gradiometry will be enhanced.

There are some minor changes to be made, but we are still on track to deliver the new platform this year. Stay tuned!

Basement interpretation from Kidson Sub-basin 2D seismic survey

Deep seismic reflection line 18GA-KB1 (Figure 2) was acquired by Geoscience Australia and the Geological Survey of Western Australia as part of the *Exploring for the Future (EFTF)* programme and the *Exploration Incentive Scheme*. The line has a total length of 872 km, stretching from 30 km west of the Kiwirrkurra community in the east, to 20 km east of Marble Bar at its western end.

The line images the Kidson Sub-basin of the Canning Basin, and a diverse range of basement geology units (from west to east): the Palaeo- to Mesoarchean Pilbara Craton; the Neoarchean to earliest Palaeoproterozoic Fortescue and Hamersley Basins; Neoproterozoic metasedimentary rocks that form part of the Paterson Orogen (Yeneena Basin and Gibson Sub-basin of the Officer Basin and the Palaeo- to Mesoproterozoic Rudall Province); unexposed sub-Canning basement of uncertain affiliation; and the Palaeoproterozoic Aileron Province with a veneer of Neoproterozoic rocks of the Amadeus Basin. The line passes close to the Telfer mine and provides an insight into the crustal architecture of this major Au-Cu-Ag deposit.

The interpretation of the pre-Phanerozoic basement geology along the seismic profile is now available from the WA Department of Mines, Industry Regulation and Safety eBookshop. A description of the basement interpretation, as well as an interpretation of the Kidson Sub-basin of the Canning Basin, can be found in the EFTF extended abstracts volume: https://www.ga.gov.au/eftf/extended-abstracts, with contributions by Doublier *et al*. and Southby *et al*, respectively. For further information contact Michael Doublier (GA) on 02 6249 9697 or Klaus Gessner (GSWA) on 08 9222 3631.

New AusLAMP results in southeast Australia

The Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP) is a collaborative project between Geoscience Australia, State geological surveys, and universities, which aims to collect long-period magnetotelluric data on a half-degree (~55 km) grid across the Australian continent. Several new AusLAMP products have recently been published in southeast Australia. The AusLAMP programmes in New South Wales, Victoria and South Australia are collaborations between Geoscience Australia, the Geological Survey of New South Wales, the Geological Survey of Victoria, the Geological Survey of South Australia, and the University of Adelaide and use equipment provided by AuScope/ANSIR and Geoscience Australia.

Magnetotelluric data from phase one of the New South Wales programme have recently been made available (Kyi *et al*. 2020). These data, together with Victorian (Duan and Kyi 2018) and South Australian (Robertson *et al* 2016) AusLAMP data have been inverted to produce a 3D resistivity model (Kirkby 2020), which is providing new insights into the tectonic evolution of the southeast Australian lithosphere. The key findings provided by the model are discussed in a paper in the journal Tectonophysics (Kirkby *et al* 2020). An important result is that the model images conductive regions at and below the base of the crust (>35 km depth), which may represent fossil fluid pathways along the Australian continental margin ~440 to 380 million years ago (Figure 3). The geometry and extent of these deep conductive regions match those revealed in the upper crust by potential field and passive seismic data, and match the crustal architecture predicted by the Lachlan Orocline model for the evolution of the southern Tasmanides (Cayley *et al* 2012, Moresi *et al* 2014, Musgrave 2015). Conductive regions in the lower crust also correlate with known gold deposits, which may help to guide future mineral exploration in southeast Australia.

The AusLAMP model of New South Wales and Victoria overlaps with a model of the Delamerian Orogen

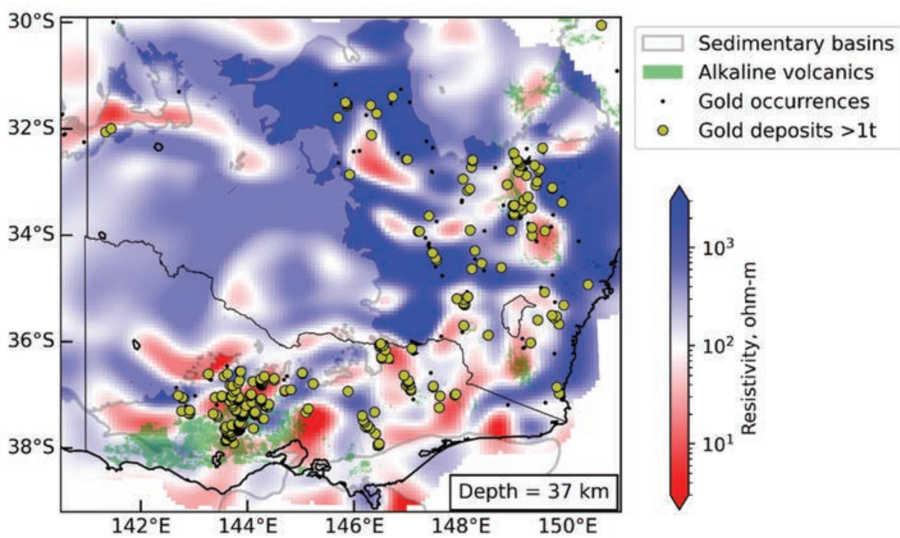

Figure 3. *AusLAMP depth slice across NSW and Victoria at 37 km showing gold deposits and occurrences, alkaline mafic volcanic rocks, and sedimentary basins. After Kirkby et al (2020).*

recently developed in a collaboration between Geoscience Australia and Geological Survey of South Australia (Robertson *et al* 2020). This new model crosses the border between South Australia, Victoria and New South Wales and is the first model to image the entire Curnamona Province and much of the onshore Delamerian Orogen.

Editor's note: For more information about this new model see the report from the Geological Survey of South Australia elsewhere in this issue.

Further information can be obtained from Alison Kirkby at Geoscience Australia at Alison.Kirkby@ga.gov.au

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

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

Table 1. Airborne magnetic and radiometric surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Line spacing Terrain clearance Line direction	Area (km²)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
Tasmanian Tiers	MRT	GA	MAGSPEC	Nov 2020	Up to an estimated 25 000	200 m 60 m N–S or E–W	4300	End of 2021	TBA	See Figure 1 in previous section (GA News)	TBA
Cobar	GSNSW	GA	GA	TBA	46 000	200 m	9200		Before end of 2021	See Figure 1 in previous section (GA News)	TBA
Gawler Craton	GSSA	GA	Various	2017	1 670 000	200 m, various orientations depending on structure	294 000	26 Jun 2019	Aug 2019	http://www.energymining.sa.gov.au/minerals/geoscience/pace_copper/gawler_craton_airborne_survey	Released
Tanami	NTGS	GA	Thomson Aviation	14 Jul 2018	275 216	100/200 m 60 m N–S/E–W	48 267	2 Dec 2018	Jun 2019	195: Aug 2018 p. 16	Released
Mt Peake	NTGS	GA	MAGSPEC	10 Jul 2019	136 576	200 m N-S	24 748	Oct 2019	Feb 2020	Aug 2019	Released

TBA, to be advised.

Table 2. Ground and airborne gravity surveys

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

(*Continued*)

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

Survey name	Client	Project management	Contractor	Start survey	Line km/ no. of stations	Line spacing/ station spacing	Area (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	See Figure 1 in previous section (GA News)	Expected release before the end of Dec 2020
SE Lachlan	GSNSW/ GSV	GA	Atlas Geophysics	May 2019	303.5 km with 762 stations	3 regional traverses	Traverses	Jun 2019	Jul 2019	See Figure 1 in previous section (GA News)	Set for incorporation into National database by Dec 2020
TISA	NTGS	GA	Atlas Geophysics	2 Jul 2019	5719	2 km × 2 km grid	31 285	Sep 2019	Nov 2019	See Figure 1 in previous section (GA News)	Released

TBA, to be advised

Table 3. Airborne electromagnetic surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Spacing AGL Dir	Area (km^2)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
Mundi	GSNSW	GA	TBA	2020/21	1900	2.5	~ 5000	Dec 2020	TBA	See Figure 1 in previous section (GA News)	TBA
Surat-Galilee Basins QLD	GA	GA	SkyTEM Australia	2 Jul 2017	4627	Variable	Traverses	23 Jul 2017	Nov 2017	188: Jun 2017 p. 21	Jun 2020
AusAEM2, NT-WA	GA	GA	CGG Tempest	May 2019	73 005 with areas of industry infill	20 km	1 074 500	~ May 2020	July 2020	201: Aug 2019 p. 16	Completed to 72% of original plan. Data has since been released. See *Preview* of Aug 2020
AusAEM20	GSWA	GA	CGG & SkyTEM	2020/21	24 000 km	20 km	480 000	Dec 21	TBA	See Figure 1 in previous section (GA News)	TBA. Survey in production

TBA, to be advised

Table 4. Magnetotelluric (MT) surveys

Location	Client	State	Survey name	Total number of MT stations deployed	Spacing	Technique	Comments
Northern Australia	GA	Qld/NT	Exploring for the Future – AusLAMP	366 stations deployed in 2016 - 2019	50 km	Long period MT	The survey covers areas of NT and Qld. Data to be released early 2021.
AusLAMP NSW	GSNSW/ GA	NSW	AusLAMP NSW	224 stations deployed in 2016-19	50 km	Long period MT	Covering the state of NSW. https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/132148 *Ongoing*
Southeast Lachlan	GSV/GSNSW/ GA	Vic/ NSW	SE Lachlan	Deployment planned to commence early/mid-2021	~4 km	AMT and BBMT	~160 sites in the Southeast Lachlan
AusLAMP TAS	GA	TAS	King Island MT	4 sites completed	<20 km	Long period MT	Covering King Island. Acquisition completed.
East Tennant	GSQ/GA	NT	East Tennant MT	131 sites completed	1.5 – 10 km	AMT and BBMT	Data and model released. http://pid.geoscience.gov.au/dataset/ga/132016 http://pid.geoscience.gov.au/dataset/ga/135011
Cloncurry	GA/GSSA/ UoA/AuScope	QLD	Cloncurry Extension	200 stations have been acquired	2 km	AMT and BBMT	Approximately 500 sites planned in the northern Cloncurry. Data acquisition is in progress
Spencer Gulf	GA/GSSA/ UofA/ AuScope	SA	Offshore marine MT	12 stations completed	10 km	BBMT	This is a pilot project for marine MT survey https://www.auscope.org.au/news-features/auslamp-marine-01

TBA, to be advised

Table 5. Seismic reflection surveys

Location	Client	State	Survey name	Line km	Geophone interval	VP/SP interval	Record length	Technique	Comments
South East Lachlan	GSV/ GSNSW/ GA/ AuScope	Vic/NSW	SE Lachlan	629	10 m	40 m	20 s	2D - Deep crustal seismic reflection	The survey covers the Southeast Lachlan Orogen crossing the Victoria–New South Wales border. Data acquisition was completed in April 2018. Raw and processed seismic data are available from Geoscience Australia and state geological surveys: http://pid.geoscience.gov.au/dataset/ga/122684
Kidson	GA/ GSWA	WA	Kidson Sub-basin	872	20 m	40 m	20 s	2D - Deep crustal seismic reflection	The survey is within the Kidson sub-basin of the Canning Basin and extends across the Paterson Orogen and onto the eastern margin of the Pilbara Craton. Data acquisition was completed in August 2018. Raw and processed seismic data are available from Geoscience Australia and the Geological Survey of Western Australia: http://pid.geoscience.gov.au/dataset/ga/128284
Barkly/ Camooweal	GA/NTGS	NT	Barkly sub-basin	813	10 m	30 m	20 s	2D - Deep crustal seismic reflection	The aim of the project was to acquire 2D land reflection seismic data to image basin and basement structure in the Barkly region in the Northern Territory. Data acquisition was completed in November 2019. Raw and processed seismic data are available via Geoscience Australia and the Northern Territory Geological Survey: http://pid.geoscience.gov.au/dataset/ga/132890

Table 6. Passive seismic surveys

Location	Client	State	Survey name	Total number of stations deployed	Spacing	Technique	Comments
Northern Australia	GA	Qld/NT	AusArray Phase 2	About 135 broad-band seismic stations	50 km	Broad-band 1 year observations	The survey covers the area between Tanami, Tennant Creek, Uluru and the Western Australia border. The first public release of transportable array data is expected by the end 2020. See: http://www.ga.gov.au/eftf/minerals/nawa/ausarray Various applications of AusArray data are described in the following Exploring for the Future extended abstracts: http://pid.geoscience.gov.au/dataset/ga/135284 http://pid.geoscience.gov.au/dataset/ga/135130 http://pid.geoscience.gov.au/dataset/ga/135179 http://pid.geoscience.gov.au/dataset/ga/134501
Northern Australia	GA	Various	AusArray, semi-permanent	12 high-sensitivity broad-band seismic stations installed in Oct 2019	~1000 km	Broad-band 4 years observations	Semi-permanent seismic stations provide a back-bone for movable deployments and complement the Australian National Seismological Network (ANSN) operated by GA, ensuring continuity of seismic data for lithospheric imaging and quality control. Associated data can be accessed through http://www.iris.edu" www.iris.edu

Geological Survey of Victoria: Airborne gravity surveying for geodesy and geology

The Geological Survey of Victoria, Surveyor-General Victoria and Geoscience Australia are collaborating to undertake airborne gravity surveying across southeast Victoria in 2020/21. Surveys covering approximately 100 000 square kilometres are being planned, covering the Victorian coast from Cape Otway to Cape Howe, including metropolitan Melbourne and the Australian Alps (Figure 1).

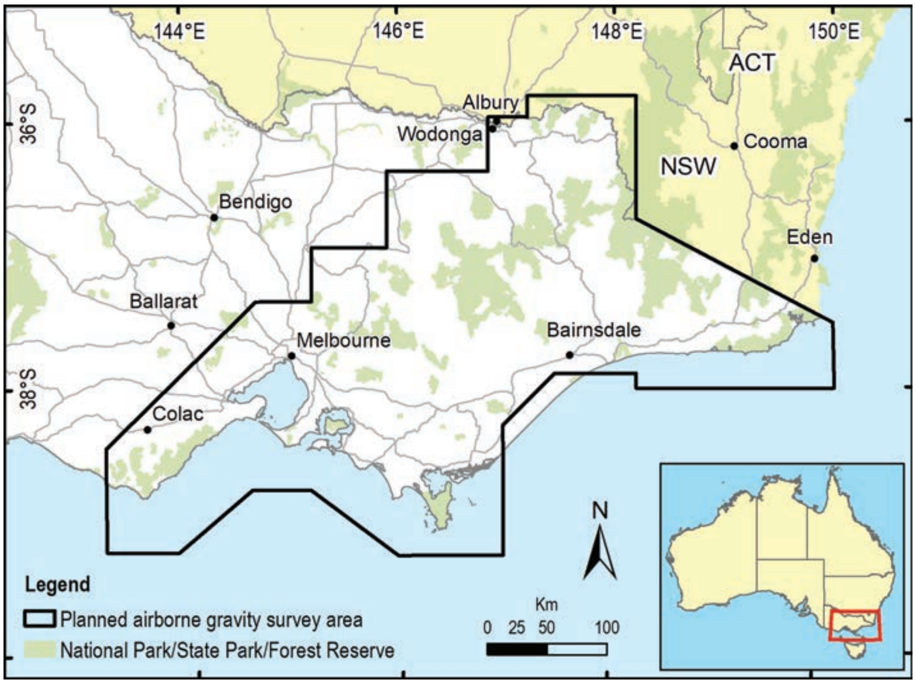

Figure 1. *Proposed airborne gravity survey area, Victoria.*

The new airborne gravity surveys will provide consistent and evenly distributed gravity measurements across diverse land types including urban and rural areas, mountainous and coastal terrain and parks/reserves with minimal disturbance to land users and the environment.

Additional gravity data is also required across southeast Australia to improve the geoid model which will form the basis of the Australian Vertical Working Surface (AVWS). The AVWS is a significant part of Geoscience Australia's *Positioning Australia* program. The exercise will upgrade and modernise the national height reference system, providing users with accurate real-world heights from GNSS positioning, instantly and seamlessly.

The new airborne gravity survey contributes to the collation of fundamental geoscience datasets that support applied geoscience research in Victoria. The data acquired across eastern Victoria will support modelling and interpretation of geological and geophysical observations across the Southeast Lachlan Crustal Transect (see *Preview* 202, p19-20), a key geological reference section for eastern Australia. The results will improve the understanding of the geological architecture, earth resources potential and natural geological hazards of eastern Victoria.

The airborne gravity survey data will be incorporated into existing state and national public geoscience databases and will be made publicly available through Geoscience Australia and the Geological Survey of Victoria. Visit www.propertyandlandtitles.vic.gov.au/surveying/airborne-gravity-survey for project updates.

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The ASEG in social media

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

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

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

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

Twitter: https://twitter.com/ASEG_news

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

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

Northern Territory Geological Survey: New gravity grid of the Northern Territory

The Northern Territory Geological Survey (NTGS) has released a new Territory-wide gravity grid (Figure 1). The new grid incorporates the recently released East Tennant and South West McArthur–Barkly gravity surveys, both funded under Geoscience Australia's *Exploring for the Future* programme. NTGS also contributed funding to extend the South West McArthur–Barkly gravity survey under the Northern Territory Government's *Resourcing the Territory* 2018–22 initiative. These surveys infilled existing 4 km-spaced data to 2 km. Figure 2 illustrates the finer scale of features visible in the new grid over the East Tennant area.

Data

Data for the new grid was sourced from government and industry surveys. The grid was generated using only ground gravity observations as opposed to previous versions that included the West Arnhem airborne gravity survey. A total of 218 155 gravity observations within the Territory were incorporated into the new grid. This represents an increase of 20 718 ground observations compared to the previous (2018) Territory wide grid, including 5855 observations from the new East Tennant and South West McArthur–Barkly surveys.

Gridding methodology

Gridding was performed using Generic Mapping Tools (GMT) software, which grids data using splines under tension (Smith and Wessel 1990). The entire Northern Territory was gridded at a constant cell size of 250 m. A tension value of zero was used to generate a smooth surface that closely matches the gravity observation values.

Available products

A suite of grids including Bouguer Anomaly, 1st order residual of Bouguer Anomaly, and 1st vertical derivative of Bouguer Anomaly, as well as a printable map are available through the NTGS Geoscience Exploration and Mining Information System (https://geoscience.nt.gov.au/gemis). Images in ECW format are also available to view and download though the NTGS Geophysical Image Web Server (http://geoscience.nt.gov.au/giws). Individual surveys including East Tennant and South West McArthur–Barkly surveys are also available for download and can be viewed on the Geophysical Image Web Server.

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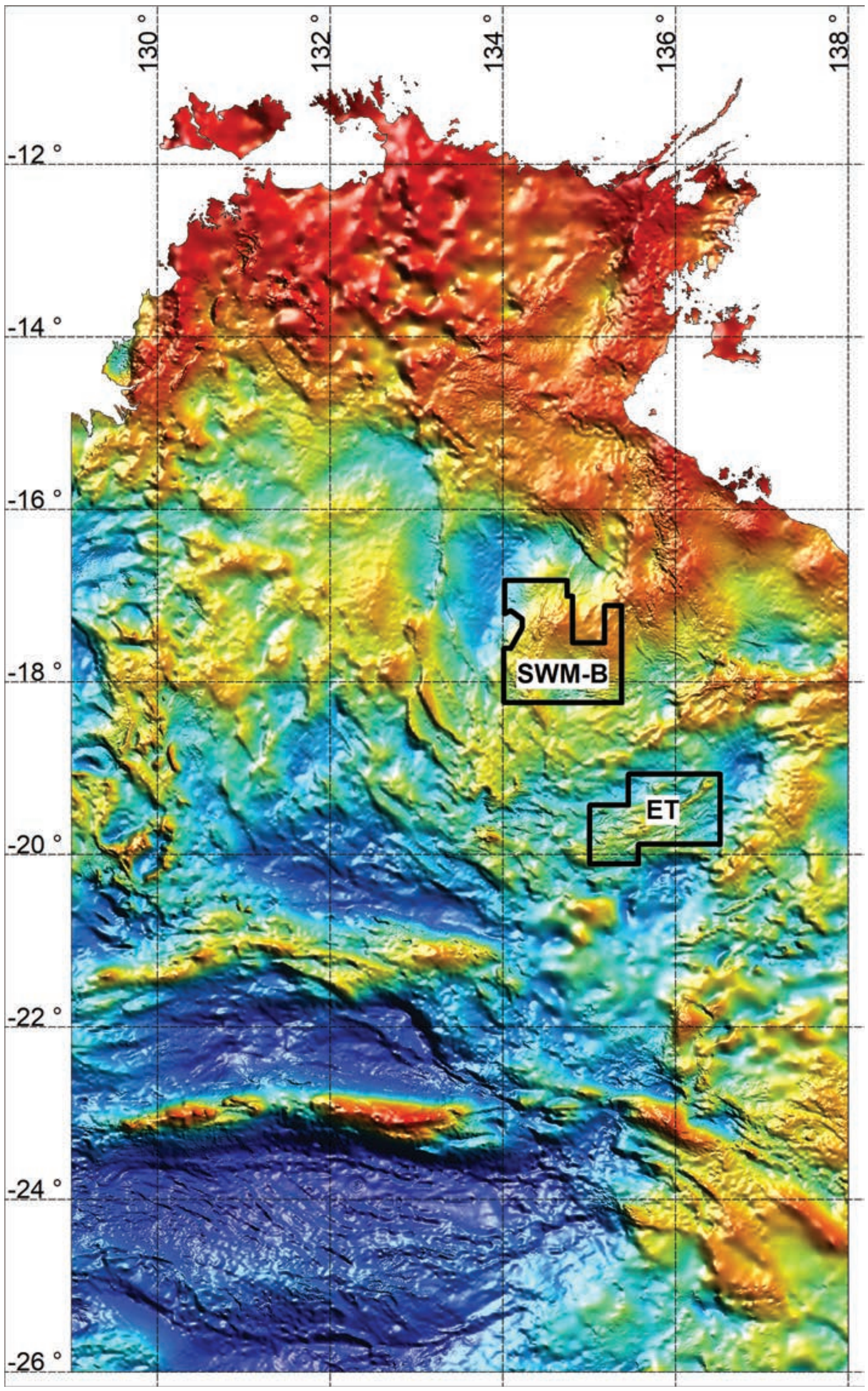

Figure 1. *New Bouguer Anomaly grid of the Northern Territory. The East Tennant (ET) and South West McArthur–Barkly (SWM–B) survey boundaries are also shown. The grid is displayed with histogram equalised pseudocolour mapping, sun shading from the northeast and sun highlights from the northwest. The projection is GDA94 geodetic.*

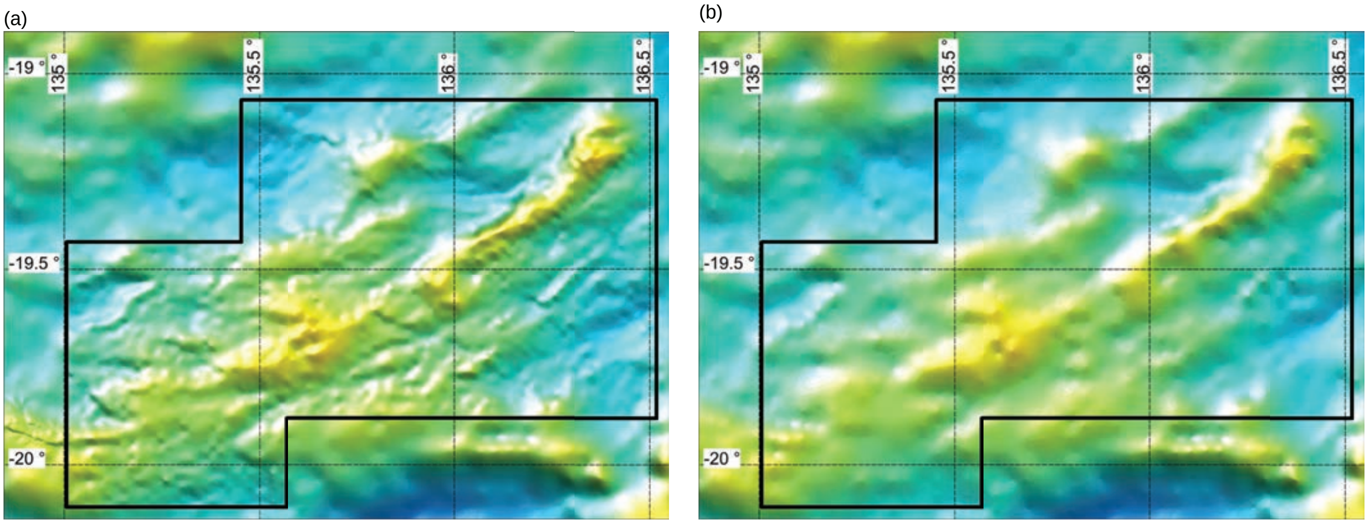

Figure 2. *New Bouguer Anomaly grid (a) compared to the 2018 Territory-wide Bouguer Anomaly grid (b) over the East Tennant area, showing finer scale features resulting from the East Tennant survey (black boundary). The colour scale and image processing are the same as Figure 1. Projection is GDA94 geodetic.*

References

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Geological Survey of South Australia: SARIG updated and a new AusLAMP model

Geophysical surveys added to SARIG's spatial layers

While all geophysical surveys reported in open file company exploration reports are available via SARIG's Georeference catalogue, they may not yet appear as a layer on SARIG. The South Australian government geophysics team has taken the opportunity provided by COVID-19 to knuckle down at home to process and upload as many historical geophysical surveys as possible.

The map below (Figure 1) shows spatially the surveys that have been released and are now visible on SARIG since the August release earlier this year. A full table of survey details and hyperlinks can be found on the SA government minerals website: https://energymining.sa.gov.au/minerals/knowledge_centre/mesa_journal/exploration_data_releases#Geophysical. The map and table will be updated quarterly.

An article in *Preview* Issue 206 contained detailed instructions on how to access geophysical data on SARIG. A brief summary is included here:

Option 1: Use the dropdown menu in the Spatial Search tab to select Geophysical Surveys. Use the Draw Area tool to select your area of interest. A pop-up window will appear listing relevant surveys. You can simply click the hyperlinks that will take you to dedicated data and metadata pages for the individual surveys.

Option 2: Use the dropdown menu in the Spatial Search tab to select Geophysical Surveys. Use the Draw Area tool to select your area of interest. This time, click the Advanced Search option (you may have to scroll down to reveal it) and follow the prompts. This option will allow you to clip the survey to the area drawn by the box.

Option 3: From the initial SARIG screen, click Map Layers and type "geophysical surveys." Once visible, switch on Geophysical Surveys and select the Identify tool under Action (in the middle of the screen). Click on the map and a pop-up window will appear similar to in Option 1. Follow the hyperlinks to access your data.

Option 4: Check open file envelopes for data not yet available the spatial layers.

For example, if you know an Exploration Licence number, select the burger menu (the three horizontal lines) and click Georeference. Click on Advanced Search and type in the EL number in the form EL01234. The results window will list any documents relating to that EL. Many smaller surveys – including gravity and ground magnetics – are often simply paper clipped to the pdf.

For assistance with downloading geophysical data from SARIG please contact:

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New AusLAMP model

A new electrical resistivity model from AusLAMP is now available. The 'Lithospheric resistivity model of the

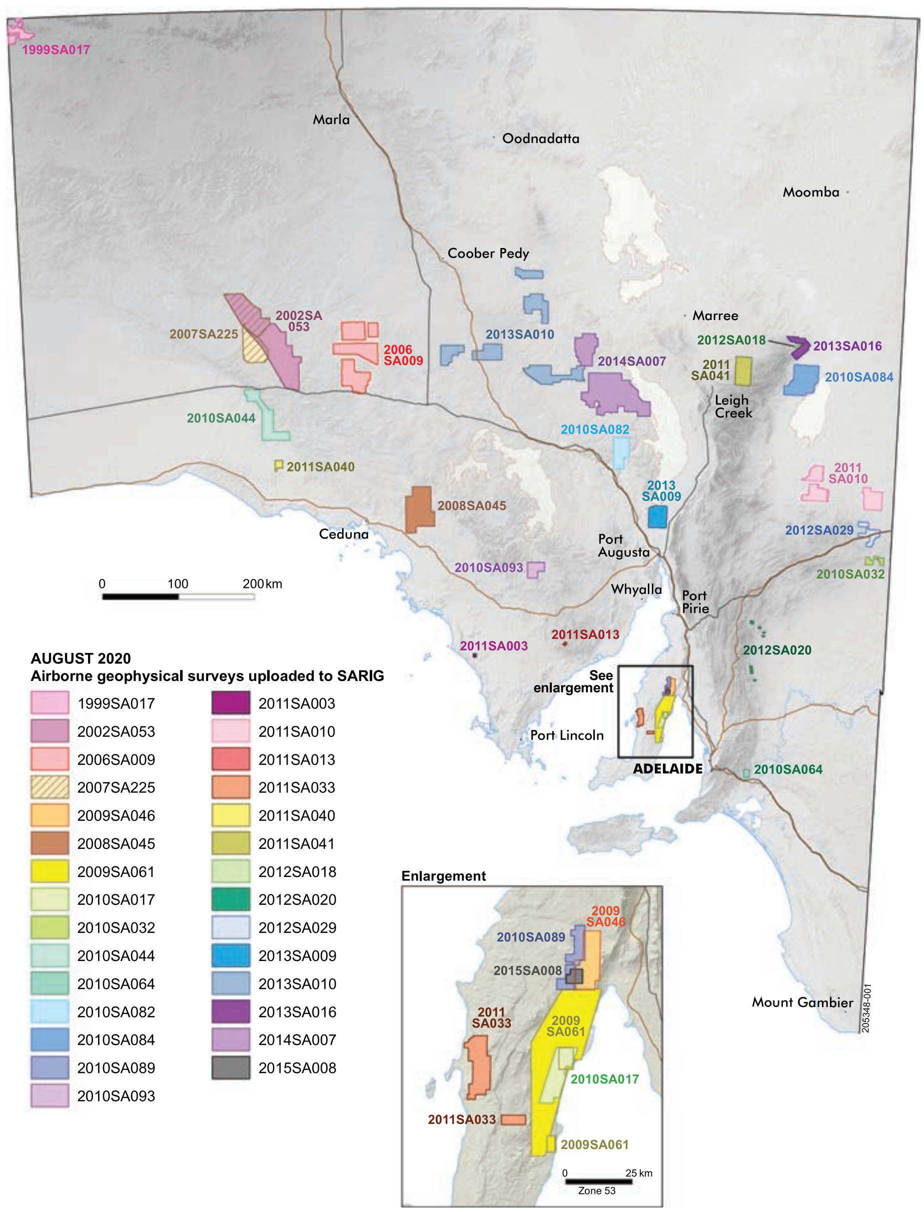

Figure 1. *Geophysical surveys that have been released and are now visible on SARIG since the August release earlier this year.*

Delamerian Orogen from AusLAMP magnetotelluric data' model can be visualised on SARIG from surficial depths to 400 km, noting that ~10 km-200 km are the most reliable depths (Figure 2).

The model can be downloaded as a package via SARIG (search 'Delamerian AusLAMP Project Area') and Geoscience Australia's website in a variety of formats suitable for various different software. The model was produced using long-period AusLAMP magnetotelluric data on a 0.5 degree array across eastern South Australia, New South Wales and Victoria. The project was a collaboration between the Geological Survey of South Australia and Geoscience Australia, and was released as part of a larger data package covering the GSSA/MinEx CRC Delamerian National Drilling Initiative project area.

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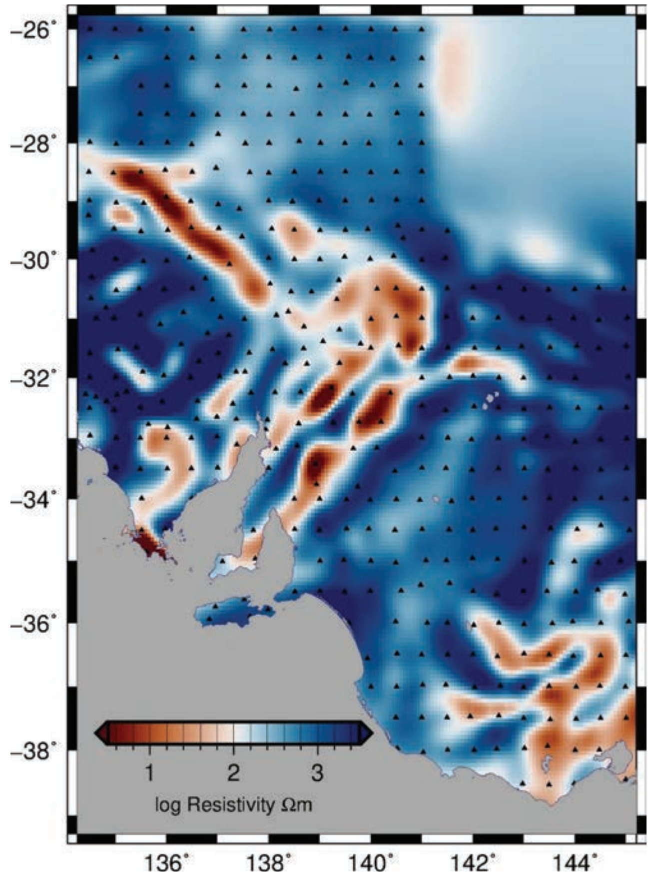

Figure 2. *Resistivity slice of Delamerian AusLAMP model at 40 km depth. Black triangles are MT site locations.*

Geological Survey of Western Australia: SWAN takes off - a new seismic monitoring project in Western Australia

The Geological Survey of Western Australia, in collaboration with the Australian National University, Macquarie University, the Department of Fire and Emergency Services and Geoscience Australia, has just installed the first seismometers of an array across the South West Seismic Zone of Western Australia. This region is one of the most seismically active areas of Australia having experienced over 2000 small (between M_L 2 to 3) earthquakes since the year 2000. Many smaller events are also noted by the local people who often hear them coming. Yes – hear them coming – this area is known for its "noisy" earthquakes. Most of these earthquakes occur in swarms rather than main shock-aftershock sequences (Dent 2015). This means that the region experiences a lot of small earthquakes, all much the same size and which occur in a similar area. These swarms can be active for years.

Figure 1. *Photo of the railway line near Meckering after the 1968 earthquake.*

Figure 2. *Aerial photo of the surface rupture associated with the 1968 Meckering earthquake.*

The hazard associated with these seismic events is relatively small. However, in the past six decades this region has also hosted five of the nine surface rupturing earthquakes in Australia, most notably; Meckering (M 6.5) in 1968 from which there are photos of the bends in the railway lines (Figure 1) and faulting of 2-3 m in height across the fields (Figure 2) (Gordon and Lewis 1980; Johnston and White 2018; Clark and Edwards 2018); Calingiri (M5.9) in 1970 and Lake Muir (M5.6), which was felt by a lot of people across Western Australia just two years ago (Clark et al. 2020).

Despite the high rates of seismicity, seismic monitoring in the region remains relatively sparse. To overcome this lack of instrumentation, the consortium of institutions mentioned above, came together for an ARC Linkage project to put in place a temporary network-the South West Australia Network (SWAN) - to improve the monitoring and detection capabilities in this area. This project will see a total of twenty-five broadband seismometers deployed across the southwest of Western Australia for a period of approximately 2 years (Figures 3 and 4).

This temporary array will enable the detection and location of smaller-magnitude earthquakes that can be used to improve the crustal velocity models which in turn enables more accurate earthquake locations and helps the understanding of the crustal structure of this part of Australia. Better velocity models also enable better magnitude calculation methods, which improve the knowledge about recurrence of earthquakes of a certain magnitude. From a seismic hazard point of view, this data has the potential to assist in the development of improved methods for modelling how shaking intensity varies as it propagates through the earth's crust from the earthquake source.

Overall, this information will feed into an improved understanding of the earthquake hazard in the Southwest region of Western Australia. For local communities, it will provide

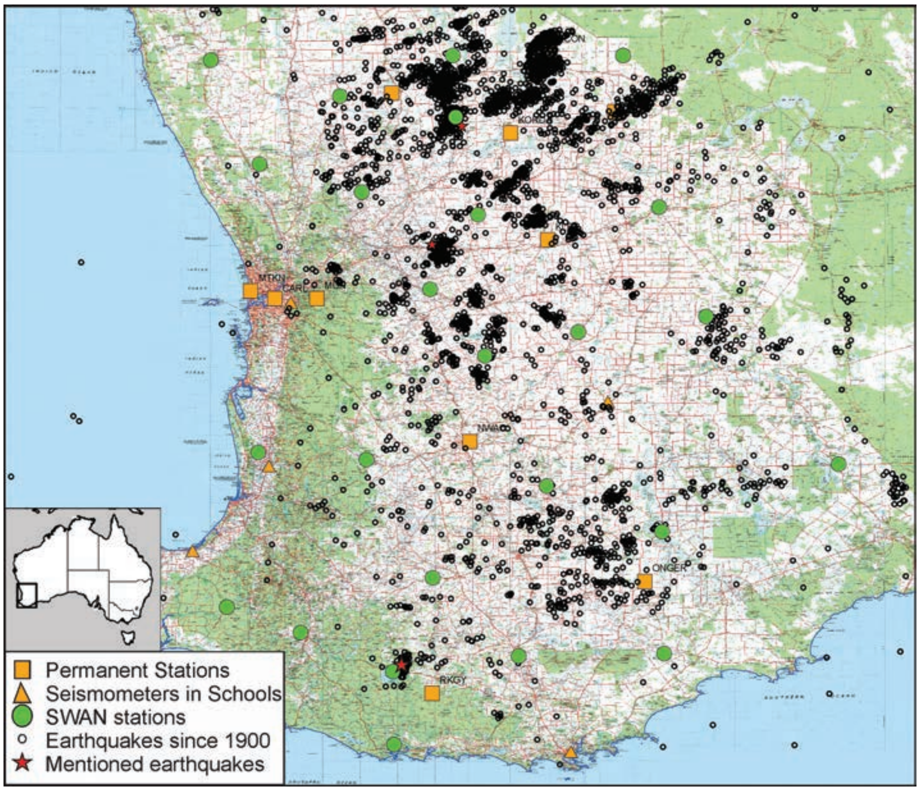

Figure 3. *Location of the SWAN seismometers in relation to the permanent networks and the earthquake activity in the south west of Western Australia.*

Figure 4. *Installing a station in the SWAN network.*

an improved situational awareness following significant earthquakes. More broadly, the improved understanding of the seismicity of the Southwest of Western Australia will enhance emergency response capabilities, and inform building codes and mitigation initiatives, which are the best methods we have to minimise the earthquake risks to communities.

Data will be released through AusPASS, the Australian Passive Seismic Server two years after the last data has been collected.

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Canberra observed

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COVID-19 tests our Federation

The National Cabinet convened by Prime Minister Morrison has worked well during the national challenge of the persistently contagious COVID-19 virus. There have been a few disagreements about virus hot spots, lock downs and border controls, but, in the future, these will be forgotten.

Of longer-term consequence are the relations between the Commonwealth and the States and Territories. For example, the Australian Government is responsible for aged care facilities, and yet the States and Territories provide health care. The Australian Government is responsible for border control, and yet the States have to provide the resources to manage quarantine arrangements and NSW Health was blamed for allowing the Ruby Princess passengers disembark in Sydney. The Federation is supposed to allow free and unfettered trade and passage within Australia, and yet the States and the NT closed their borders.

COVID-19, and whatever other pandemics may follow, do not recognise borders on maps, but usually attack in clusters. The Prime Minister tried to get agreement over the definition of a 'hot spot' in the National Cabinet but failed. He should persist because that is probably the best way to deal with a pandemic, without closing borders, and we know that COVID-19 is going to be with us for at least another year.

Morrison goes for gas

Many energy and climate change analysts acknowledge the need for gas as a transition fuel, for the next 20 years or so, but for Morrison, his commitment to "1,000 MW of new dispatchable capacity by the summer of 2023-24, with final investment decisions by the end of April 2021" means that Australia will be locked into further decades of greenhouse gas emissions from fossil fuels. This interference in the electricity generating market is likely to discourage future investment in renewable energy generation and storage. And the cost of the gas-generated electricity is unknown.

Earlier this year the Australian Energy Market Operator indicated a need for only about 155 MW of dispatchable electricity by 2023, and it has been reported that AGL is going to install a 100 MW battery as part of a larger battery farm at the Liddell Power Station site. Could the Prime Minister be advocating a policy to tackle a problem that does not exist?

In his 5000-word speech Morrison never mentioned climate change or global warming, nor did he indicate how he arrived at the 1000 MW number or how this investment will affect our emissions target.

There needs to be a price on carbon emissions and a plan to reduce our reliance on fossil fuels. Consider the Santos situation regarding the depleted Moomba gas field and whether it can be used to store CO_2. With a price on carbon the economic value can be estimated. Without it, the project is only of research interest.

Coalition plans to dilute environmental controls

Clean air and water, bushfires, biodiversity of flora and fauna and a healthy environment are national issues and critical for a healthy economy. One might have thought that the Australian Government should have the responsibility for these matters. But that is not what the current coalition government thinks. It wants them all sent back to the States and Territories.

In October 2019 Professor Graeme Samuel AC, an expertise in public policy in economic reform and regulation, was appointed to chair a review of the Environment Protection and Biodiversity Conservation (EPBC) Act.

His interim report delivered to the Government on 30 June found that: "Australian governments had failed to protect Australia's unique wildlife and habitats and recommended an overhaul of the laws to make the country's systems of environmental protection more effective." He also recommended the devolution of approval powers to the states along with the introduction of national environmental standards and an independent regulator to enforce the law.

In July 2020, the environment minister, Sussan Ley, rejected the recommendation of an independent regulator, but said she would put a Bill to parliament that streamlined the approval process and promised to introduce prototype standards to ensure environmental protection at the same time. However, the bill introduced in August was reported to be a near replica of failed "one-stop-shop" legislation introduced under Tony Abbott's government. It contained no reference to any of Samuel's other recommendations, including national standards. It passed the lower house in August after the coalition gagged debate.

It was also reported that the Office of Parliamentary Counsel began drafting the changes to the legislation on 19 June, 11 days *before* the Government received the interim report of the review the national environment laws. The final report should be released in October and then it will probably be up to the Senate to deal with any associated legislation. However, without legislated national environmental standards, it is difficult to see how any compliance could work.

Is oil going the same way as coal?

COVID-19 has played havoc with oil supply and its price. Travel has been reduced everywhere, and now there is now a glut of oil. Figure 1 shows the daily oil price from 2010-20 of West Texas crude. Notice that the price had declined from 2014, before the COVID-19 effect.

The oversupply of oil was already there and COVID-19 just hammered this home. Is this pattern similar to what we saw with the price of coal?

Mineral exploration investment is currently performing well on the back of gold (Figure 2), but offshore petroleum exploration in the June quarter fell to a seasonally adjusted $67 million. That

Figure 1. *Daily oil price of West Texas Crude, from https://www.macrotrends.net/2516/wti-crude-oil-prices-10-year-daily-chart.*

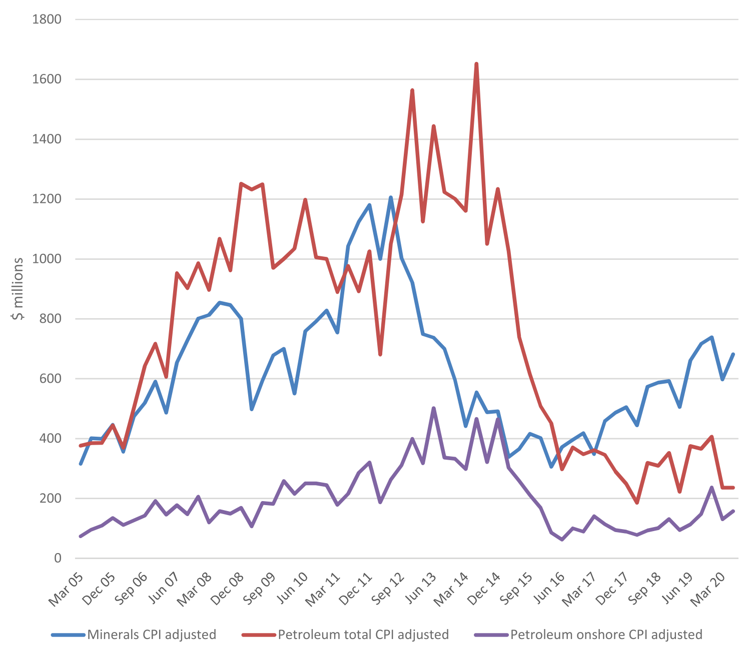


Figure 2. *Quarterly investment in mineral, total petroleum and onshore petroleum exploration 2005-2020. The investment in offshore exploration appears to be at its lowest point for 30 years*

appears to be the lowest expenditure in at least the last 30 years and, in a rare event, the seasonally adjusted onshore investment ($153 million) was larger than that offshore.

The implications for the government's policy to invite companies to bid for offshore exploration tenements are huge. Does it persist in trying to invite companies to explore, or does it just wait and see what happens in a year's time? Difficult decisions; made harder by the high cost of offshore exploration and development.

Maybe best to do nothing at the moment. But that may not be the advice the Government wants to hear.

Government's plan to lower emissions still hooked on fossil fuels

In September, the Morrison Government released its plans to reduce Australia's greenhouse emissions. There is still an emphasis on fossil fuels. And no targets have been set.

Carbon Capture and Storage is on the list, even though it has still not been proven cost effective, after over 20 years of experimentation, and hydrogen is going to be mainly sourced from LNG.

There is nothing in the statement about encouraging electric transport, improving the efficiencies of solar panels and wind generators or designing and building more energy efficient buildings.

It is not clear why these issues are not included as priorities.

For record the five priority technologies and goals to make new technologies as cost-effective as existing technologies are:

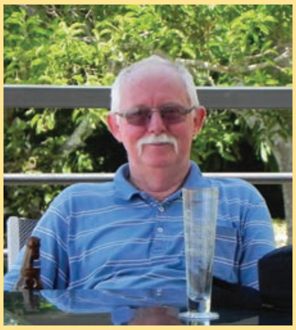
- Hydrogen production under $2/kg.
- Long duration energy storage (6 hours or more) dispatched at less than $100/MWh.
- Low carbon materials – low emissions steel production under $900/t, low emissions aluminium under $2700/t.
- CCS – CO_2 compression, hub transport, and storage under $20/t of CO_2.
- Soil carbon measurement under $3/ha/yr – a 90% reduction from today's costs.

And there eleven key actions:

- Establish a Technology Investment Framework to prioritise the Government's investments in new technologies.
- Invest $1.9 billion in a new energy technology package; establishing Australia's first regional hydrogen export hub, a King Review Co-Investment Fund, a CCS Deployment Fund and a Future Fuels Fund to support new and emerging technologies.
- Finalise new or revised Emissions Reduction Fund methods to support CCS and soil carbon within 12 months.
- Commence a soil carbon innovation challenge to rapidly reduce the cost of measuring the impact of new farming practices on soil carbon sequestration.
- Introduce legislative reforms to ARENA and the CEFC to give their boards flexibility to respond to the Government's priorities.
- Require key agencies (ARENA, CEFC and the CER) to focus on accelerating the priority technologies.
- Direct key agencies to publicly report on what action they are taking to accelerate the priority technologies.
- Establish a permanent Technology Investment Advisory Council.
- Expand Australia's international collaboration with trading partners.
- Conduct a review of legislative or regulatory barriers to technology uptake as part of the second annual Low Emissions Technology Statement.
- Complete the development of Australia's Long Term Emissions Reduction Strategy before COP26.

The Low Emissions Technology Statement is available on the Department of Industry, Science, Energy and Resources website: http://industry.gov.au/LETS2020

Minerals geophysics



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Gravity corrections

For any gravity survey, a series of corrections is required to transform raw field data into the finished product. In exploration-style (i.e.: semi-regional, detailed, or very detailed) vertical component gravity surveys, taking the infinite slab approach these corrections typically comprise: conversion from instrument units to milligals, correction for Earth tidal drift, correction for instrument drift, correction for geographic position (latitude), correction for gravity station height, correction for underlying rock density and, where appropriate, correction for terrain topography. In most cases the gravity survey results are also tied to the Australian National Gravity Database (ANGD) via a tie reading loop between the survey and a known ANGD station.

In the main these are routine corrections, and for commercial surveys are typically applied by the geophysical contractor prior to delivery of the final version data. Details of all these corrections should be provided in the accompanying contractor's survey report. I'll elaborate a little on implications for the elevation, rock density and terrain corrections, particularly the latter two that require decisions based on the geological environment.

With respect to the routine corrections, conversion of readings from instrument units to milligals is achieved by multiplication with an instrument-specific factor. Correction for Earth tidal drift is made via existing tables. Correction for instrument drift is made by taking local base station readings at the beginning and end of each reading loop and scaling any differences across the readings taken during the loop. Correction for geographic position uses a latitude dependent formula to correct gravity values for effects from the oblate spheroidal shape of the Earth. Applying all these corrections generates observed gravity values.

The elevation dependent *free-air correction* uses a formula to adjust observed gravity values for variations in station heights. This formula can simplistically be expressed as *0.3086 x station height* and is *added* to each gravity value. The station height is usually measured from the Australian Height Datum (AHD), but, because we are dealing with relative and not absolute gravity values, could be measured from any convenient datum.

The elevation and density dependent *Bouguer correction* uses a formula to adjust free-air gravity values for the presence of material beneath each station. By assuming a slab of infinite lateral extent, this formula can simplistically be expressed as *0.04191 x density x station height*, and is *subtracted* from each gravity value. The Bouguer density is an estimate of the average density of the material constituting the slab; the station height is as defined for the free-air correction.

Common practice for large scale surveys is to use 2.67 g/cc as the Bouguer density, this value historically being considered the average density of crustal rocks. Such a value may have merit for regional scale gravity surveys, but it is clearly inappropriate for limited extent exploration surveys, where variations in magnitudes of Bouguer corrections are controlled by the slab thickness measured from each station height to the height of the lowest station in the survey. The portion of the Bouguer slab correction for material below the height of the lowest station will be the same for every station in the survey. Thus Bouguer corrections effectively only utilise the density of the material above the level of the lowest station. The Bouguer density can be estimated from a knowledge of the local near-surface geology of the survey area, or by measuring the density of appropriate samples. For gravity surveys in sand dunes an appropriate Bouguer density may be well under 2 g/cc, in outcropping mafic terrain it may be well over 3 g/cc.

Where there is no information on the subsurface materials, an approximate Bouguer density value may be deduced by plotting Bouguer gravity profiles calculated for a series of densities and comparing them with the corresponding topographic profile. If these gravity data aren't provided in the survey results, you will have to calculate them from the data you do have. The resulting Bouguer gravity profiles will range from topography sympathetic (density too low) to topography antipathetic (density too high). The gravity profile showing minimum correlation with topography will identify the Bouguer density to use. Of course, this approach does assume that topographic variations are independent of any inherent gravity anomalism, which may not necessarily be the case. So, caution is needed, and you may have to select an appropriate area within your survey for this process.

The topography dependent *terrain correction* is effectively a modification to the Bouguer correction to take account of material missing from the slab below the station elevation (valleys) and material added to the slab above the station elevation (hills). Both effectively reduce the magnitude of the Bouguer slab effect, so the terrain correction is *added* to gravity values to compensate. Here too, the density value(s) used should be appropriate to the materials involved. In the past this correction was calculated by subdividing the terrain around each station into zones and manually estimating the average terrain elevation difference for each zone; digital elevation models now permit this to be done semi-automatically. Terrain corrections are not always necessary in mineral exploration surveys, but may be appropriate for larger surveys, areas of steep topography and for very detailed surveys on mine sites, for example, where the ground surface has been disturbed by earth works, excavations, etc.

So, when reviewing the results from a gravity survey, be on the lookout for pattern elements apparently mimicking topography. They may simply relate to the use of an inappropriate Bouguer density value. It's a distraction you can do without.

Seismic window

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CSIRO not alone with ML

The *Preview Editor* sent me an article submitted by Beloborodov *et al* because she thinks that I am an expert in Machine Learning, which is a far cry from the truth, but I vaguely know how it works.

The article recognises that the well log characteristics of a facies or rock type vary with depth and each facies may have a different depth dependent relationship. It is this variation in the characteristics of a particular facies with depth that bamboozles machine learning attempts to classify facies based on well logs alone. To solve this problem the researchers have come up with a hybrid approach with the machines doing their thing based input from rock physics in the form of depth trends.

Well, I don't want to steal the limelight so here is the full article describing the CSIRO approach.

Not by machine learning alone: Automatic facies classification for seismic inversion

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The CSIRO has developed a new approach to rock facies classification that fuses machine learning and rock physics. Pre-processing of well log data required for quantitative interpretation of seismic data now takes minutes instead of weeks.

With the advent of the machine learning (ML) era, many time-consuming and tedious manual processing tasks have been automated, drastically reducing time from survey to discovery. Unfortunately, petrophysical facies classification, a pre-processing step required for quantitative interpretation, seismic inversion and reservoir modelling, is not one of those tasks. Previous attempts at developing automatic facies classification algorithms have failed owing to a fundamental problem, namely, that petrophysical properties of rocks change with compaction, a ubiquitous geological process. This means that the properties of a rock vary significantly at different depths even within the same facies having the same composition and depositional history. These burial trends of petrophysical properties obscure class boundaries and hoodwink the best ML algorithms.

However, when ML algorithms fail on their own, rock physics comes to the rescue by providing understanding of depth-dependent rock properties. Numerous theoretical and empirical rock physics models exist for several specific rock types. Only some of these models take depth-dependency into account explicitly. These models are generally developed for rock types that exhibit strong variation of elastic properties with stress, such as unconsolidated sandstone. Overburden stress, as a proxy for depth, is explicitly incorporated into their equations. Other models, such as those for cemented sandstones, shales and carbonates, do not explicitly derive rock properties as functions of stress but may be indirectly related to depth via changes in density, porosity or cementation.

It is well established that different rock types exhibit distinctive compaction trends. For this reason, the compaction trends that would generally hinder rock facies classification can be transformed into positive characteristics. Data points can be assigned to the right classes using both their physical properties combination at each depth and also the variations in these properties with depth. The ML algorithm called Expectation-Maximization (EM) is advantageous to accomplish this. Starting from a random guess on class memberships, the EM algorithm iteratively fits rock physics models and then updates memberships to maximise the likelihood of the system. The free parameters of the best-fitting rock physics model, such as crucially important cement fraction or coordination number, are estimated at the same time. The algorithm is most successful when theoretical rock physics models fit nicely the petrophysical data in a well but a user can instead choose to fit empirical trends from local or global datasets. However, the physical parameters of practical importance such as cement fraction or sorting cannot be estimated in this case.

In addition to identifying the most probable rock type the EM algorithm also estimates the probabilities for alternative rock types. This uncertainty estimation can be propagated forward into quantitative interpretation, for example, when using a probabilistic approach for seismic inversion.

The challenges around rock typing, such as selecting the set of rock physics models that best describes the true lithologies, are not unique to energy resources. As mineral exploration moves into more complex geological settings under sediment cover, rock physics models are becoming increasingly relevant for the robust delineation and characterisation of mineral resources. Strategies that have proven to be successful in the context of energy resources are likely to also be successful for the more challenging setting around mineral resources.

Data trends

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Wavelet transforms

The wavelet transform is a relative newcomer to potential fields, but is starting to appear more frequently in literature. While most of us are familiar with the Fourier Transform (FT), what is this new application of the FT?

Luckily there are people like Robi Polikar of Rowan University who in 2006 published the second edition of his 70 page introduction for the rest of us, the Wavelet Tutorial (Polikar 2006). He informs us he wrote the tutorial for mathematics professors and engineers confused by the idea, and that the rest of us should not feel embarrassed if we are also confused.

Geophysicist Jean Morlet and Alexandre Grossmann's technique (Grossmann and Morlet 1984) purports to improve on Heisenberg's Principle in signal analysis – that we can only pick one property to define – either the frequency or its position in time/space, but not both. Polikar demonstrates with both stationary and non-stationary signals that transform into near identical frequency graphs. This shows the Fourier Transform accounts for all frequencies within a signal (has full frequency resolution) but cannot distinguish where they occur (poor time resolution).

The Short Time Fourier Transform (STFT) introduced time/space windows to break the signal into piecewise segments. Segments small enough you can assume stationarity independent of the rest of the signal. This increases time resolution (where frequencies occur in the signal) but ignores signal outside the windowed section of time/space. It has reduced frequency resolution and cannot resolve frequencies outside the time window that also contribute.

Now we have the shotgun approach of the Wavelet Transform which combines piecewise convolution of the signal with a wavelet that changes size to resolve a range of frequencies (see Figure 1).

$$F(\tau, s) = \frac{1}{\sqrt{|s|}} \int_{-\infty}^{\infty} f(t) \boxed{\varphi\left(\frac{t-\tau}{s}\right)} dt$$

Figure 1. *Continuous wavelet transform equation*

It is still a conventional convolution of signal *f(t)* with wavelet ψ(), and |*s*| ensures the energy of the result remains constant with input. I want to focus on the terms that influence the wavelet function ψ(), which show the wavelet transform is really just an iterative series of FT convolutions. The keywords are *scales* (s) and *translations* (t - τ).

- s : *scale.* For a number of predetermined scales, the wavelet will be stretched or compressed. Different scales will resolve difference frequencies.
- *t* – τ : the offset by which the centre of the wavelet is *translated* along the signal

An easier general description, which borrows heavily from Vinay Yuvashankar's pseudocode (Yuvashankar 2016) is as follows:

Determine the range of scales and translations
FT the signal
For each scale
    Scale the wavelet
    For each translation
    Translate wavelet along the signal
        Convolve wavelet with signal
        Invert the result
        Store the magnitude

The magnitudes derived from various scales are used as coefficients to model the signal (Figure 2). The coefficients are used in deep neural networks, compression such as ECW (Enhanced

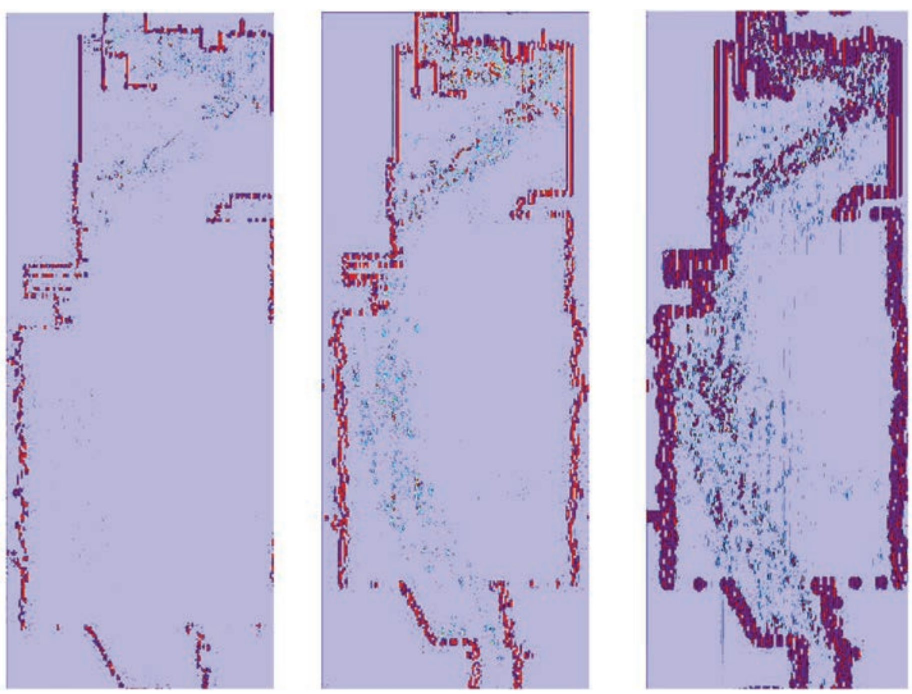

Figure 2. *Example of coefficients produced by the continuous wavelet transform. Generated using MatLab© cwtft2 command running default settings on an Analytical Signal grid of the Delamerian project area. Starting from left, wavelet scaling resolved high frequency from outcropping in the shallow northern area (far left), progressing to lower frequencies resolved in the centre and south around the Renmark Trough (right).*

Wavelet Compression) and those derived from the Analytical Signal are the basis of edge detection methods such as "Worming" (Sid-Ali Ouadfeul et al. 2012).

I hope this helps fellow newcomers to a better understanding of wavelet transforms.

Acknowledgements

Gary Reed, Peter Waring, and Des Fitzgerald

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Webwaves

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A look at some IT initialisms

This month in *Webwaves* we are looking at some common IT initialisms and their meanings. As with previous *Webwaves* columns, security is the main course, with a side of software.

SSH

Secure shell (SSH) is a secure protocol for communicating with remote servers and was designed as a replacement for Telnet and remote shell (rsh). Secure shell uses symmetric cryptography to establish a secure connection between two points then supports a variety of authentication mechanisms, including asymmetric cryptography by way of public and private key pairs. Here, the user shares a public key with the remote machine and authentication is performed with the private key which is safely stored by the user. Secure shell only uses the keys for authentication and not for the encryption of the connection. The SSH protocol can also be used for file transfer using mechanisms such as SCP (secure copy) or SFTP (SSH file transfer protocol). Secure shell is a common way of authenticating with remote servers and VM's (virtual machines).

SSO / MFA

Previous *Webwaves* posts have discussed password security. MFA (multifactor authentication) and SSO (single sign on) are two strategies that can be used to simplify your online security. MFA is a methodology for securing accounts by requiring an additional form of verification. MFA has been widely adopted by Australian banks, through the use of a physical hardware token or SMS prior to approving transactions. This improves security by requiring something you have (phone/token) in addition to something you know (password). Single sign on is the use of a single login for multiple services. Several of the FAANG companies offer SSO, with the ability to use a single login across multiple services. Single sign on reduces password fatigue, and, when coupled with MFA, can provide an easier and more secure way to manage online credentials.

DoS and DDoS

A DoS attack (denial-of-service attack) is a malicious cyber-attack designed to render a machine or network resource unavailable to intended users. There are two basic forms of attack: crashing or flooding. A machine could be crashed using buffer overflow through an attack using all of an available resource, such as memory. A flood attack is where the target is overwhelmed by needless requests, saturating bandwidth and preventing access. A distributed denial of service attack (DDoS attack) is where multiple sources are used for the attack. For example, a number of malware infected computers being used to overwhelm infrastructure. In August 2020, the New Zealand stock exchange was the victim of multiple days of DDoS attacks, resulting in the closure of the exchange.

OSS/FOSS

Open source software is a broad term covering non-proprietary software. Open source software has the source code released under a licence granting users wide ranging rights use of the software. Common licences can be found listed at opensource.org (https://opensource.

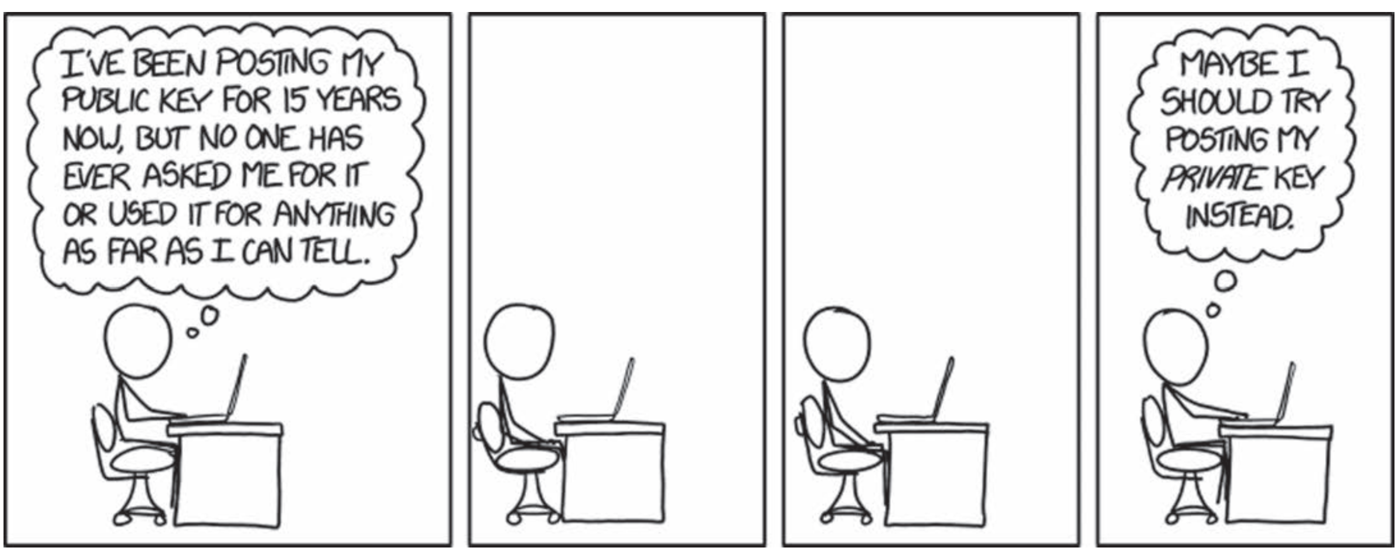

Figure 1. *(public_keypng). Credit to xkcd https://xkcd.com/1553/*

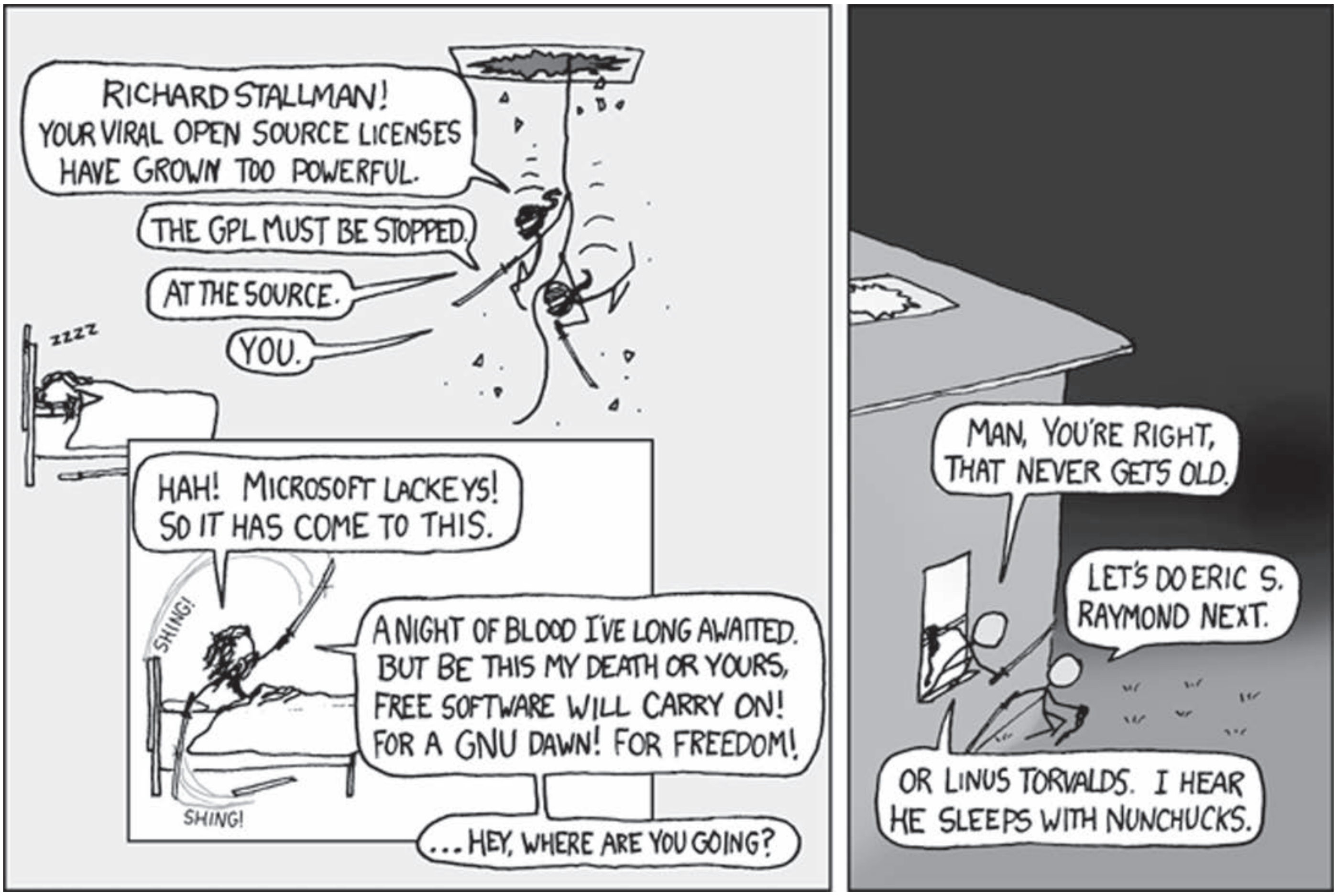

Figure 2. *(open_source.png). Credit to xkcd https://xkcd.com/225/*

org/licenses). The free in FOSS does not refer to monetisation, rather to the user's civil liberties (free speech). The geophysical community has access to a wide range of (F)OSS tools that can be applied to various different geophysical methods. The ASEG website has a page on open source geophysical software (https://www.aseg.org.au/open-source-geophysical-software). Should anyone have content or (F)OSS software that can be linked to from this page, please contact the webmaster using webmaster@aseg.org.au

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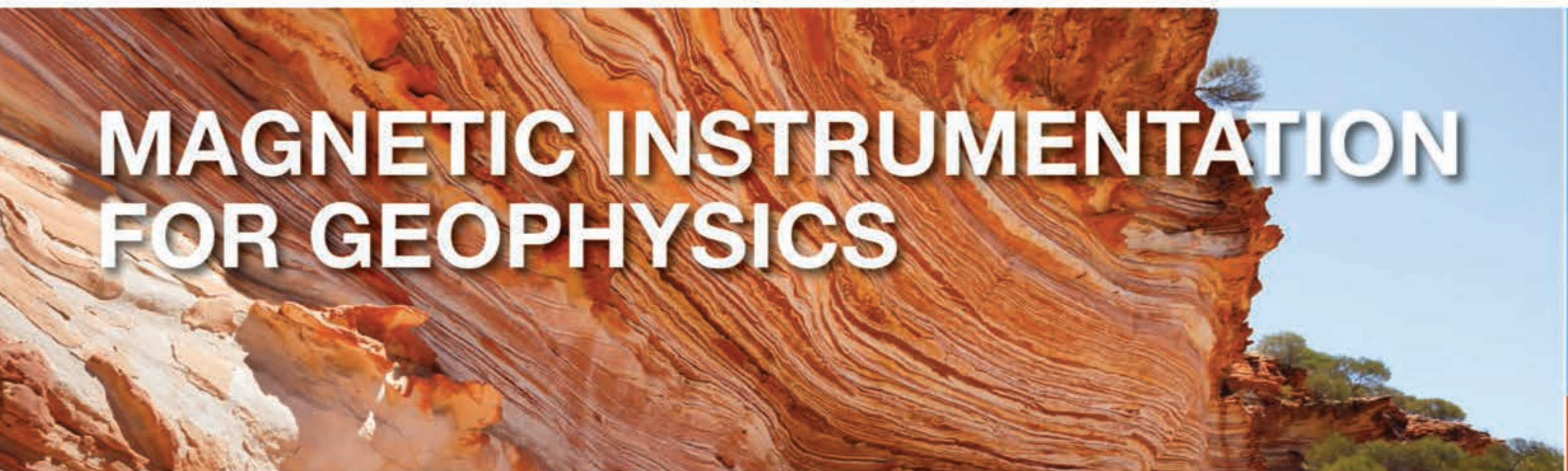
YouTube: https://www.youtube.com/channel/UCNvsVEu1pVw_BdYOyi2avLg

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



MAGNETIC INSTRUMENTATION FOR GEOPHYSICS

Bouguer's gravity corrections and the shape of the Earth

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In the gravity method of exploration geophysics, Bouguer is the name of a specific correction to measurements, and also the name of the anomaly remaining after that correction and other corrections are made. For a full explanation of these two terms see Sheriff (1991). The terms are named after Pierre Bouguer (1698-1758), a French mathematician and astronomer who also gave his name to a crater on Mars, another on the moon and an asteroid[1].

As a child prodigy, Pierre was taught mathematics, hydrography and astronomy by his father, Jean Bouguer, who was Royal Professor of Hydrography at Le Croisic in Brittany. When Jean died in 1714, Pierre applied for his father's position and, with his brilliance and knowledge of the subject, was appointed Professor of Hydrography at the age of sixteen. He proceeded to win three Grand Prix at the French Académie Royale des Sciences: the first in 1727 on the masting of ships, the second in 1729 on observing the altitudes of stars at sea, and the third in 1731 on observing magnetic declination at sea[2]. Thus, his strong involvement in things nautical became apparent, and Pierre was soon a leading French authority on the subject. He was made a full member of the Academy in 1735.

However, Pierre was also interested in geodesy, which makes him more interesting to geophysicists and, indeed, they are especially interested in his involvement in the quest to measure the shape of the Earth. In the 18th century, it was generally accepted that the Earth was not flat (!), but it is hard to imagine that 300 years ago it was still being debated as to whether it was an oblate spheroid (with a bulge at the equator) or a prolate spheroid (with a bulge at the poles).

Isaac Newton believed the Earth to be oblate, as caused by rotation and resulting centrifugal forces. In his *Principia Mathematica* (Newton 1687) he stated ".. the earth is higher under the equator than at the poles" and he even put the excess at "about 17 miles" (27.4 km). This is amazingly close to the exact figure for someone working only theoretically, as the true number is close to 19 miles (30.6 km) (see Milsom 2018, 119).

In terms of gravity readings, if the shape is oblate, values will increase with increasing latitude. Indeed, measurements of gravity by Jean Richer near the equator in French Guyana in 1672 (Richer 1679) had shown a reduction in values compared to those in Paris. Newton regarded this as further proof of oblateness. But still, many notable French physicists of the time considered the whole idea of gravitational attraction by an unseen force as suspect or even incomprehensible and continued to argue in favour of the shape being prolate. To support their beliefs, they adopted an alternative theory of vortices in an ether expounded by René Descartes, a French philosopher, in 1644 (Descartes 1644)[3]. His followers became known as the 'Cartesians'. The debate between them and the supporters of Newton, the 'Newtonians', ensued for decades. Bouguer originally gave equal consideration to both schools so as not to harm his standing in the Academy.

The sure way this debate could be settled was to accurately measure the length of a degree of latitude in different parts of the earth, and especially at the equator and the poles where the values would be extreme, and compare them. Figure 1 shows the different lengths for the two types of shape. For an oblate shape, the length of one degree at the poles is more than the length of one degree at the equator.

At this time, a site at which to measure the length of one degree on the equator was not easy to find. The coastline of equatorial Africa was considered too dangerous, and relevant Asian islands were too far away, especially given the available means of transport. A somewhat more civilised place, due to strict Spanish control, but still very far from France, was in what was then a part of the Viceroyalty of Peru, now Ecuador, centred on Quito the capital. Figure 2 is a map of colonial South America as it was known in about 1740, with Quito on the western side near the equator. Also shown on the north-eastern side of the continent is Cayenne in French Guyana, where Richer made his gravity measurements.

To use this location required the cooperation of Spain, which was negotiated by the Minister of the Navy of France (the Comte de Maurepas). In fact, an expedition would be undertaken with the agreement and protection of the King of Spain. As Ferreiro (2011) points out, this endeavour was unprecedented in being the first scientific expedition involving two nations with participants from both countries[4].

Thus in 1735 at the age of 38, while reluctant to travel outside of France because of suffering from sea-sickness and not in good health generally, Bouguer was enticed by Maurepas, with new astronomical instruments and other incentives, to join the expedition sponsored by the French Academy to measure the length of a degree of latitude at the equator[5]. Bouguer was known by Maurepas for his work on naval interests.

[1]His name is variously pronounced 'bu-ger', 'bu-gai', or in Brittany where he was born, 'bu- gawr'.

[2]The above brief information on Bouguer's career can be easily found on websites such as Wikipedia.org, Encyclopedia.com and mathshistory.st-andrews.ac.uk. See References.

[3]One reference specifically on the Vortex Theory in English is Aiton (1972).

[4]Ferreiro (2011) also suggests that scientists in Europe saw it as a model for future scientific expeditions. One such international enterprise following it in the 1760s was the coordination of four countries, Britain, France, Russia and Austria, to observe the transit of Venus around the world.

[5]This 'Geodesic Mission to the Equator' as it was called then, is expertly told in great and entertaining detail by Ferreiro (2011) and also, with more emphasis on the science and mathematics, by Milsom (2018).

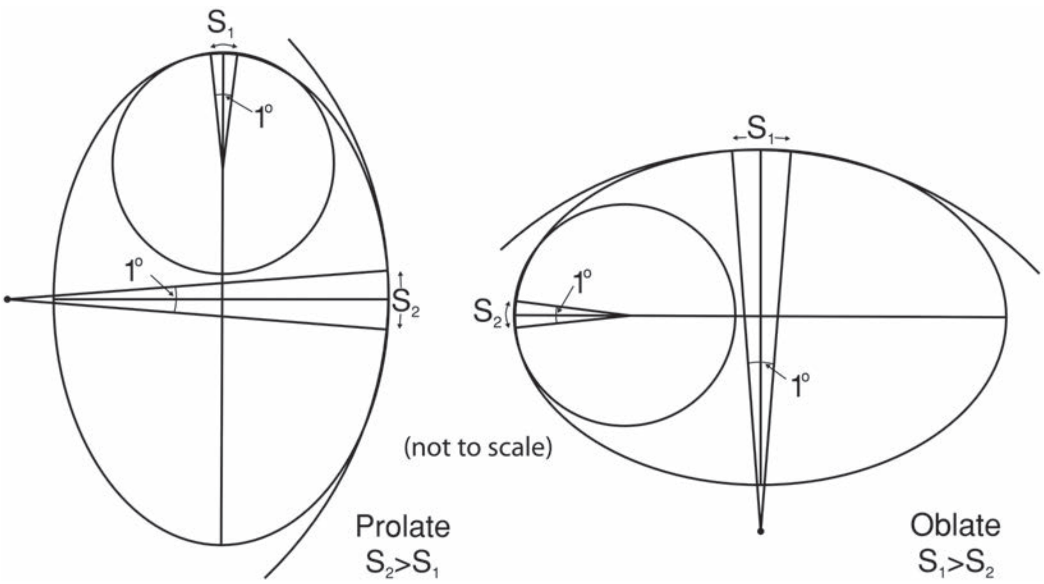

Figure 1. *Lengths of a degree of latitude for an oblate and a prolate Earth. For the case of an oblate Earth, the length at the pole (S_1) is greater than at the equator (S_2). From Ferreiro 2011, Figure 1.3, also crediting Eliecer Vilchez Ortega.*

The full human content of the expedition of 10 principals (not counting the usual complement of attendants and slaves) included, as well as Bouguer, two other members of the French Academy, Charles-Marie de La Condamine and Louis Godin, the initial leader of the expedition, plus a doctor, surgeon, engineer, draftsman and instrument maker, and, as added by the King of Spain, two Spanish naval officers who were also astronomers[6].

In May 1735 the expedition departed, expecting to be away three to four years. In fact Bouguer was away from France for almost nine years. The voyage to their destination alone took over one year, and another year to return. The long travel time was mainly due to having to wait, sometimes for two or three months, for ships to be available at various places along the route. This was especially true at the Isthmus of Panama where the Panama Canal would not be available for another 179 years. As a result, the 70 km crossing of the isthmus by all personnel and equipment had to be made by portage.

As revealed by Milsom (2018), like a good field operator, Bouguer made some use of the two-month wait in Panama to make a gravity observation. He also made a gravity measurement at Manta, upon the first landfall of his journey to Ecuador, and no doubt the first by anyone in that country.

Upon arrival in Quito, which was to be the base for the entire mission, a particular area was chosen in the vicinity to perform the survey. It had the Andes Mountains to provide the substantial relief needed for the triangulation, which was the generally accepted way to measure long distances accurately. In this case a length of over 300 km was laid out, sufficient for three degrees of latitude. Also the two chains of mountains were separated by a broad flat area, which was preferred for laying out the baselines for the triangulation where the utmost accuracy was required[7].

[6]The two Spanish members, Jorge Juan and Antonio de Ulloa, later wrote their own account of the expedition as seen through their eyes. (Juan and de Ulloa 1765).

[7]The very flat area of the mission's base line near Quito was recently used for the new Quito International Airport.

Despite all the difficulties experienced as a consequence of the remoteness, the intense tropical and energy-sapping heat, the constant torrential rain and the hostility of the natives, Bouguer laboured earnestly and diligently with deteriorating health for seven years. His work was later seen to be very accurate, despite these trying conditions.

However, from the first letters from home after being away for over a year, the expedition learnt that another expedition was planned to the Arctic Circle to measure the length of a degree of latitude near the North Pole. The location was closer to Paris than Ecuador and a much easier site in which to work, so that expedition returned with a result after little more than one year. In August 1737, as the distance calculated was longer than equivalent measurements at Paris, it was then official that the Earth was oblate. Newtonianism had won over Cartesianism.

Despite the great disappointment when this news was received by Bouguer and his party, Maurepas knew that both sets of data were needed to give a precise determination of the Earth's dimensions. So, the Ecuador expedition continued their task.

Finally, the purpose of the expedition was achieved admirably, thanks to Bouguer being in charge at the end (Godin having been found to be grossly inadequate as a leader). After almost six years on site, the final value of the length of a degree of latitude was measured as 110.56 km. As it was shorter by 1.29 km than the length at the Arctic Circle (111.85 km), it proved conclusively that the Earth was indeed oblate, as Newton had postulated six decades earlier. Later, Bouguer used the three data points of the lengths of the degree of latitude at the Arctic Circle, in France and at the equator, to mathematically define the precise curve of the Earth's shape.

In addition to these achievements, Bouguer made use of spare time, while waiting for stages of triangulation to be completed, to conduct other geophysical experiments. To begin with he set about examining all the factors related to gravity that he thought would influence his pendulum measurements (see Milsom 2018, Coda 4 for a mathematical formulation of these factors). When he was high in the Andes, he first considered the effect of elevation above sea level on gravity measurements if there was

Figure 2. *A map of South America as it is thought to be around the time of the expedition. Quito is near the equator on the western side and Cayenne is on the eastern side. From Ferreiro 2011, also crediting Eliecer Vilchez Ortega.*

only air in the space between the two levels. For this he could use Newton's inverse square law, and from this Bouguer deduced that the decrease in measured gravity was proportional to height above sea level. This is now known as the "free -air effect" and a correction involving height can be made for it. (see Sheriff 1991).

Next, Bouguer also realised that there would be an additional effect on the measured value due to the attraction of the mass between the measurement level and sea level. Milsom (2018) suggests that Bouguer may well be the first person to realise this effect on measured gravity. Suitably then, the allowance for this effect is now called the "Bouguer correction" (see Sheriff 1991). It is achieved by assuming an infinite plate of uniform density and thickness equal to the difference in measurement levels, called the "Bouguer plate" (see Sheriff 1991).

Bouguer was thus developing, for the first time, the corrections to measured gravity due to latitude, elevation and topography.

He then made an attempt to determine the overall density of the Andes by comparing the ratio of gravity at two heights to the ratio of the measurement elevation to the radius of the Earth. His results were incorrect, not because his measurements were not sufficiently accurate (as it transpired, they were found

Figure 3. *A map of the 'Audiencia of Quito' (mostly now Ecuador) around the time of the expedition showing Manta, where Bouguer first landed and Mt. Chimborazo (just north of Riobamba). From Ferreiro 2011, also crediting Eliecer Vilchez Ortega.*

to be accurate) but his assumption of the topography was too uniform. He lacked the knowledge of the detailed topographic variations that only became available over 200 years later from Digital Terrain Models[8].

During another one of the lulls in progress with determining the shape of the Earth, Bouguer found time to try another experiment that he had always hoped to do one day. That was to practically validate Newton's theory of universal gravitational attraction of discrete masses, something that had so far not been done even though it was proposed by Newton (1687) over 50 years earlier. Newton had theoretically calculated that a hemispherical 'mountain' with a radius of 3 miles (4.83 km) and the same density as the Earth would have enough mass to cause a deflection in the local vertical of almost two minutes of arc. At the time Newton was sceptical that it could be ever measured to this level of accuracy (see Milsom 2018, 146).

However, Bouguer knew that he was capable of detecting a deviation of less than one minute. He had tried this before in France but none of the mountains in Europe were large enough to produce an effect that he could measure. In Ecuador he was surrounded by the Andes, which were thought, at the time, to be the biggest mountains in the world. As it happened, just 25 kilometres from Pierre's hacienda was Mt. Chimborazo, the tallest of them all at 6263 m. Its height had already been measured, and it had the regular shape of the extinct volcano, so he decided to try and use it. The map in Figure 3, which is of the detail surrounding Quito at around the time of the Expedition, shows the location of Mt. Chimborazo[9]. Bouguer wasn't to know that the summit of this mountain is the point on Earth that is furthest from the Earth's centre.

The survey was performed in December 1738 with the assistance of his companion, La Condamine. Because of the rough conditions the base of the mountain could only be reached on foot, and with bad weather and problems with the instruments the deflection at around seven seconds was not as much as estimated. However, it was anomalous and had proved the concept. As revealed by Ferreiro (2011), this feat was not repeated by Bouguer nor by anyone else in the 20 more years of his lifetime. In 1774 a British astronomer, Maskelyne, used a technique similar to Bouguer's on a mountain in Scotland[10].

Of course, the assumption was being made at the time that the Earth's crust was uniform in density surrounding the site of measurement (the Bouguer plate). It wasn't until the early 1800s that the variability of the density of the crust was appreciated and the anomalies it produced, after standard corrections are applied, were the 'Bouguer anomalies' now ascribed to near-final gravity results and used in geological mapping. Nor was

[8]More on this is in Milsom (2018, 133–5).

[9]Also shown in Figure 3 is Manta, on the western coast where Bouguer measured gravity on his first arrival to Ecuador.

[10]In the early 1800s the Survey of India conducted largely by the Surveyor General, George Everest, was fully aware of the deviation of their verticals caused by the Himalayas.

Figure 4. *A portrait of Bouguer at age 55, painted in 1753, which can be seen in the Louvre in Paris. Source http://arts-graphiques.louvre.fr/*

the concept of mountain 'roots' understood or the Theory of Isostasy to come later.

Bouguer returned home in January 1744, after almost nine years away, when he had not only definitive proof of the Earth's oblateness but he had also practically verified, for the first time, Newton's theory of universal gravitational attraction. These results were published in 1749 in *La Figure de Terre, ...* (Bouguer 1749) which became the official account of the mission[11]. He quickly became one of the most esteemed scientists in France and later, Director of the Academy and its most prolific author. Figure 4 is a portrait of Bouguer at age 55, which can be seen in the Louvre in Paris.

Bouguer continued to produce several important papers on naval architecture and navigation in 1746, 1753 and 1757. These papers were to become useful for navigation at sea and marine explorers like James Cook and his French contemporaries benefited from them. Pierre was also good at inventing instruments such as the heliometer, and in 1748 he was probably better known as the "father of photometry". In 1750 he was elected a fellow of the British Royal Society. After enduring all the health hazards of Ecuador for nearly seven years, he succumbed to the polluted water of Paris in 1758.

Acknowledgment

The author is very grateful to Larrie Ferreiro for his ready permission granted to reproduce Figures 1, 2 and 3.

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[11]The Bouguer 1749 reference given is a much-shortened version of the 54 French words of the full title.

David Annetts' best of *Exploration Geophysics*

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It is an honour and a pleasure to be able to review 50 years of ASEG technical material in order to choose the best. However, nominating a best paper, even with implicit disclaimers around comparisons of work from minerals, petroleum and geo-technical applications from different periods, and assuming the establishment of a useful metric, is a particularly uncomfortable task.

Unashamedly, I drew candidates from my somewhat narrow field of time-domain electromagnetic prospecting in the hope of easing my task. Yet even with self-imposed restrictions, the task is not so simple because the field requires cooperation of hardware and software components in order to successfully interpret the data using physics-based models to provide quantitative predictions. This article, therefore, offers a number of honourable mentions before nominating my choice of best paper from 50 years of *Exploration Geophysics*.

A hardware-centric approach to a choice of best paper might start with the introduction of SIROTEM by Buselli and O'Neill (1977). Summarising work that commenced only two years after the formation of the ASEG, they describe SIROTEM's design and provide field examples of the instrument's use. A continuation of this theme might sojurn at Duncan *et al*. (1992) who described the SALTMAP system which evolved to Tempest AEM system (Lane *et al*. 2000) that is currently being flown in order to map electrical conductivity as part of Geoscience Australia's AusAEM program (Ley-Cooper *et al*, 2018). From left-field, Elliott's (1998) introduction of the FLAIRTEM system might be a courageous, prescient choice with the industry on the cusp of ubiquitous drone use.

Noise determines what can reasonably be interpreted from measured data. Thus, work by Lane *et al*. (1998), who described noise sources in the use of streamed data by the Tempest AEM system must also be considered on the same level as hardware, as must work by McCracken, Pik, and Harris (1984) who described noise sources and offered practical procedures to minimise some noise sources.

In my choice of best *Exploration Geophysics* paper, I considered timeliness, impact and foresight. It is especially pleasing that three of the paper's five authors remain active and equally pleasing that the paper was a product of the CRC-AMET program which served to align industry, government and academic institutions towards the solution of a difficult topical problem. Supported by a number of papers (e.g. Macnae, Bishop, and Munday 2001; Worrall *et al*. 2001) showing practical applications, my choice for best *Exploration Geophysics* paper was published at a time to take advantage of the unique confluence of theoretical and instrumental developments, computing power, and offering the promise of processing electromagnetic data in a conductivity-depth transformation so that results looked like geology, and encouraging further development of both rapid approximate and slower, more rigorous techniques, the algorithm described by Macnae *et al*. (1998) made electromagnetic data easily accessible. In my view, their work was timely, impactful and presaged a future in which a data set providing unique insight into the earth's structure could be an integral part of an exploration program and that is why it is my choice of best paper in *Exploration Geophysics*.

Best paper

Macnae, J., A. King, N. Stolz, A. Osmakoff, and A. Blaha. 1998. Fast AEM data processing and inversion. *Exploration Geophysics* **29**, 163–169.

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Fast AEM data processing and inversion

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Abstract

When airborne electromagnetic (AEM) data is acquired as a streamed or time-series data set, the great redundancy in the data favours compression as a first step in processing. Traditional data compression schemes are time windowing and spatial averaging. An alternative, more efficient data compression scheme is to transform time or frequency domain data to time-constant tau space, which has the effect of removing the waveform dependence of the AEM response.

When there are many local anomalies and a variable background, the next stage of rapid processing is to transform the response to a conductivity-depth image (CDI) to facilitate geological interpretation of the background response. Use of the full time range of recorded data, particularly the inclusion of on-time data, improves the stability of the CDI process.

The final AEM data processing step for mineral exploration is to assess the likelihood that any local anomaly corresponds to a desired economic target. This step involves the extraction of target geometry and conductivity information from the AEM data. The only economically feasible route at the present time is to parameterise both the data (using inductive and resistive limits) and the model to allow inversion of the local anomalies. A fit to one or two platelike conductors can be achieved in seconds; fits to a blocklike body take minutes on a fast PC. A significant research challenge remains to speed up and stabilise this process.

Introduction

A recent trend in airborne electromagnetic (AEM) data is the acquisition of data using continuous analogue-to-digital conversion and recording. Sampling of the transmitter and receiver components occurs on the order of every 10 microseconds, and if all sampled data are recorded, then data volumes are of the order of gigabytes per day of flying. There is generally far too much data to comprehend or interpret in this raw form, and data compression is obviously required. Because of the nature of the EM diffusive process, the vast majority of the data is actually redundant, and stacking and windowing methods have long been used to improve signal-to-noise ratios and reduce data volumes to manageable size. Both the physics of diffusion (Stolz and Macnae 1998) and principal component analysis (Green 1998) suggest that there are no more that about 4 or 5 independent piece of information per decade of system bandwidth. With (say) 256 equally spaced waveform samples covering just over two decades in time, there will be no more than about 10 (spaced logarithmically in time) independent parameters required to completely characterise the EM response, although a much larger number may be required to define the noise characteristics.

*Note, these contact details have almost certainly changed

The resulting AEM data have typically been presented as stacked profiles for manual- or computer-assisted interpretation. In areas with surficial glacial sediments or in regolith dominated terrain, there is usually a variable background response with one or more local anomalies per line-kilometre. Conductivity-depth sections have proven to be a useful tool to map this variable regolith background.

The second stage in mineral exploration with AEM is to determine which of the many local anomalies has the greatest chance of being an economic mineral deposit. Because economic mineral deposits come in many shapes and sizes depending on their origin and tectonic history, and can have a wide range of possible conductivities, it is desirable to model or invert each of these local anomalies to determine the likelihood of correspondence to a range of physical property (and by inference geological) models. As with any interpretation technique, inferences made will rely on correspondence between physical properties and geology, and conductors may not necessarily be ore itself, but indicative of nearby mineralisation.

System-independent EM representation

Stolz and Macnae (1998) described a method by which arbitrary waveform data can be transformed into a form that is independent of the EM system. We consider this to be a key step in the development of fast processing and interpretation tools, as generic rather than system waveform-specific algorithms can be implemented in any later processing steps. There is a trade-off in the time taken to transform the data, a requirement that the transformation adequately and stably represents the original data, and in practice there are problems accurately defining the actual system waveform and transformation parameters.

In time domain, this procedure consists of preconvolving a set of exponential decays with the repetitive system waveform (Appendix A), and fitting a linear combination of these to the observed data. In the frequency domain the procedure involves fitting a linear sum of mathematically equivalent single-pole, single-zero responses (Grant and West 1965) to the observed data. Following the fitting procedure, the time or frequency data is reduced to a set of amplitudes with an associated time constant, and is independent of system waveform. Differences between individual systems or different waveforms of a given system lie in the range of time constants (tau values) that can be resolved and the noise levels in the data which carry through into the tau domain.

Conductivity-Depth-Imaging (CDI)

One method of converting AEM data into a conductivity-depth-section is to invert the data on a point-by-point basis to a set of 1D models, and then stitch these together to form a pseudo 2D section. This method requires relatively powerful computing resources, but is in routine use by World Geoscience on Questem data (Sattel 1998). However, inversion using a 3-layer model is considerably slower than data acquisition.

There are a number of methods in the literature for deriving fast conductivity-depth sections from EM data. One group of methods is based on the Maxwell receding image concept, where conductivity is derived from a predicted depth to an image of the source. This method was described by Macnae and Lamontagnc (1987) and by Nekut (1987). Eaton and Hohniann (1989), Fullagar (1989), Fullagar and Reid (1992) and Smith, Edwards, and Buselli (1994) developed approximate imaging schemes based on the actual depth of maximum current or the maximum sensitivity to a layer in a half-space.

Given data in the tau domain, it is possible to predict the step response and derive a conductivity-depth-image from AEM data by the method described in Macnae *et al*. (1991). In practice, it is not necessary to predict the step response because processing can be carried out directly in the tau domain. One of the reasons for using fast CDI transformations based on current diffusion is that CDI sections are equivalent to, or even better than, stitched ID inversions over 2D or 3D conductive structures (Nekut 1987. Eaton and Hohniann 1989; Stolz and Macnae 1998).

The use of on-time data

Recent work by Smith *et al*. (1996) and by Stolz and Macnae (1998) suggest that on-time AEM data should extend system sensitivity to both very rapid and very slow decays. Figure 1 clearly demonstrates this on-time sensitivity in a plot of the secondary response throughout a typical AEM waveform. When both on- and off-time data are used to derive the AEM response in the tau domain, we would expect that the resolution should be more stable over a wider range of tau values, i.e., an increased bandwidth, provided that the primary field is well known. The following example demonstrates this be the case.

Figure 2 shows a 20-km line of 37.5-Hz Questem data of 1992 vintage collected over an area with conductive surface cover, and a CDI derived from off-time data using the Maxwell receding image technique using program EMFlow developed within AMIRA project P407. The geology consists of transported sediments overlying a Proterozoic basement, which is generally resistive except where weathered at its present or palaeo-surface. This horizontal (*x*) component data was collected in summer and is quite noisy (50 ppm) at late delay times. Under the ID assumptions used in CDI processing, a response of 'small' amplitude will be interpreted as coming from 'great' depth. Thus responses (of signal, and by inference noise) of small to moderate amplitude will mostly show up in the CDI at depth. The effect of the noise thus appears to cause a number of narrow responses (vertical striping) to appear at depth in the CDI, which responses do not correlate between lines. Geological reasoning would indicate that most valid basement conductors would show some strike (across-line) consistency, which is not seen in these CDI images.

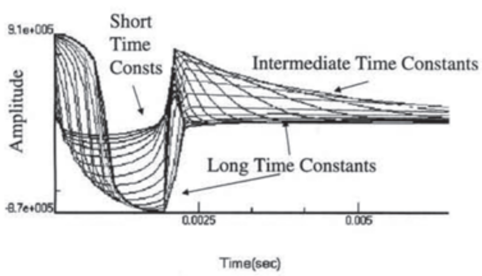

Figure 1. *Exponential decays convolved with a 1992 Questem waveform (received from an approximate half-sine transmitter current waveform): the time constants range from 0.01 ms (short) to 10 ms (long).*

When all-time data is processed and plotted at the same scale as Figure 2, we note as expected a significant improvement in the coherence of the processed CDI section (Figure 3). Note that each of the 1600+ individual stations has been processed without regard to its neighbours. All vertical striping has been eliminated from the section, and the predicted depth to the top of the shallowest conductor is generally more consistent with the surface (0 m), although this is not obvious on the plots. Although drilling and physical property logging are not available to confirm that this CDI section is more geologically correct than that shown in Figure 2, the result is consistent with known geology, although less interesting from a target generation point of view. Generally, shallow dips would be expected at the base of the sediments or at the top of unweathered bedrock as seen in this all-time CDI, and geological units in the local Proterozoic basement are expected to be very resistive. Use of the on-time data has thus allowed production of a more geologically believable image, and which theoretically should be more sensitive to slow decays indicative of conductive targets at depth below the conductive cover than was the off-time data alone. This conclusion can not however be verified from this data set.

Parameterising local EM responses

Grant and West (1965) described the inductive and resistive limits of an EM response in frequency domain and suggested that they were generally diagnostic of the main features of an AEM response from a local conductor in free space. In essence, the inductive limit represents the response in free space when current is confined to the surface of a conductor. Mathematically the inductive limit condition is expressed as $\omega\mu\sigma l^2 >> 1$, where ω is frequency, σ conductivity, μ magnetic permeability and l a characteristic dimension. For a given conductor, the inductive limit is a function of geometry only. The time-domain step response inductive limit is identical to the frequency-domain inductive limit if scaled by the total primary field (Macnae *et al*. 1998)

The resistive limit in frequency domain consists of the time derivative with respect to ω of the secondary EM response at the low frequency limit ($\omega\mu\sigma l^2 << 1$). In time domain, the resistive limit is the area under the step response decay curve (Appendix A) and is easy to calculate. At the resistive limit, the response is a linear function of conductivity and the response of bodies that not in galvanic contact do not interact and are linearly additive (Lamontagnc 1975).

Figure 4 shows an example of the predicted resistive limit estimated from a segment of AEM field data. Because the response is decomposed into a sum of exponential decays, it is possible to calculate the contribution of each of these decays to the resistive limit. Since a good conductor will have a slow decay, we would expect that the long taus would contribute more to the resistive limit than would be the case for a poorer conductor. The total resistive limit profile shown in Figure 4 on the upper plot characterises the spatial amplitude variation of any local anomaly, as indeed does the raw data plotted on the bottom axis. Variations in the contribution to the total resistive limit from early, intermediate and late taus can be used to discriminate adjacent conductors, as is done using time-constant analysis. The advantage of the resistive limit is that, unlike raw data, its amplitude is directly proportional to the conductivity of the associated conductivity structure.

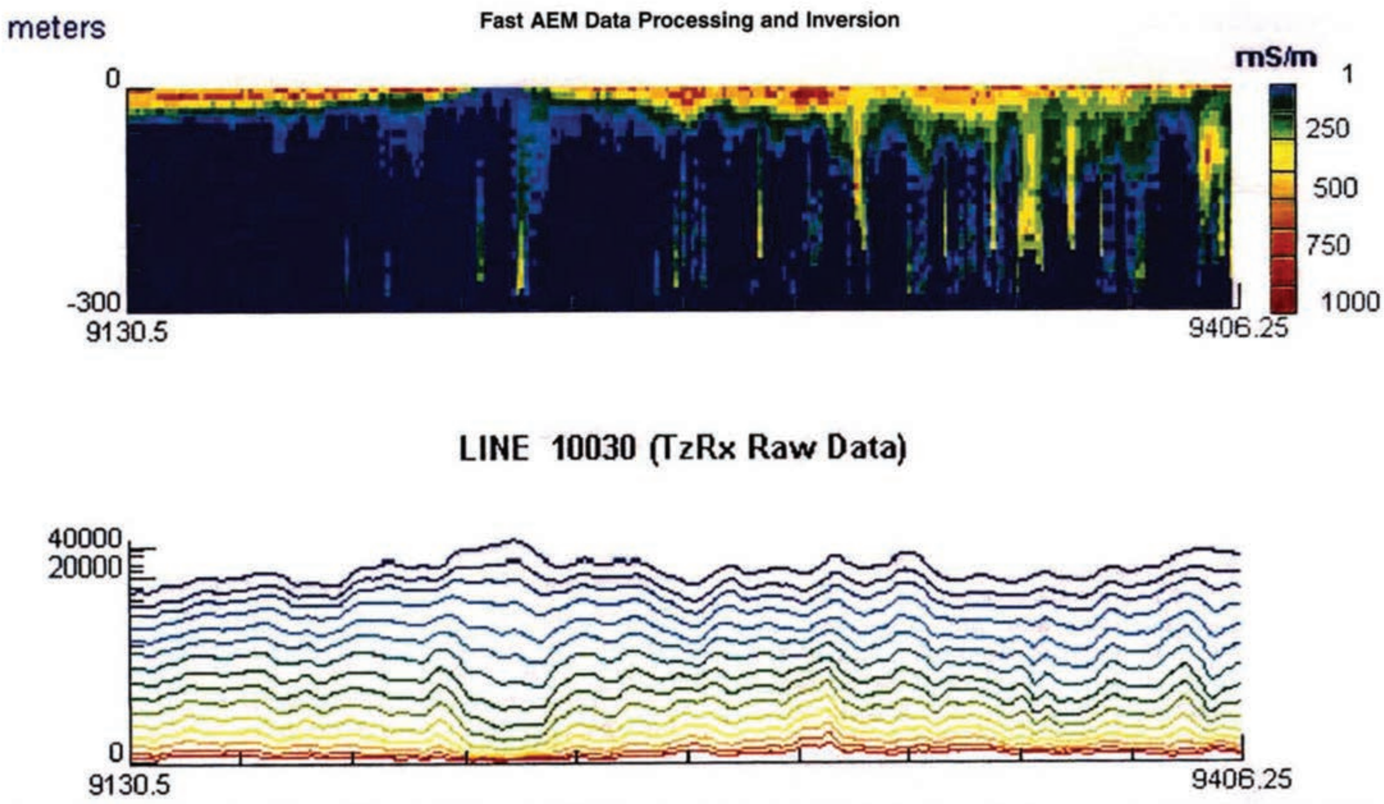

Figure 2. *Conductivity-depth image (CDI) of slightly noisy 1992 QUESTEM data leads to false indications of both poor and good conductors at depth. The profile is 20 km long and the geology consists of sediments covering a Proterozoic basement.*

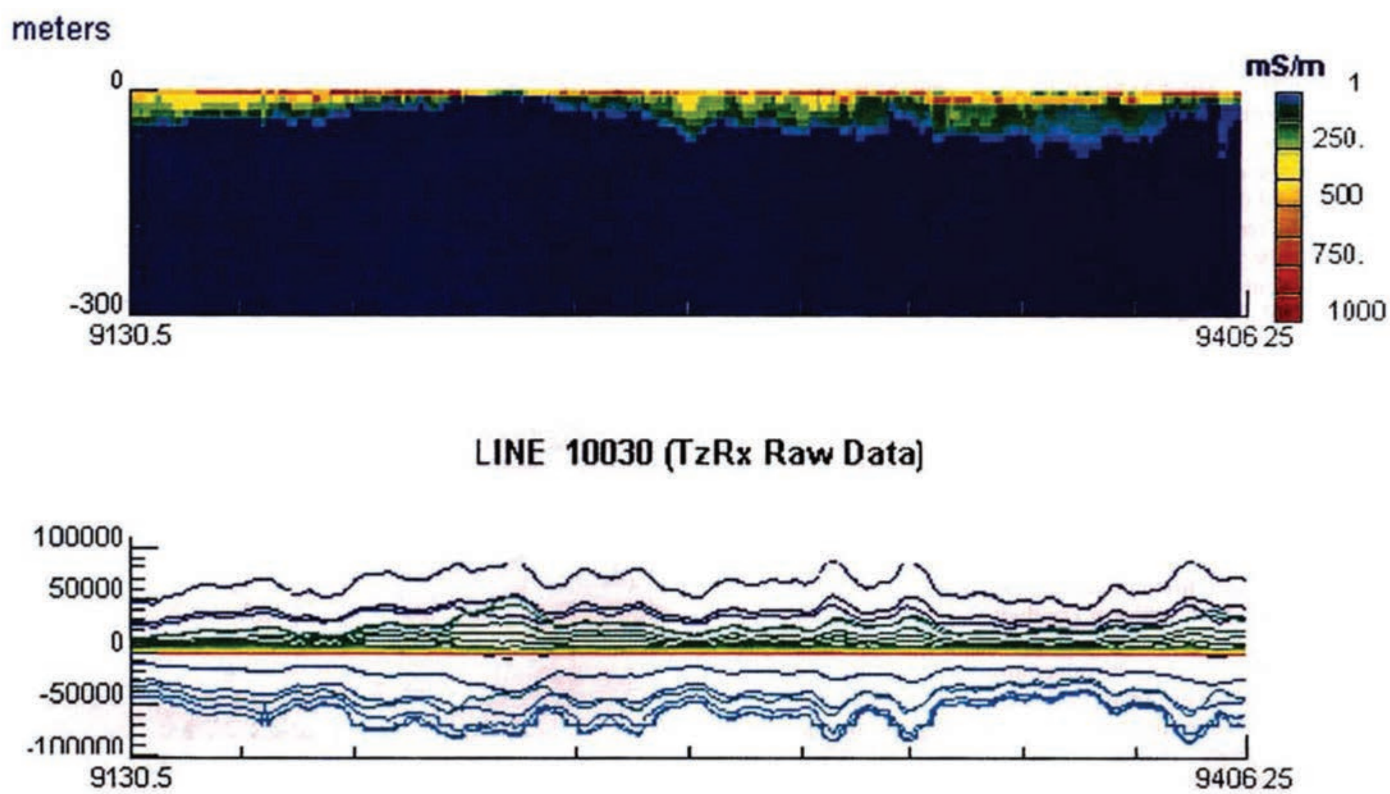

Figure 3. *CDI section of the same line as Figure 2 derived from all-time data. There are no obvious artefacts or instabilities at depth.*

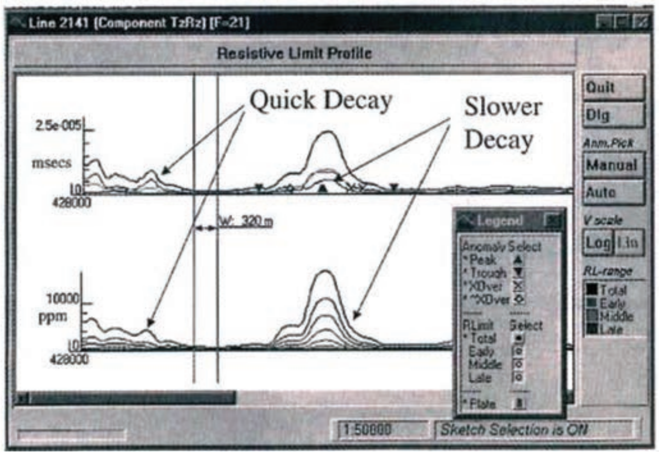

Figure 4. *Decomposition of 15 channel AEM data (bottom) into the resistive limit (top), showing the contribution from short (early), middle and slow (late) tau values.*

A key aspect to the application of these limits is the recognition that it is possible to estimate the inductive limit of a local target under, but not in contact with, conductive cover. Conductive cover not in contact with a target has two effects: it firstly delays the propagation of primary EM fields through it to energise the target, and further delays the secondary field of induced target currents during their passage back to an EM receiver. These delays and associated time-smoothing lead to the second effect: amplitude attenuation in frequency domain or in repetitive time domain waveforms. The estimation method we use involves fitting field decays with time-retarded and attenuated decays based on model data, and then using the model data to predict the free-space inductive limit. The method is described in detail in King (1998), and is conceptually the inverse of the approximate forward modelling method of Liu and Asten (1993).

Fast forward and inverse models

To be able to fit a response to every local anomaly on an AEM survey, it may be necessary to model on the order of 500 local anomalies per AEM system per day (Macnae *et al*. 1998). Clearly, if one computer is used to process the data from one AEM system, the modelling process is limited to more than a minute or two per anomaly if it is to keep up with data acquisition. This places a severe constraint on which models can be used to interpret the data.

Rapid forward models that are presently available are based on both mathematical and physical convenience, e.g., an assumption of uniform conductivity, and on geological constraints such as an assumption of a typical shape. Massive sulphide deposits are commonly tabular due to their origin as sediments from hydrothermal activity at the sea floor, and are commonly represented by plate-like models. Programs Plate (Dyck, Bloore, and Vallee 1980) and MultiLoop (Lamontagnc, Macnae, and Poller 1988) are examples of rapid computer programs which execute forward models in seconds. Most 2D or 3D conductivity structure models for a 3D source however execute in hours rather than seconds and are too slow to consider for routine application.

Many EM algorithms are based on parameterised models, and are represented by a very small number of parameters rather than a complex distribution of conductivity. For example, a tabular body requires only 10 parameters (3 for location, 3 for attitude, 3 for size and one conductivity). Finite-element or finite-difference models will tend to have a larger number of parameters, but frequently many of these parameters such as cell conductivity will be the same. Once overburden or conductive host is included, the response becomes more complicated and program execution times increase.

The inductive and resistive limit responses of single plate like targets are relatively easy to fit (Stolz and Macnae 1998; King 1998). Figure 5 shows a test of this fitting approach on relatively complex synthetic data, using Program EMFlow' to interactively fit a plate model to synthetic horizontal (*x*) and vertical (*z*) component fixed-wing AEM data. The raw time-domain data (not shown) were first deconvolved to tau domain and the resistive limit calculated. Each component in Figure 5 contains a double-peaked resistive limit anomaly which can not be fitted by a single plate-like source. Two plates, however, provide a virtually perfect fit to the calculated resistive limit and accurately recover the original locations of the plates used in forward modelling. The model parameters listed are for the 'solid' dipping target on the plot. The inversion process takes several seconds per iteration for two plate-like bodies, but manual interaction is required in practice to force the solution away from local minima by choosing a reasonable starting model. Such local minima typically provide very poor fits to the data. The manual interaction involves adding a second conductor if a poor fit is obtained with a single conductor, and making a fairly obvious choice as to its starting location under that part of the anomaly not well fitted by a single conductor. With AEM systems having a footprint limited to about 300 m (Xie, 1998), we usually choose to fix the strike length of any model to be of this order. This implies that the fitting is most applicable to targets of strike length exceeding 200 to 300 m.

It is possible to numerically calculate the inductive limit of any body in free space, using potential-field algorithms that enforce the boundary condition that no magnetic field can penetrate into the conductor (King 1998). A forward model takes about 10 seconds on a fast PC. Figure 6 shows an example of fitting a wide dipping target to the inductive limit predicted from x-component Questem data. About 5 to 10 minutes on a Pentium PC is typically required for a such a fit. In this case, the response has not yet converged but has exceeded a

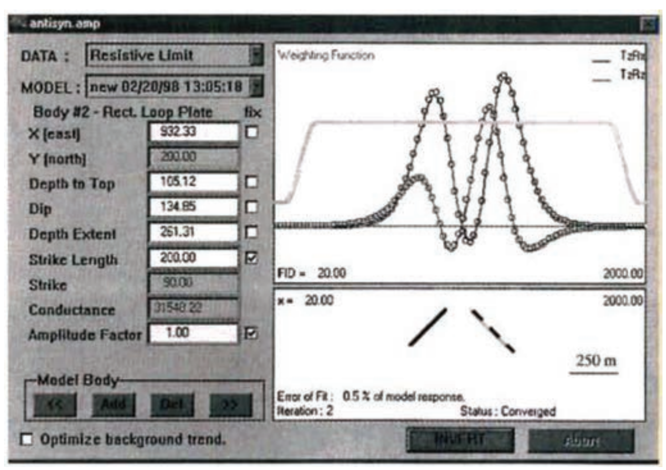

Figure 5. *A fit of two plate-like bodies: about two minutes on a Pentium PC was taken to fit this 'anticline' model to resistive limit AEM synthetic data using both the x and z; components. I'he profile is 2 km long.*

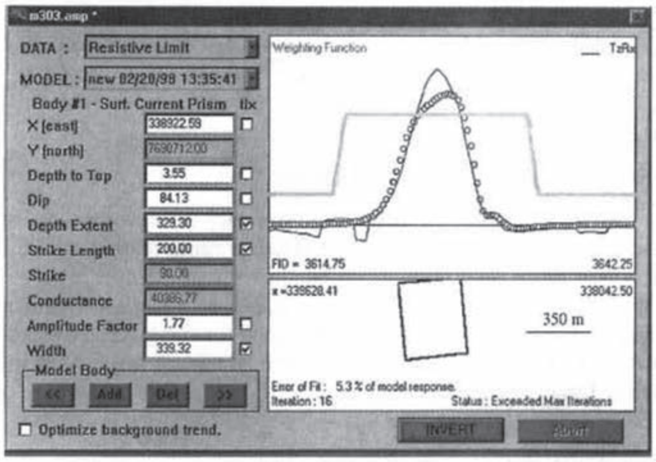

Figure 6. *An approximate fit of the resistive limit predicted from field data to a wide dipping target. A single, wide body was not able to fit the peak of the field data response. Tbe geology consists of a series of steeply dipping shales in crystalline host.*

preset iteration limit which can be easily extended by manual intervention. No simple block model was found that could fit the peak of the resistive limit, where visual inspection shows most difference between the data and the model. The data were obtained over a steeply dipping band of shales hosted in more resistive crystalline rocks.

With many such anomalies routinely detected in AEM surveys, faster models or computers are essential if each of the (say) 500 anomalies detected in the course of a day of flying needs to be modelled. If this step could be made more robust and accurate than at present, the task of interpreting local anomalies contained within the data would be greatly simplified. This may be achieved in future with better automatic model selection and better starting models for inversion.

Discussion and conclusions

The great redundancy in AEM data acquired as equi-spaced samples favours data compression as a first step in processing. This may involve both time windowing and spatial averaging. As part of this process, it is advantageous to transform data, whether in time or frequency domain, to time constant (tau) space in order to remove the waveform dependence of the observed AEM response.

With many local anomalies and a variable background, the next logical stage of processing is transformation of the response to a conductivity-depth image (CDI) to facilitate geological interpretation of the background and to guide subsequent modelling. Use of all the available recorded data, particularly the inclusion of on-time data, appears to improve the stability of the CDI process.

The objective of subsequent interpretation in mineral exploration is to assess the likelihood that each local anomaly detected represents economic mineralisation. This step involves the extraction of geometrical and conductivity information from the AEM data. The only feasible route at the present time is to parameterise both the data, to say the inductive and the resistive limit, as well as the model to allow rapid inversion of the local anomalies. A fit to one or two plate-like conductors can be achieved in seconds; fits to a wide body take minutes on a fast PC. Any automated inversion process should avoid local minima, be stable in the presence of noise from any source, account for all physically detectable effects such as IP or magnetic susceptibility, and be tolerant of imperfect system description. A significant research challenge remains to speed up and stabilise this process.

Acknowledgments

We acknowledge the support of the sponsors of AMIRA project P378 (Pasminco, Aberfoyle, CRA, BHP) and AMIRA project P407 (Pasminco, MIM, Billiton. CRA. BHP. North. World Geoscience), who together with CRCAMET supported the development of software based on the ideas expressed in this paper. The paper benefited immensely from very thoughtful and constructive reviews by Peter Fullagar and Perry Eaton. This paper is published with permission of the CRC for Australian Mineral Exploration Technologies (CRC AMET), established and supported under the Australian Government's Cooperative Research Centres Programme.

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Appendix A: Mathematical basis of arbitrary waveform decomposition

This brief summary includes some sign corrections from the article by Stolz and Macnae(1998):

Representation of time-domain step and frequencv-doniain response

The step function response of an isolated conductor can be expressed as:

$$A(t) = \sum_i A_i \exp(-t/\tau_i) \quad (1)$$

where there is an upper limit on the range of τ_i, i.e., a maximum time constant. The inductive limit A_0, which is the response at time $t=0$, is given by

$$A_0 = \sum_i A_i \quad (2)$$

Physically at this limit, current flow is restricted to the surface of the conductor such that the perpendicular component of the local magnetic field remains a constant. In the frequency domain there is an exact decomposition of the response $A(\omega)$ into

$$A(\omega) = \sum_i A_i \frac{j\omega\tau_i}{1+j\omega\tau_i} = \sum_i A_i \frac{j\omega\tau_i + \omega^2\tau_i^2}{1+j\omega^2\tau^2_i} \quad (3)$$

where $j=\sqrt{-1}$ and the A, are identical to those in equation **(1)**.

In frequency domain, the concept of the resistive limit has proved useful in interpretation; defined as the slope of amplitude versus ω in the low-frequency limit:

$$RL = \lim_{\omega\to\infty} \frac{1}{j}\frac{\partial A}{\partial\omega} = \sum_i A_i\tau_i \quad (4)$$

This, in the case of the step response formulation, can be seen to be exactly

$$RL = \sum_i A_i\tau_i = \int_0^\infty A(t)dt \quad (5)$$

Lamontagne (1975) has shown that for a ramp primary excitation, the resistive limit is simply the magnetic field of the steady-state current that will flow in the conductor after transients have decayed. With a coil receiver measuring the time derivative of the response, this steady-state current produces zero response. Since at the limit $\omega \to 0$ there is no magnetic interaction between conductors, their resistive limit responses are additive.

Square wave response

The measured response of a square wave system can be obtained from an infinite sum of alternating step responses to give

$$A(t,T) = \sum_i A_i (e^{-t/\tau_i} - e^{(t+T/2)/\tau_i} + e^{(t+T)/\tau_i} - e^{(t+3T/2)/\tau_i} \ldots) \quad (6)$$

This infinite series can be analytically summed to give

$$A(t,T) = \sum_i A_i \frac{e^{-t/\tau_i}}{1+e^{-T/2\tau_i}} \quad (7)$$

Sampled step and square wave responses

In a practical TEM system, the signal is sampled in windows that may extend from time to t_k to $t_k + 1$. In this case the sampled response is given by

$$A(T,t_k,t_{k+1}) = \frac{1}{t_{k+1}-t_k}\int_{t_k}^{t_{k+1}} A(t,T)dt \quad (8)$$

where t_k is defined with respect to the $t=0$ transition. Integration is easily performed to give, in the case of the square wave,

$$A(T,t_k,t_{k+1}) = \frac{\tau_i}{(t_{k+1}-t_k)}\frac{A_i}{(1+e^{-T/2\tau_i})}(e^{-t_k/\tau_i} - e^{-t_{k+1}/\tau_i}) \quad (9)$$

Sampled periodic ramp response

We can choose to represent arbitrary waveforms by a sequence of periodically repeated linear ramp responses. For each of these responses it can be shown from simple algebra that the sampled response in window t_k to t_k+1 from a linear primary field ramp, amplitude change ΔP_m over a time interval from t_m to t_m+1 (both of which are earlier in time than t_k) is given by

$$A(T,t_k,t_{k+1},t_m,t_{m+1}) = \sum_i \frac{\tau_i}{(t_{k+1}-t_k)}\frac{\tau_i}{(t_{m+1}-t_m)}\frac{A_i\Delta P_m}{(1+e^{-T/2\tau_i})} (e^{-t_k/\tau_i} - e^{-t_k+1/\tau_i})(e^{t_{m+1}/\tau_i} - e^{t_m/\tau_i}) \quad (10)$$

If the primary field change coincides exactly with the sampling time, the response can be separated into two components: one from previous repetitions of the waveform given by the equation above with an appropriate substitution of $(t_m - T/2)$ for t_m,$(t_m + 1 - T/2)$ for $t_m + 1$ and ΔP_n for ΔP_m; plus the single section where sampling and primary ramp are coincident in the interval t_n to $t_n + 1$. For this last part is is possible to express the response as an integral to obtain

$$C = \Delta P_m \int_{t_n}^{t_{n+1}} \frac{\tau[1\text{-}\exp((-t-t_0)/\tau)]}{(t_{n+1}-t_n)^2} \quad (11)$$

which has the solution

$$C = \Delta P_m p[1+p(\exp(-1/p)-1)] \quad (12)$$

where $p = \tau/(t_{n+1} - t_n)$.

Fitting arbitrary waveform data

Once the convolution of an exponential decay with an arbitrary waveform has been computed using the equations given above, the tau domain amplitude coefficients A*i*, can be extracted through inversion of the equation:

$$\begin{bmatrix} D(t_1) \\ \vdots \\ : \\ D(t_n) \end{bmatrix} = \begin{bmatrix} R(t_1,\tau_1) & \cdots\cdots\cdots & R(t_1,\tau_m) \\ \vdots & & \vdots \\ : & & : \\ R(t_n,\tau_1) & \cdots\cdots\cdots & R(t_n,\tau_m) \end{bmatrix} \begin{bmatrix} A_1 \\ \vdots \\ A_m \end{bmatrix} \tag{13}$$

where *D(t)* is the data, *R(t*,t) the convolution of *m* exponentials with the transmitter waveform, as measured in each of the *n* time windows of the EM system. This inversion procedure is discussed in texts such as Menke (1989) or Stolz (1998). Stabilisation through positivity or smoothing constraints has been found to be a requirement.

CDI Imaging

The mathematical basis of this procedure can be found in Macnae and Lamontagne (1987) and Macnae et al. (1990). Essentially, the process involves determining the correspondence between a set of delay times *t* and a set of depths z. This is achieved through finding sets of times *t* and depths *z* at which the amplitude *A(l*) of the step response decay is equal to the amplitude *A(z)* of calculated secondary field if the mirror image transmitter was at depth *2z* in the ground. The cumulative conductance at any depth *z* is proportional to *dtldz,* and the conductivities at depth *z* are then given by

$$\sigma = \frac{1}{\mu_0}\frac{\partial^2 t}{\partial z^2} \tag{14}$$

Extraction of the resistive limit of a target under conductive cover

Because resistive limits are additive, the resistive limit response of a target at depth can be derived through simple subtraction of an assumed or modelled background, analogous to regional-residual separation in gravity interpretation.

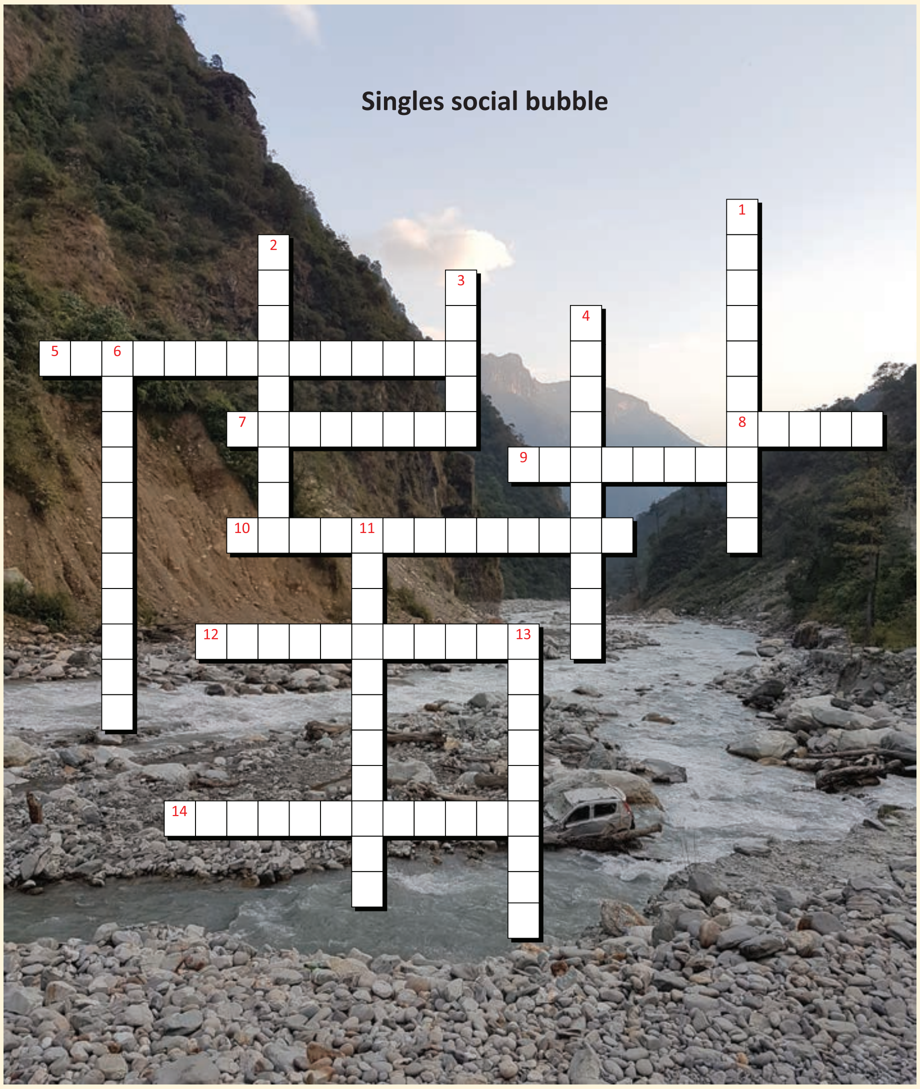
Extraction of the inductive limit of a target under conductive cover

The response at the inductive limit of a local target can be derived by comparison with a pre-computed set of blanked decays (Macnae et al. 1998). This process makes the assumption (Liu and Asten 1993; King 1998) that the conductive cover acts only to delay and broaden the response of the target at depth. If the free-space step response is given by equation (1), then the step response of a target under thin conductive cover of conductance *S* is given by the sum of the overburden step response *O(t)* at the receiver and the convolution of the free-space step response of the target with the impulse response *I(t)* of the overburden as seen at the target:

$$R(t) = O(t) + \sum_i A_i \exp(-t/\tau_i) * I(t) \tag{15}$$

We can perform the convolution of a predetermined set of exponentials with the (calculated) impulse response at the target. In equation (15), because of linearity we can strip the background response *O(t)* to get the 'anomalous' response of the target alone. If a look-up table is created of the results of a set of these convolutions, it is possible to simply estimate the free space coefficients A_i, using the same linearmathematics as described in equation (13).

Preview crossword #10



Across	Down
5. The effect in the observed frequency of a wave when there is relative motion between the wave source and the observer.	**1.** The frozen parts of the hydrosphere.
7. The tendency of a mineral to break along flat planar surfaces as determined by the structure of its crystal lattice.	**2.** The fossilised remains of faeces.
8. The dark, organic material that forms in soil when plant and animal matter decays.	**3.** A conspicuous isolated hill with steep, often vertical sides and a small, relatively flat top.
9. The interval of time required for one-half of the atomic nuclei of a radioactive sample to decay.	**4.** The depression formed by a block of stagnant ice detached from a retreating glacier that becomes wholly or partially buried in sediment and slowly melts.
10. A fold whose hinge line and axial plane are horizontal or sub-horizontal.	**6.** The comprehensive oceanic domain surrounding the supercontinent Pangea in Late Paleozoic and Early Mesozoic times.
12. From the Greek name, hydrargyrum, this element is informally named for its mobility.	**11.** All geomorphic processes by which bulk transport of soil, regolith and rock debris move down slopes in response to the pull of gravity.
14. Often considered a type of divination when used to try to locate things that exist underground, including water, oil, and precious metals.	**13.** A floor hand, or member of the drilling crew who is tasked to make or break connections as drill pipe is tripped in or out of the hole.

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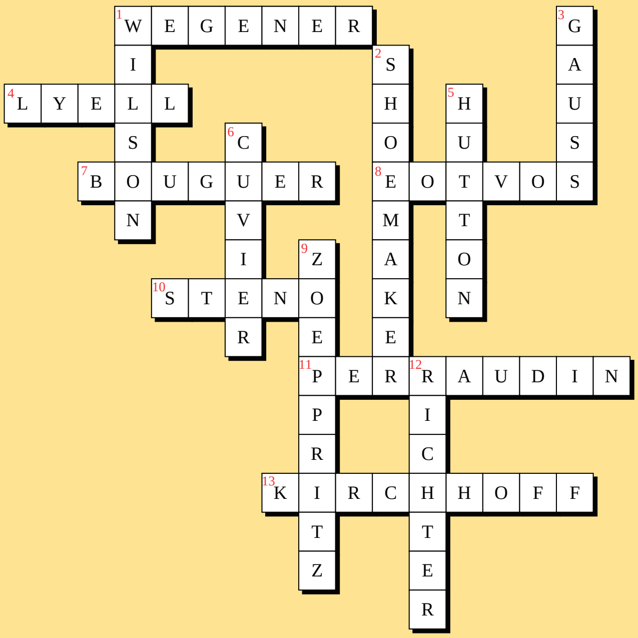
Preview crossword #9 solution

Famous names in the geosciences



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

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

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

Twitter: https://twitter.com/ASEG_news

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

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

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

Application for Active & Associate Membership 2020

INSTRUCTIONS FOR APPLICANTS

1. Determine the membership level you wish to apply for, according to the eligibility criteria outlined in Section 2.
2. Fill out the application form. Note that applicants for Active Membership must nominate a proposer and a seconder who are Active Members of ASEG. Student members must include a Supervisors Name and Signature. Under exceptional circumstances the Federal Executive Committee may waive these requirements.
3. Attach the appropriate dues and submit the two pages of your application to the Secretariat at the address shown on the top of this page, retaining a copy of this page for your own records. If payment is to be made by credit card, the application may be sent by fax.

Section 1. **Personal Identification**

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

Section 2. **Choice of Membership Grade** (Tick one)

- ❑ Active — Please complete all sections (With the exception of **Section 5)**
- ❑ Associate — Please complete all sections (With the exception of **Section 5)**
- ❑ Active Graduate — Please complete all sections
- ❑ Student — Please complete the separate Student Membership Application Form

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

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

Active Graduate – an applicant is available for no more than two years. The membership is subsidized by 50%. Members accepting Graduate Membership Grants would be required to write on article for the newsletter and *Preview* with the goal of raising both their profile and ASEG's support.

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

Section 3. **Academic and Professional Qualifications**

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

Section 4. **Nominators (Must be ACTIVE Members of ASEG)**

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

Section 5. **Expected Graduation Date:** ____________________

Section 6. **Membership of Other Societies**

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

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

❑ Others ____________________

Section 7. **ASEG Membership Directory Record**

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

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

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

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

MEMBERSHIP GRADES AND RATES

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

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

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

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

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

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

Yes / No (please circle)

Section 9. **Promotional Opportunities**

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

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

Section 10. **Declaration**

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

Signature: ____________________ *Date:* ______________

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Application for Student Membership 2020

INSTRUCTIONS FOR APPLICANTS

1. Student Membership is available to anyone who is a full-time undergraduate student in good standing at a recognised university working towards a degree in geophysics or a related field. Eligibility for Student Membership shall terminate at the close of the calendar year in which the Student Member ceases to be a graduate or undergraduate student. However, Student Membership must be renewed annually. The duration of a Student Membership is limited to five years.
2. Fill out the application form, ensuring that your supervisor signs Section 2.
3. Submit the two pages of your application to the Secretariat at the address shown on the top of this page, retaining a copy of this page for your own records.

Section 1. Personal Details

Surname | Date of Birth

Given Names

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

Address

State | Post Code

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

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

Mobile

Section 2. Student Declaration

Institution

Department

Major Subject | Expected Graduation Date

Supervisor/Lecturer* | Supervisor Signature

* Must be an active member of the ASEG

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

MEMBERSHIP GRADES AND RATES

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

Section 4 *Preview & Exploration Geophysics*

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

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Yes / No (please circle)

Section 5 Declaration

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

*Signature:*________________________ *Date:*______________

ASEG CODE OF ETHICS

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

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

October	**2020**		
11–16	SEG International Exposition and 90th annual Meeting https://seg.org/aM/2020	Houston	USA
November	**2020**		
2–4	3rd Asia Pacific Meeting on Near Surface Geoscience & Engineering https://eage.eventsair.com/3rd-apac-nsge/	Chiang Mai	Thailand
2–6	Offshore Technology Conference Asia (OTC Asia) http://2020.otcasia.org/welcome		*Virtual event*
10–11	2nd Joint SbGf-SEG Workshop on Machine Learning https://seg.org/Events/Second-Workshop-on-Machine-Learning	Rio de Janeiro	Brazil
December	**2020**		
2	Advances in Marine Seismic Data Acquisition Workshop https://seg.org/Events/Advances-in-Marine-Seismic-Data-Acquisition-Workshop	Singapore	Singapore
7–11	AGU Fall Meeting https://www.agu.org/Fall-Meeting	San Francisco	USA
8–11	82nd EAGE annual Conference and Exhibition	Amsterdam	The Netherlands
March	**2021**		
22–26	proEXPLO 2021 https://www.proexplo.com.pe/en		*Virtual event*
April	**2021**		
25–30	European Geosciences Union https://www.egu2021.eu/	Vienna	Austria
May	**2021**		
31–3 Jun	83rd EAGE Conference & Exhibition 2021	Madrid	Spain
August	**2021**		
16–21	36th International Geological Congress https://www.36igc.org/	Delhi	India
23–27	Advanced Earth Observation Forum 2020 https://earthobsforum.org/	Brisbane	Australia
September	**2021**		
8–10	Mines and Wines 2021 Discoveries in the Tasmanides https://minesandwines.com.au/	Orange	Australia
15–20	Australasian Exploration Geoscience Conference (AEGC 2021) 2021.aegc.com.au	Brisbane	Australia
27–1 Oct	Australian and New Zealand Geomorphology Group Conference https://www.anzgg.org/conferences	Alice Springs	Australia
December	**2021**		
13–17	AGU Fall Meeting	New Orleans	USA
August	**2022**		
15–19	12th International Kimberlite Conference https://12ikc.ca/	Yellowknife	Canada

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

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

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

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

Preview is published bimonthly in February, April, June, August, October and December. The deadline for submission of material to the Editor is usually the second Friday of the month prior to the month of issue. The deadline for the December issue is 13 November 2020.

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