Australian Society of Exploration Geophysicists

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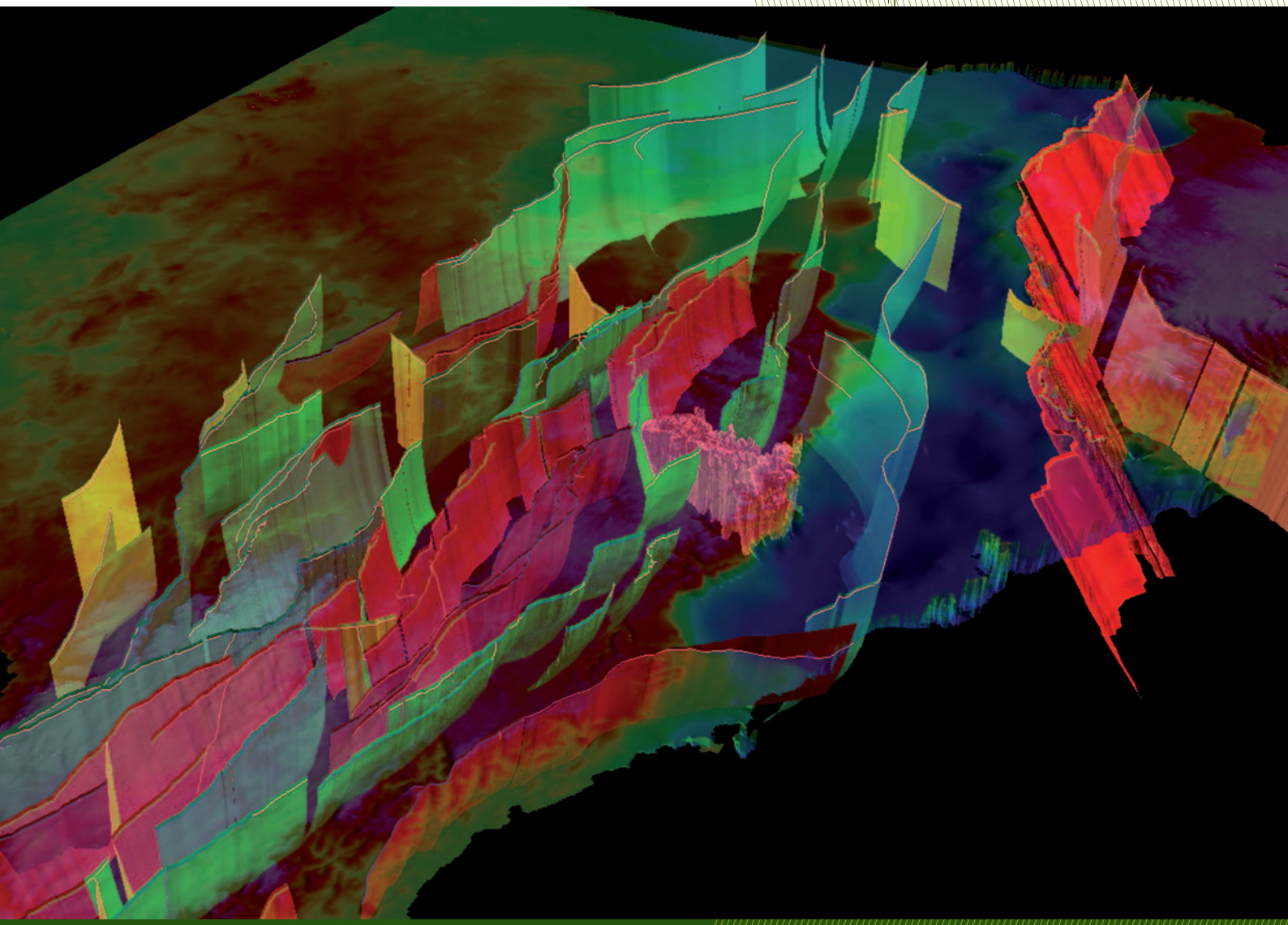
PREVIEW



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Velseis Pty Ltd
Tel: +61 7 3376 5544
Email: info@velseis.com

ASEG CORPORATE MEMBERS

Archimedes Financial Planning
Contact: Noll Moriarty
Tel: 1300 387 351
Email: Noll.Moriarty@ArchimedesFinancial.com.au

Instrumentation GDD Inc.
Contact: Pierre Gaucher
Tel: +1 418 877 4249
Email: pgaucher@gcc.ca

Santos Ltd
Tel: +61 8 8116 5000
Web: https://www.santos.com

Southern Geoscience Consultants Pty Ltd
Tel: +61 8 6254 5000
Email: geophysics@sgc.com.au
Web: http://sgc.com.au/

FRONT COVER

3D fault model of the Eastern Lachlan Orogen with the statewide depth to basement in the background. Source: Geological Survey of New South Wales. See Geophysics in the Surveys for more information.

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CONTENTS

Editor
Lisa Worrall
Email: previeweditor@aseg.org.au

Associate Editors
Education: Michael Asten
Email: michael.asten@monash.edu

Government: David Denham
Email: denham1@iinet.net.au

Environmental Geophysics: Mike Hatch
Email: michael.hatch@adelaide.edu.au

Minerals Geophysics: Terry Harvey
Email: terry.v.harvey@glencore.com.au

Petroleum Geophysics: Michael Micenko
Email: micenko@bigpond.com

Geophysical Data Management and Analysis: –

Book Reviews: Ron Hackney
Email: ron.hackney@ga.gov.au

ASEG Head Office & Secretariat
Alison Forton
The Association Specialists Pty Ltd (TAS)
Tel: (02) 9431 8622
Email: secretary@aseg.org.au
Website: www.aseg.org.au

Publisher
CSIRO Publishing

Production Editor
Helen Pavlatos
Tel: (03) 9545 8472
Email: helen.pavlatos@csiro.au

Advertising
Tel: (03) 9545 8400
Email: publishing.advertising@csiro.au

Editor's desk

This issue of *Preview* has something for everyone, so crack open that bottle of red and settle down in your favourite armchair!

We feature the trial of a new and experimental extractive technology for unconventional resources in the Cooper Basin. Ray Johnson and his collaborators, Real Energy Corporation Ltd, are going out on a bit of a limb with this one, and I hope that they will keep *Preview* readers posted as the trial progresses. We also feature an article by Roger Henderson that asks the question; was Edgar H Booth the father of Australian exploration seismology? Roger tells me that this article is the last in his series on the origins of Australian geophysics so, enjoy whilst you can!

Our commentators have been particularly busy. David Denham (*Canberra observed*) introduces us to the astonishingly detailed data on the floor of the Indian Ocean that was acquired during the search for MH370. This data is now publically available through Geoscience Australia. David also bemoans the continuing decline of government investment in R&D but, it is difficult to fault state and federal governments in terms of their ongoing investment in geophysical surveys (*Geophysics in the surveys*). The management and storage of increasing volumes of survey data is a perennial topic of discussion at the ASEG Technical Standards Committee meetings. Tim Keeping is the Chair of the ASEG Technical Standards Committee and, as guest editor of *Data trends,* he asked Sam Roberts of Pitney Bowes to report on MRR – a new, soon to be freely accessible, raster storage format that could solve some of the raster data storage and management issues that have been identified.

But wait, there is more, Michael Asten (*Education matters*) treats us to a mini-feature on the ARC Basin GENESIS Hub at Sydney University. If you are not familiar with the work of this hub I can guarantee that you will be intrigued, and unable to resist the temptation to go online and cruise through the group's graphical representations of the evolution of the Australian continent. Mike Hatch (*Environmental geophysics*), who was disappointed by some of his own recent inversion results, takes another look at low induction number approximation. Terry Harvey (*Minerals geophysics*) re-evaluates his relationship with sulphides. Mick Micenko (*Seismic window*) considers the importance of rock physics in seismic interpretation and, finally, Dave Annetts (*Webwaves*) warns us to be mindful of how we use, and misuse, passwords.

Cheers!

Lisa Worrall
Preview *Editor*
previeweditor@aseg.org.au

President's piece

Marina Costelloe

Welcome to a new edition of *Preview*!

National volunteer week was in May this year, and we took the opportunity to celebrate our volunteers in an email. I'd like to again to thank, congratulate and praise the work of ASEG volunteers, with a special mention to the Branch Presidents, Branch Secretaries and Branch Treasurers. ASEG events, workshops, seminars and the day to day working of Branches are successful because of our volunteers. If you have not had the opportunity to be on a Branch committee you might not see or fully understand the work that goes on daily to support all our Members. On that note, why not send your local Branch President and Branch committee a thank you email. We also thank and acknowledge ASEG volunteers who run Conferences, Special Interest Groups (SIGs) and other committees which are listed on our website https://www.aseg.org.au/committees. Most of our volunteers have been staunch long term advocates of geophysics, science education and, of course, the ASEG and we thank everyone for their time and professionalism. If you would like to volunteer let me know, and we can find a role that suits you.

Recently I was surprised and heartened to receive a letter from Senator the Hon. Matt Canavan, Minister for Resources and Northern Australia. Matt congratulated me on my election as President of the ASEG. I share this wonderful news with you because this reflects positively on our Society and the value exploration geophysics has at the highest levels of government. Yes, I have framed the letter and have it hanging in the study.

In March, Minister Canavan addressed the National Press Club on the topic 'The Long Mining Boom' where he announced the establishment of an expert-led Resources 2030 Taskforce. The Taskforce, chaired by Andrew Cripps, formerly Queensland Minister for Natural Resources, has been tasked with identifying and bringing forward bold, attainable reforms to the Australian resource sector. Each reform will ensure the sector's competitiveness and sustainability to 2030 and beyond. The taskforce, which includes former Geoscience Australia CEO Chris Pigram, will present its findings to the Minister by August 2018 and those findings, which should be of considerable interest to all ASEG Members, will be used by the Federal Government to develop a National Resources Statement.

In June I attended a two day MinEx CRC meeting and met the CRC's CEO Andrew Bailey. The MinEx CRC is in the early planning phase and started its ten-year program officially in July 2018. The CRC will create new opportunities for mineral discovery by delivering industry led, outcome focussed research. It was a good opportunity to connect the ASEG and voice our strengths and possible collaboration with the CRC, particularly in the data acquisition and data standards space. The discussions were intense and delved deeply into where pain points exist and solutions can be maximised to support industry and investment.

Marina Costelloe
ASEG President
president@aseg.org.au

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Marina Costelloe: President
Tel: (02) 6249 9347
Email: president@aseg.org.au

Ted Tyne: President Elect (Publications Committee Co-Chair, ASEG Research Foundation)
Tel: 0434 074 123
Email: presidentelect@aseg.org.au

Megan Nightingale: Secretary (Young Professionals Network)
Tel: 0438 861 556
Email: fedsec@aseg.org.au

Danny Burns: Treasurer (Finance Committee Chair)
Tel: 0407 856 196
Email: treasurer@aseg.org.au

Andrea Rutley: Past President (Promotions Committee Chair)
Tel: (07) 3834 1836
Email: pastpresident@aseg.org.au

Katherine McKenna: (International Committee)
Tel: 0400 594 220
Email:

Kim Frankcombe (AGC Representative, Conference Advisory Committee and Technical Standards Committee)
Tel: (08) 6201 7719
Email: kfrankcombe@iinet.net.au

Marina Pervukhina (Professional Development Committee Chair, State Branch Representative, Specialist and Working Groups Liaison)
Tel: (08) 6436 8746
Email: branch-rep@aseg.org.au

David Annetts (Web Committee Chair)
Tel: (08) 6436 8517
Email: david.annetts@csiro.au

Kate Robertson (Communications Committee)
Tel: (08) 8429 2564
Email: communications@aseg.org.au

Leslie Atkinson (Membership Committee)
Tel: 0414 804 028
Email: membership@aseg.org.au

Andrew Squelch (Education Committee Chair)
Tel: (08) 9266 2324
Email: education@aseg.org.au

Standing Committee Chairs

Finance Committee Chair: Danny Burns
Tel: 0407 856 196
Email: treasurer@aseg.org.au

Membership Committee Chair:
Leslie Atkinson
Tel: 0414 804 028
Email: membership@aseg.org.au

State Branch Representative: Marina Pervukhina
Tel: (08) 6436 8746
Email: branch-rep@aseg.org.au

Conference Advisory Committee Chair:
Michael Hatch
Email: cac@aseg.org.au

Honours and Awards Committee Chair:
Andrew Mutton
Tel: 0408 015 712
Email: awards@aseg.org.au

Publications Committee Chairs:
Danny Burns and Ted Tyne
Tel: 0407 856 196 and 0434 074 123
Email: publications@aseg.org.au

Technical Standards Committee Chair:
Tim Keeping
Tel: (08) 8226 2376
Email: technical-standards@aseg.org.au

ASEG History Committee Chair:
Roger Henderson
Tel: 0406 204 809
Email: history@aseg.org.au

International Affairs Committee Chair:
Nick Direen
Tel: –
Email: international@aseg.org.au

Professional Development Committee Chair:
Marina Pervukhina
Tel: (08) 6436 8746
Email: continuingeducation@aseg.org.au

Education Committee Chair: Andrew Squelch
Tel: (08) 9266 2324
Email: education@aseg.org.au

Web Committee Chair: David Annetts
Tel: (08) 6436 8517
Email: david.annetts@csiro.au

Research Foundation Chair: Philip Harman
Tel: 0409 709 125
Email: research-foundation@aseg.org.au

Communications Committee Chair:
Kate Robertson
Tel: (08) 8429 2564
Email: communications@aseg.org.au

Specialist Groups

Near Surface Geophysics Specialist Group
President: David Annetts
Tel: (08) 6436 8517
Email: nsgadmin@aseg.org.au

Young Professionals Network
President: Megan Nightingale
Tel: 0438 861 556
Email: ypadmin@aseg.org.au

ASEG Branches

Australian Capital Territory

President: James Goodwin
Tel: (02) 6249 9705
Email: actpresident@aseg.org.au

Secretary: Adam Kroll
Tel: (02) 6283 4800
Email: actsecretary@aseg.org.au

New South Wales

President: Mark Lackie
Tel: (02) 9850 8377
Email: nswpresident@aseg.org.au

Secretary: Steph Kovach
Tel: (02) 8960 8443
Email: nswsecretary@aseg.org.au

Queensland

President: Ron Palmer
Tel: 0413 579 099
Email: qldpresident@aseg.org.au

Secretary: James Alderman
Tel: –
Email: qldsecretary@aseg.org.au

South Australia & Northern Territory

President: Kate Robertson
Tel: (08) 8429 2564
Email: sa-ntpresident@aseg.org.au

Secretary: Mike Hatch
Tel: –
Email: sa-ntsecretary@aseg.org.au

NT Representative: Tania Dhu
Tel: 0422 091 025
Email: nt-rep@aseg.org.au

Tasmania

President: Mark Duffett
Tel: (03) 6165 4720
Email: taspresident@aseg.org.au

Secretary: Steve Kuhn
Tel: (03) 6226 2477
Email: tassecretary@aseg.org.au

Victoria

President: Seda Rouxel
Tel: 0452 541 575
Email: vicpresident@aseg.org.au

Secretary: Thong Huynh
Tel: –
Email: vicsecretary@aseg.org.au

Western Australia

President: Heather Tompkins
Tel: 0477 988 810
Email: wapresident@aseg.org.au

Secretary: Matt Owers
Tel:
Email: wasecretary@aseg.org.au

The ASEG Secretariat

Alison Forton
The Association Specialists Pty Ltd (TAS)
PO Box 576, Crows Nest, NSW 1585
Tel: (02) 9431 8622
Fax: (02) 9431 8677
Email: secretary@aseg.org.au

Executive brief

The Federal Executive has been very busy updating policy and procedures, it sounds boring but good governance is important. Firstly we have a draft Volunteer policy, if you are interested in taking a look at this policy please email the secretary@aseg.org.au and we will send it out to you. The ASEG values our volunteers and we want to make sure the Society is doing its best to comply with best practice standards in this area.

Talking about volunteers, we have been lucky enough to get a few volunteers to help us update the 2004 Procedures Manual. Over the next two months we will be adding the new policies, procedures and guidelines that have been written in the past 14 years, and we will stage the release of the updated manual on the Members section of the ASEG website in order to facilitate comment. A huge thank you to Leonie Jones, Grant Butler and Phillip Wynne who are questioning and updating the manual.

We have also been looking at membership. To better serve the Society and support our young professionals we have decided to introduce a Graduate membership grant, which means the ASEG will now offer a 50% membership fee subsidy for students in their first two years post-graduation. In turn, we will ask recipients of the Graduate membership grant to write an article for *Preview*. This is a pilot program and more details will made available in an upcoming ASEG newsletter. Multiyear membership and Life membership rates have also been reviewed and changes will be promoted closer to membership renewal time.

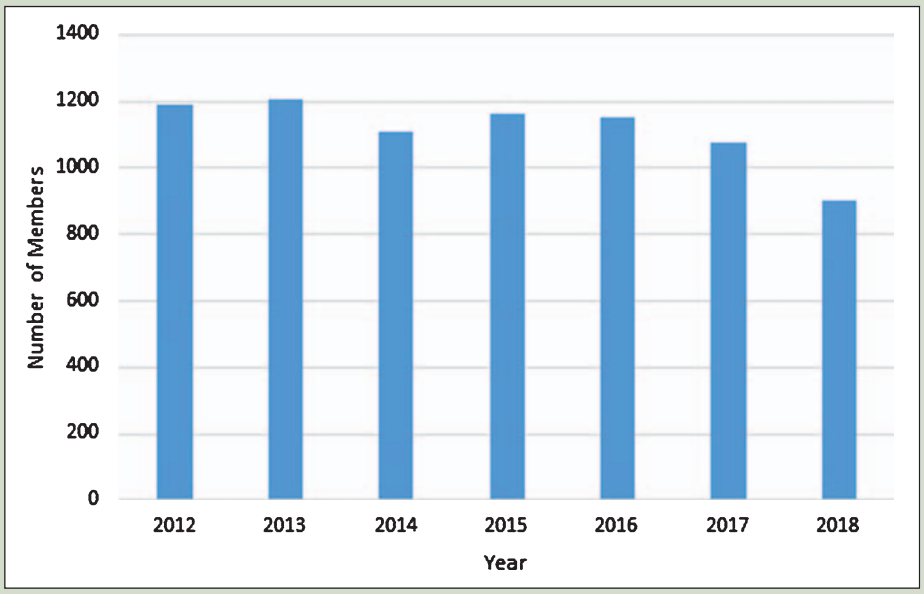

Figure 1. *ASEG membership levels between 2012 and 2018.*

Finances

The Society's financial position at the end of June 2018:

Year to date income: $146 794

Year to date expenditure: $279 386

Net assets: $725 251

Membership

At the time of this report, the Society had 903 Members. This is down 16% from last year (Figure 1).

Numbers are down similarly across most of the States with the least drop in Members being 15.5% in the ACT and the most being a 26% drop in NSW (Figure 2).

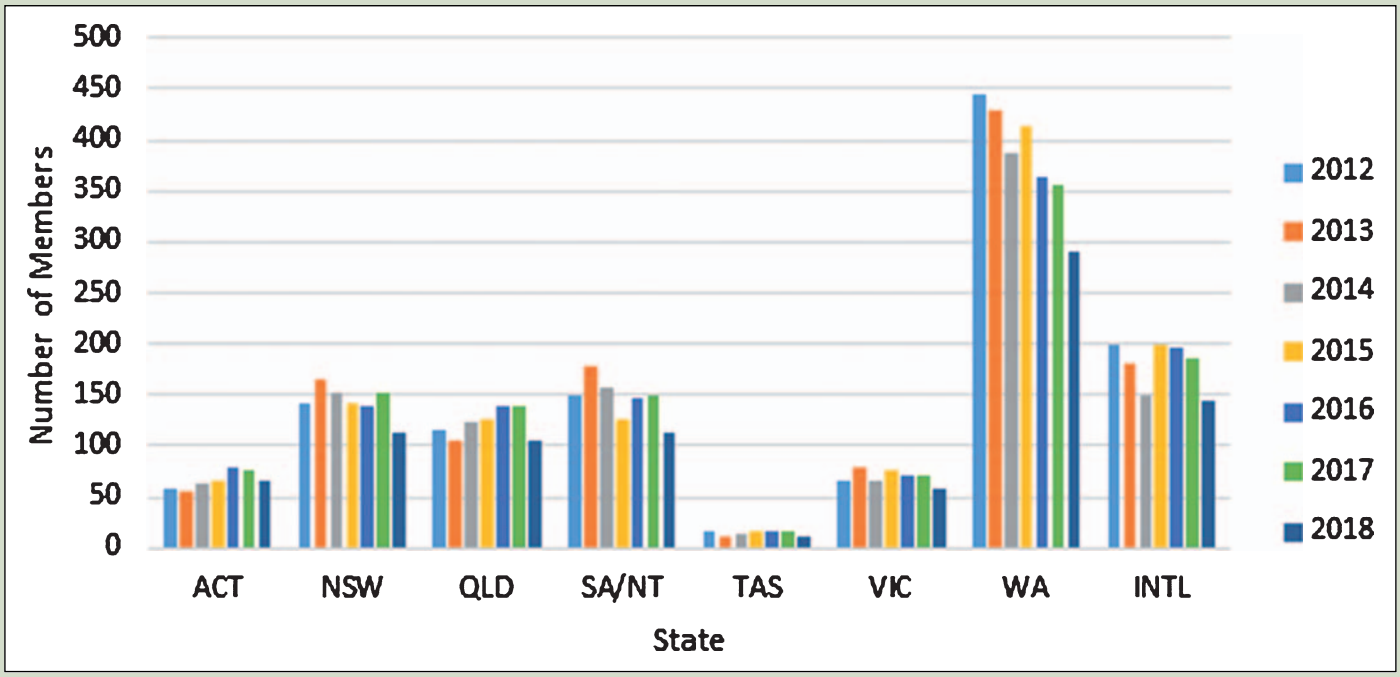

Figure 2. *ASEG membership by State between 2012 and 2018.*

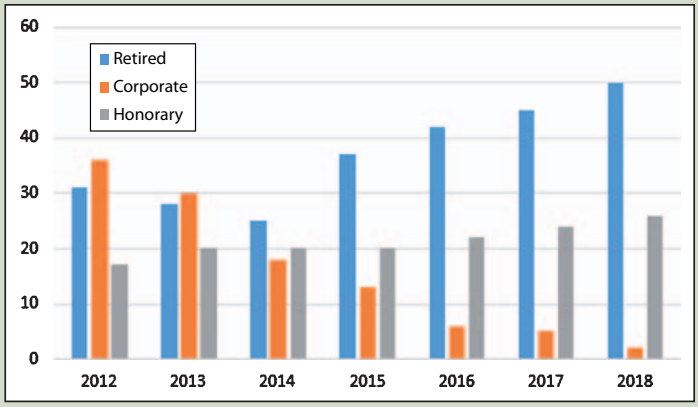

Figure 3. *ASEG Retired/Honorary and Corporate membership between 2012 and 2018.*

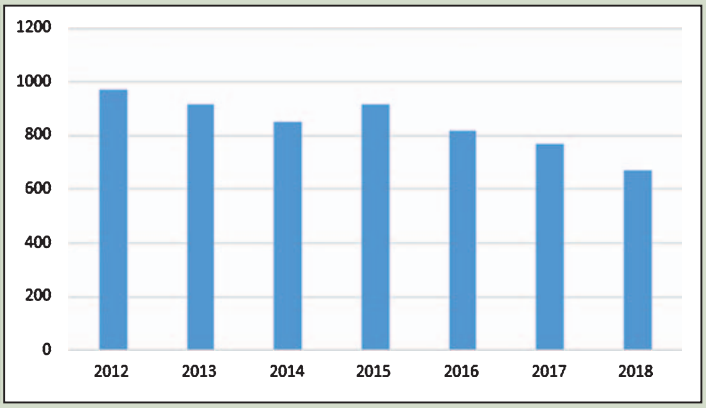

Figure 4. *ASEG Active and Associate membership between 2016 and 2018.*

Retired and Honorary membership numbers have increased by 5% and 9% respectively (Figure 3), while there has been a 12.5% decrease in Active/Associate Members (Figure 4), and a significant 50% decrease in the number of Student Members from last year (Figure 5).

These figures highlight the diminishing resource of invaluable experience from within our ranks, and has focused our attention on the importance of mentoring programs to pass along skills and insights to the next generation of exploration geophysicists.

We've also seen the loss of another valued Corporate Member. The ASEG recognises the importance of retaining and building new relationships with Corporate Members and is currently working on packages to attract corporate interest and investment for the betterment of the Society and our Members.

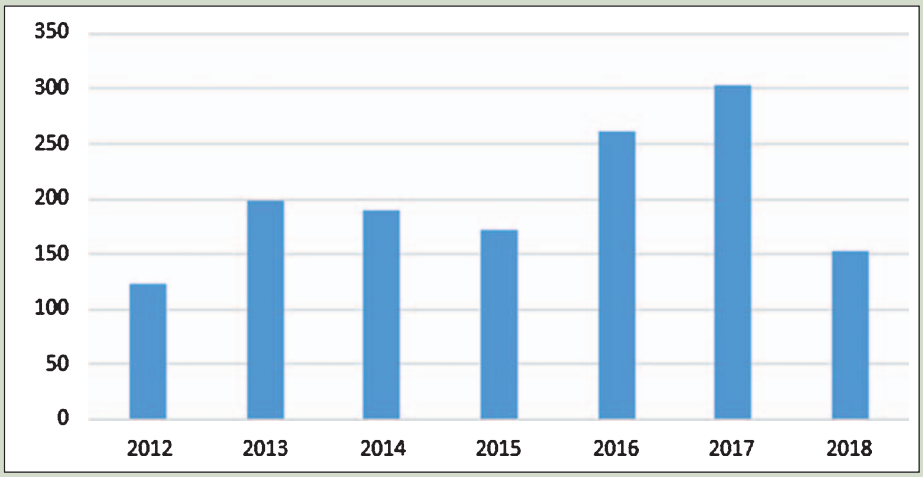

Figure 5. *ASEG student membership between 2012 and 2018.*

Megan Nightingale
Secretary
fedsec@aseg.org.au

Welcome to new Members

The ASEG extends a warm welcome to 13 new Members approved by the Federal Executive at its June and July meetings (see table).

First name	Last name	Organisation	State	Country	Membership type
Gabriel	Bretthauer	Macquarie University	NSW	Australia	Student
Emily	Grellman	Charles Sturt University	NSW	Australia	Student
Yuwei	Li	Australian National University	ACT	Australia	Student
Kaylah-Faith	MacIntosh	Tunnelling Business Unit	NSW	Australia	Student
Louise	McLaughlin	Curtin University	WA	Australia	Student
Dean	Monteiro	University of Queensland	QLD	Australia	Student
Mark	Reed	Zonge	Arizona	USA	Active
Celina	Sanso	Adelaide University	SA/NT	Australia	Student
Jeremy	Smith	HiSeis	WA	Australia	Associate
George	Symonds	Adelaide University	SA/NT	Australia	Student
Kristina	Tietze	German Research Centre for Geosciences	SA/NT	Australia	Active
Alice	van Tilburg	Macquarie University	NSW	Australia	Student
Michael	Zang	Minerva Intelligence Inc.		Canada	Active

ASEG committees

The ASEG has many talented, articulate, approachable professionals that help run a healthy and diverse society – through our specialist groups and committees. In the last issue of *Preview* we begin a three part series highlighting some of the amazing their amazing work. Remember, you can keep up to date with committee activity through social media, signing up to their specialist email lists as detailed below, or emailing the committee chair directly (details at https://www.aseg.org.au/committees). On behalf of all Members, all of the committee chairs and committee sub-groups are thanked for their passion, knowledge and accountability.

In this edition of *Preview* we take a look at the Honours and awards, Conference advisory and Membership Committees. More about our learned colleagues and other committees next month.

Honours and awards Committee

Andrew Mutton.

The Honours and awards Committee is responsible for overseeing the process of advertising, nomination, selection, recommendation of awardees to the Federal Executive, and presentation of the ASEG awards at each conference. In practice, the Chair carries out most of these tasks after soliciting advice and obtaining consensus from the Committee, which presently comprises six long-standing Members representing a broad geographical and technical spectrum of the membership. Andrew Mutton is the Committee Chair. Everyone is encouraged to nominate worthy ASEG Members for awards which include: ASEG Gold Medal, Grahame Sands Award, Laric Hawkins Award and Shanti Rajagopalan Memorial Award to name a few (https://www.aseg.org.au/about-aseg/honours-awards).

The Conference advisory Committee

Mike Hatch.

The Conference advisory Committee reports to the FEDEX and consists of the Chair (or other senior office holders) of previous conference organising committees. The roles of the Conference advisory Committee are:

- To advise the FEDEX on all conference matters
- To monitor the conference organising committee and give advice if required/ where appropriate
- To plan future conference strategies
- To keep reports, records and statistics of ASEG conferences.

Michael Hatch is currently the Committee Chair.

Membership Committee

Leslie Atkinson.

The Membership Committee is charged with the responsibility of managing the overall membership process and to advise the FEDEX and the ASEG Secretariat on issues relating to membership. Leslie Atkinson is currently the Chair of the Membership Committee. Each month the Chair submits membership data to the Fed Ex for strategic planning and budgeting decisions. The Membership Committee also are responsible for reminding Members to renew their membership. To help our Membership Committee please pay your membership fees on time, which also entitles you to a discount.

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News from the ASEG Young Professionals Network

Victoria

In June the Victorian YP seminar series continued with a talk on Seismic Depth Conversion by **Jarrod Dunne**. In July we had an excellent attendance for a talk by **David Briguglio** on Petroleum System Modelling. Networking drinks after both events were well attended by mentees and mentors.

Dave Briguglio presenting to the Victorian YPN.

Western Australia

The ASEG-PESA Mentoring Program has seen a fantastic response from WA Members and there are now 20 mentor-mentee pairs from diverse backgrounds, ages and professional experiences. Participants have attended framing sessions and a kick-off session where they defined how they would measure success at the end of the mentoring journey. The mentoring coordinators have already received positive feedback from the pairs on how the event has been organized and they are looking forward to the Mid-Program Tracking Session on 5 September. If you have any questions regarding the program, please don't hesitate to email **Carolina Pimentel** at wa-mentoring@aseg.com.au or **Ishtar Barranco** at wa-mentoring@pesa.com.au.

Australian Geoscience Council Convention

The 2018 Australian Geoscience Convention (AGCC) is being held between the 14th and 18th of October (Earth Science Week) in Adelaide. Discount registration is still available for early career scientists and all early career scientists, including students, are invited to take part a 3 minute rapid-fire presentation event. Great prizes are on offer for the event winners. Numerous networking events are also being organized for early career geoscientists, including welcoming drinks, a trivia night and a scavenger hunt through the exhibition. There are also several workshops that are pitched at YPs but they won't necessarily all run unless minimum numbers are achieved by a cutoff date set by the conference organising committee.

Don't miss out on these fantastic opportunities – register today!

Megan Nightingale
ASEG Young Professionals Network
ypadmin@aseg.org

ASEG Branch news

South Australia & Northern Territory

We have had a very busy few months since the last edition of *Preview*. In June we had guest speaker Associate Professor **Simon Holford**, whose talk titled 'Three-dimensional seismic imaging of shallow crustal volcanic plumbing systems' lured around 30 people out on a cold wintry night, and they weren't disappointed. Simon's work demonstrated that a volcanic eruption won't always be directly above the magma reservoir, with 3D seismic imaging showing significant lateral transport of magma (tens of kilometres) in some locations, and that a good 3D seismic analysis in regions with volcanic plumbing systems can reduce exploration risk.

We had three events in July, starting with a lunchtime talk by Dr **Clive Foss** from CSIRO held at the Department for Energy and Mining building in the city. Dr Foss is currently a regular visitor to the Geological Survey of South Australia because he is working on the Gawler Craton Airborne Survey. The talk, 'Paragon Bore – a special place in the South Australian magnetic field', was about the highly magnetic anomaly at Paragon Bore along the northern margin of the Gawler Craton. For the princely sum of a gold coin, attendees were provided sandwiches, cakes and a very enjoyable talk. We had a large turnout of around 30 people, so after a long hiatus of lunchtime technical events we will certainly be looking to continue with the lunchtime talks.

On Monday 16 July we had the SEG Distinguished Instructor Short Course by Professor **Kurt Marfurt**, 'Seismic Attributes as the Framework for Data Integration throughout the Oilfield Life Cycle', which was well received, with Kurt being an abundant source of knowledge. The next day we had another lunchtime event, this time a little more formal at the Hotel Tivoli with a two course meal followed by a talk from Kurt, just hours before he jumped on a plane to continue his tour around Australia. The talk, 'Finding and exploiting correlations between 3D seismic, log, and engineering data using machine learning (The future requirements of integrated E&P: Shallow learning – but deep thinking!' was enjoyed by 28 attendees, a very good turnout for our first formal lunchtime event in several years.

Our next event is back at the Coopers Alehouse in the CBD on Tuesday 7 August. Dr **Satish Singh** will talk on 'Seismic Full Waveform Inversion for Fundamental Scientific and Industrial Problems'. Food and drinks from 5:30 pm, talk at 6:15 pm. Free for Members and students and $10 for non-members.

We are always looking for ways to give our Members value and opportunities. We are only early into discussions at the moment, but our intention is to run a mentoring program in 2019 with a launch event later this year, where we will be seeking feedback on the structure, timing and eligibility criteria for the mentor program.

Lastly, a save-the-date for your calendars: we have secured the Gallery on Waymouth Street for our annual Melbourne Cup event on Tuesday 6 November this year, so stay tuned for an invite in the coming months.

If you have any suggestions/comments on the recent events we have hosted, in particular the new lunchtime talks, I would love to hear from you. I'm also happy to hear any suggestions for guest speakers or if you have any visitors in town whose work may interest other members. I would also like to take this opportunity to thank our six sponsors who help make all of our events possible – Beach Energy, Department for Energy and Mining, Minotaur Exploration, Heathgate Resources, Vintage Energy and Zonge Engineering.

Kate Robertson
sa-ntpresident@aseg.org.au

Tasmania

Electrical and EM specialist **Kate Hine** of Mitre Geophysics presented some highlights from her recent exploration experience to a joint meeting of the ASEG and Australian Institute of Geoscientists Tasmania branches, together with the University of Tasmania's Society of Economic Geologists (the other SEG) Student Chapter. The meeting was held on 10 July in the CODES Conference Room at the university.

Kate Hine

Kate's talk covered mainly downhole EM and IP applications in arenas ranging from coal to massive sulphide exploration. It emphasised the importance of planning: understanding exactly what is being sought and the characteristics of the methods used, with the implications of one for the other, then rigorously comprehending what is detected. It was illustrated by several examples of successful illumination, where 'success' varied in nature from technical to very much economic. Finding new targets in volumes thought to have been already tested (even with similar methods) was a recurring theme. An appreciative audience came away with some extremely valuable lessons in geophysical capabilities and geoscientific exploration philosophy.

An invitation to attend Tasmanian Branch meetings is extended to all ASEG Members and interested parties. Meetings are usually held in the CODES Conference Room, University of Tasmania, Hobart. Meeting notices, details about venues and relevant contact details can be found on the Tasmanian Branch page on the ASEG website. As always, we encourage Members to also keep an eye on the seminar program at the University of Tasmania/CODES, which routinely includes presentations of a geophysical and computational nature as well as on a broad range of earth sciences topics.

Mark Duffett
taspresident@aseg.org.au

Victoria

As your committee alluded to in the last issue of *Preview*, the early onset of the annual Melbourne winter hiatus meant we had to ration our local stock of speakers. Without fear, a call was put out to our

overseas counterparts and they have delivered in spades!

In May, we had great pleasure in welcoming **Maz Faruki** from PGS. Maz is also this year's SEG South Pacific Honorary Lecturer. A small gathering braved the Antarctic-like conditions to hear his take on the latest advances in marine seismic acquisition and its impact on data quality versus efficiency. Maz alluded to a number of new ideas and current developments that could potentially change the way we measure our seismic data in the future.

In late June, during the deepest and darkest cold of winter, your Branch was invited to meet with a visiting delegation from the Bangladesh Geological Survey. Melbourne was surprisingly high on their list of Australian destinations as they took a break during a nation-wide tour learning Australian best practices in relation to coal exploration. Your committee had the pleasure of speaking to them at length about the benefits of our Society and how it generates common interests throughout the wider geoscience community.

In keeping with the international theme, the ASEG welcomed **Kurt Marfu**rt to Australia as this year's DISC lecturer. Kurt presented a one-day workshop in Melbourne on 18 July titled 'Seismic Attributes as the Framework for Data Integration throughout the Oilfield Life Cycle', which was followed by a Branch talk the next day. Thank you to all of those that came to the workshop and talk. They were ground-breaking events!

And, to cap off a season of international visitors, the Branch will be welcoming **Satish Singh**, this year's SPE/AAPG Distinguished Lecturer, whose presentation on 2 August will cover the various aspects and uses of seismic Full Waveform Inversion.

Lastly, the much anticipated annual winter social is just around the corner, so stay tuned for further information. This will be an event not to be missed!

Seda Rouxel
vicpresident@aseg.org.au

Western Australia

Since our last update, the West has held several thought-provoking technical events featuring local and international speakers. The well attended June 13 Tech night was a *Mineral* stream presentation by **Chris Wijns** (First Quantum Minerals) on 'Exploration geoscience inside the mining gate', which highlighted several exploration techniques and technologies that can assist mining operations for a variety of commodities. This was followed by two *Petroleum* stream events in July by SEG Distinguished Lecturer **Kurt Marfurt**. On 11 July Kurt Marfurt (SEG DISC) hosted a 1 day workshop on 'Seismic Attributes as the Framework for Data Integration throughout the Oilfield Life Cycle' for 18 participants at the Tech Park Function Centre, and on 12 July he spoke at our monthly tech night on 'Finding and exploiting correlations between 3D seismic, log, and engineering data using machine learning. The future requirements of integrated E&P: Shallow learning – but deep thinking'. We also look forward to hearing from 4 speakers in August; one *Petroleum* presentation by **Satish Singh** (SEG Distinguished Lecturer) on 15 August, and three *Groundwater* presentations by **Southern Geoscience Consultants** on 29 August.

The ASEG-PESA Mentoring Program has seen a fantastic response from WA Members and includes 20 mentor-mentee pairs from diverse backgrounds, ages and professional experiences. Participants have attended framing sessions and a kick-off session where they defined how they would measure success at the end of the mentoring journey. The mentoring coordinators have already received positive feedback from the pairs on how the event has been organised, and they are looking forward to the Mid-Program Tracking Session on 5 September. If you have any questions regarding the program, please don't hesitate to email Carolina Pimentel at wa-mentoring@aseg.com.au or Ishtar Barranco at wa-mentoring@pesa.com.au.

Upcoming WA events include:

- 15 August Tech night – *Petroleum* – Satish Singh (SEG Distinguished Lecturer) will present on 'Seismic Full Waveform Inversion for Fundamental Scientific and Industrial Problems'.
- 29 August Tech night – *Minerals/ Groundwater* – **Heather Skeen**, **Brendan Ra**y, and **Karen Gilgallon** from Southern Geoscience Consultants

*June *Mineral* stream tech night in Perth. The presenter was Chris Wijns (First Quantum Minerals).*

*June *Young Professional* mentor-mentee meeting as part of the ASEG-WA mentoring program, jointly run with PESA-WA.*

will present on the use of geophysics for hydrogeology applications in Nevada, the Perth Basin, and Exmouth, WA.

- 5 September– *Young Professionals* – Mentoring Program tracking session.
- 12 September Tech night – *Minerals/ Groundwater* – **Alan Aitken** from UWA will present on 'Modelling Microgravity for Groundwater Storage'.

The Tech night schedule is subject to change due to speaker availability. Please check the website for up-to-date information.

We are currently finalising Branch sponsorship for 2018/2019, and would like to take this opportunity to thank our 2017/2018 sponsors for their ongoing support and assistance over the last year: Globe Claritas, First Quantum, Geosoft, GPX Surveys, HiSeis, NRG, Resource Potentials, Southern Geoscience, Teck, Western Geco, Atlas, CGG, ExploreGeo, NGI, and a private donation in memory of Marion Rose.

Planning for the 2018 Branch AGM and Christmas Party will start shortly. If you would like to provide the Branch feedback on previous events or share with us ideas for 2018, please send us an email (wapresident@aseg.org.au).

Heather Tompkins
wapresident@aseg.org.au

Australian Capital Territory

In May, **Lachlan Hennessy** presented his fascinating research on how lightning network data and earth-ionosphere wave propagation modelling were being used to predict the time of arrival, azimuth and amplitude of lightning strikes recorded in time-series EM data. His work highlighted that the location and geometry of local and regional structures can be inferred by calculating the rotation of measured data from their predicted arrival azimuths.

In June, the ACT Branch enjoyed a great presentation from **Alison Kirkby**. Alison showed the Branch her results from the recent 3D inversion of magnetotelluric data along the 09GA-GA1 magnetotelluric and deep seismic reflection transect. In particular, a 3D isotropic resistivity model was produced which highlighted significant structural trends and conductive bodies, throughout the Davenport and Aileron Provinces, that are coincident with the structures visible in the seismic reflection data.

Also, the ACT Branch is looking forward to a number of upcoming events, including:

- 1 August, 1630, Geoscience Australia – Distinguished Lecturer **Satish Singh**: 'Seismic Full Waveform Inversion for Fundamental Scientific and Industrial Problems'.
- 13 September, 1230, Geoscience Australia – **Marina Costelloe** (ASEG Federal President): 'The ASEG: How it works and what we are up to'.

James Goodwin
actpresident@aseg.org.au

New South Wales

In May, **Andy Green**, from OTEC presented a talk about budget allocation and the stopping problem in mineral exploration. Andy outlined that most mineral exploration projects involve a process of testing targets on the basis of geoscientific data. However, questions still arise as to how many targets should be tested before an area is dropped. Andy's talk addressed this topic, walking us through a proposed model and a kimberlite exploration study, to emphasise how it can be applied. There were many questions.

In June, **Ned Stolz** and **Bob Musgrave** from the Geological Survey of New South Wales presented two talks. Ned walked us through the various geophysical programs that the geological survey is currently involved in. Ned highlighted the current magnetic and gravity acquisition as well as seismic reflection and MT projects. Bob spoke about the work that he does, discussing about his dream of having a petrophysics database of all the NSW rock types thorough to understanding the tectonics of NSW gleamed from his palaeomagnetic studies. Much discussion followed, with more questions about the eruption being asked over a few reds.

At the June meeting we also thanked the NSW ASEG award winners, **Andrew Sloot**, **John Denham** and **Dave Robson**. Congratulations on your awards and thank you for all the work you have done.

An invitation to attend NSW Branch meetings is extended to interstate and international visitors who happen to be in town at the time. Meetings are generally held on the third Wednesday of each month from 5:30 pm at the 99 on York Club in the Sydney CBD. Meeting notices, addresses and relevant contact details can be found at the NSW Branch website

Mark Lackie
nswpresident@aseg.org.au

Queensland

The Queensland Branch hosted **Brad Cox** from Aeris Resources on 14 June. Brad manages mining and exploration geology teams at Aeris Resources' Tritton project in central NSW. Brad gave a presentation on the use of geophysics and, in particular, EM over the years, how these data were used, and the successes they produced. The original discovery was made on the back of SIROTEM data and, during the life of the project, several GeoTEM and VTEM surveys were acquired. Over the last two years a large moving loop EM ground survey has been acquired with the intention of investigating to depths of 400–500 m. This survey was followed by fixed loop surveys over selected targets. The presentation was well received and many interesting questions were put to Brad at the conclusion of his presentation.

July has been a busy month for the QLD ASEG. We hosted **Kurt Marfurt** on 25 July, when he gave his SEG DISC workshop on 'Seismic Attributes as the Framework for Data Integration throughout the Oilfield Life Cycle'. Kurt also presented an evening technical talk on 26 July, jointly hosted by PESA and the QLD ASEG branch. QLD ASEG have been working closely with other professional organisations in the area to ensure, wherever possible, dates for our technical talks do not clash, giving joint Members a chance to attend as many events as possible, and giving the QLD ASEG a chance to recruit new Members!

Continuing the SEG theme we are hosting Dr **Satish Singh**, the 2018 SEG/AAPG Distinguished Lecturer on 6 August.

Taking a breather from technical talks, we are looking forward, to holding our Zoeppritz Drinks Night on Friday 20 July starting at the Brisbane Brewing Co in West End; all are welcome, and the ever popular ASEG-PESA Trivia night is on the horizon – details will be sent out soon. Lookout for technical talk dates being announced leading up to the end of the year. If you would like to present a talk please get into contact with the QLD Branch President or Secretary.

James Alderman
qldsecretary@aseg.org.au

ASEG national calendar: technical meetings, courses and events

Date		Branch	Event	Presenter	Time	Venue
1	Aug	ACT	SEG/AAPG DL	Satish Singh	1630	Scrivener Room, Geoscience Australia, Symonston
2	Aug	VIC	SEG/AAPG DL	Satish Singh	1730	Kelvin Club, 18-30 Melbourne Place, Melbourne
6	Aug	QLD	SEG/AAPG DL	Satish Singh	TBA	TBA
7	Aug	SA-NT	SEG/AAPG DL	Satish Singh	1730	Coopers Alehouse, 316 Pulteney Street, Adelaide
8	Aug	NSW	SEG/AAPG DL	Satish Singh	1730	The University of Sydney
14	Aug	TAS	SEG/AAPG DL	Satish Singh	1730	CODES Conference Room, University of Tasmania, Sandy Bay
15	Aug	WA	SEG/AAPG DL	Satish Singh	1730	Ground Floor, 1 Ord Street, West Perth
20	Aug	QLD	Zoeppritz Drinks Night		TBA	Brisbane Brewing Co, West End
29	Aug	WA	Tech night	Southern Geoscience Consultants	1730	Ground Floor, 1 Ord Street, West Perth
5	Sep	WA	YPN mentoring session	Various	1715	Ground Floor, 1 Ord Street, West Perth
12	Sep	WA	Tech night	Alan Aitken	1730	Ground Floor, 1 Ord Street, West Perth
13	Sep	ACT	Tech talk	Marina Costelloe	1230	Geoscience Australia, Symonston
6	Nov	SA	Melbourne Cup lunch		TBA	Gallery on Waymouth Street, Adelaide

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

Vale: Search Exploration Services

In July 2017 Search Exploration Services celebrated 30 years in the exploration industry. Based in Adelaide and formed by Peter Elliot and Alex Copeland, Search provided contract ground geophysical surveys. They originally used Zonge and Scintrex equipment but when Peter left the company he took the Zonge gear and Alex continued to use the Scintrex IP equipment for several years until he began to develop his own transmitters and receivers in the late nineties. This involved collaboration with Phil Palmer of CIRA for the hardware and John Paine of Scientific Computing and Applications for the software. Following the death of Alex in 2015, David McInnes supported Search as a technical consultant.

The equipment used by Search Exploration Services has recently been sold to Moombarriga Geoscience, run by Shane Evans out of Perth, with whom Search has had a successful working relationship for the past three years. Employing ex-Search employees and using the name Search IP Surveys both Shane and Gerry are happy to see Alex's legacy and the name Search continue to play a part in the exploration industry both in Australia and overseas. Shane hopes to continue developing Search's technologies in association with Phil Palmer and John Paine with a new transmitter in development and designs for a new receiver in the pipeline.

During the past 30 years Search Exploration Services has come into contact with innumerable people as it has undertaken IP surveys and would like to take this opportunity to thank them not only for the work but also for the support and friendships, which have developed over time. Search wishes you well as you continue in the exploration industry.

Gerry Bown
gerry@searchex.com.au

AEGC 2019 continues to gather momentum

The Australasian Exploration Geoscience Conference, to be held in September 2019 at Crown Perth, is shaping up to be a major highlight in next year's calendar. With the theme 'Data to Discovery', the conference organising committee are close to calling for abstracts and expect that there will be some incredibly interesting submissions.

The networking and social functions are plentiful, with opportunities to connect with colleagues and build new relationships. Additionally, an exciting field trip is being planned. Stay tuned for more details about this!

Sponsorship options are now available, and these are being taken up at a rapid pace. With opportunities to suit all budgets, it's a wonderful way for businesses to promote their services to delegates. As the leading geoscience conference in Asia Pacific, co-hosted by AIG, ASEG and PESA, the audience is a genuinely diverse group of professionals from the geoscience sector.

To register your interest in sponsorship, exhibiting, speaking or attending as a delegate, visit www.aegc.com.au, or follow the LinkedIn page for updates – http://www.linkedin.com/company/aegc2019/.

Maud Kay
AEGC 2019 Publicity & Marketing Chair
maudkay@gmail.com

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 13 July 2018)

Further information on these surveys is available from Murray Richardson at GA via email at Murray.Richardson@ga.gov.au or telephone on (02) 6249 9229.

Table 1. Airborne magnetic and radiometric surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Spacing AGL Dir	Area (km²)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
Tasmanian Tiers	MRT	GA	TBA	TBA	Up to an estimated 66 000	200 m 60 m N–S or E–W	11 000	TBA	TBA	TBA	The National Collaborative Framework Agreement between GA and MRT is being updated
Isa Region	GSQ	GA	GPX	3 Jul 2017	120 062	100 m 50 m E–W	11 000	5 Nov 2017	Preliminary final point-located data were made available to GA on 26 Mar 2018	188: Jun 2017 p. 21	Data released via GADDS 31 May 2018
Tallaringa N (1A)	GSSA	GA	Thomson Aviation	26 Oct 2017	97 922	200 m 60 m E–W	17 320	26 Mar 2018	TBA	190: Oct 2017 p. 26	TBA
Tallaringa S (1B)	GSSA	GA	Thomson Aviation	26 Sep 2017	145 367	200 m 60 m E–W	26 010	99.2%	TBA	190: Oct 2017 p. 26	TBA
Coober Pedy (8A)	GSSA	GA	Thomson Aviation	18 Sep 2017	90 425	200 m 60 m N–S	16 140	21 Dec 2017	TBA	190: Oct 2017 p. 26	TBA
Billa Kalina (8B)	GSSA	GA	MAGSPEC Airborne Surveys	10 Oct 2017	90 353	200 m 60 m N–S	16 140	18 Dec 2017	TBA	190: Oct 2017 p. 26	TBA
Childara (9A)	GSSA	GA	MAGSPEC Airborne Surveys	5 Nov 2017	134 801	200 m 60 m N–S	23 910	2 May 2018	TBA	190: Oct 2017 p. 26	TBA
Lake Eyre (10)	GSSA	GA	MAGSPEC Airborne Surveys	2 Oct 2017	91 938	200 m 60 m E–W	16 180	22 Mar 2018	TBA	190: Oct 2017 p. 26	TBA
Streaky Bay (5)	GSSA	GA	GPX Airborne Surveys	21 Jun 2018	90 630	200 m 60 m E–W	15 966	TBA	TBA	194: Jun 2018 p. 19	18% complete as at 10 Jul 2018
Gairdner (6A)	GSSA	GA	GPX Airborne Surveys	TBA	105 075	200 m 60 m N–S	18 307	TBA	TBA	194: Jun 2018 p. 19	TBA
Spencer (7)	GSSA	GA	MAGSPEC Airborne Surveys	11 Jun 2018	50 280	200 m 60 m E–W	8716	TBA	TBA	194: Jun 2018 p. 19	44% complete as at 10 Jul 2018
Kingoonya (9B)	GSSA	GA	MAGSPEC Airborne Surveys	TBA	150 565	200 m 60 m N-S	26 651	TBA	TBA	194: Jun 2018 p. 19	TBA
Cloncurry North	GSQ	GSQ	GPX Surveys	Mid-May 2018	101 597	100 m	8687	TBA	TBA	This issue (GSQ section – Figure 1). For more information about this survey please contact geophysics@ dnrme.qld.gov.au	TBA
Tanami	NTGS	GA	TBA	TBA	275 216	100/ 200 m 60 m N-S/E-W	48 267	TBA	TBA	This issue	TBA

TBA, to be advised.

Table 2. Gravity surveys

Survey name	Client	Project management	Contractor	Start survey	No. of stations	Station spacing (km)	Area (km²)	End survey	Final data to GA	Locality diagram (*Preview*)	GADDS release
Kidson Sub-basin	GSWA	GA	CGG Aviation (Australia)	14 Jul 2017	72 933	2500 m line spacing	155 000	TBA	3 May 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	TBA
Lawn Hill	GSQ	GA	Atlas Geophysics	21 May 2018	7240	1000 m line spacing	8024	8 Jul 2018	TBA	194: Jun 2018 p. 19	TBA
Little Sandy Desert W and E Blocks	GSWA	GA	Sander Geophysics	W Block: 27 Apr 2018	52 090	2500 m line spacing	129 400	W Block: 3 Jun 2018	TBA	This issue	TBA
Kimberley Basin	GSWA	GA	Sander Geophysics	4 Jun 2018	61 960	2500 m line spacing	153 400	TBA	TBA	This issue	TBA
Warburton-Great Victoria Desert	GSWA	GA	Sander Geophysics	TBA	62 500	2500 m line spacing	153 300	TBA	TBA	This issue	TBA

TBA, to be advised.

Table 3. AEM surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Spacing AGL Dir	Area (km²)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
East Kimberley	GA	GA	SkyTEM Australia	26 May 2017	13 723	Variable	N/A	24 Aug 2017	Nov 2017	TBA	TBA
AusAEM (Year 1)	GA	GA	CGG	TBA	59 349	20 km with areas of infill	TBA	TBA	98%	186: Feb 2017 p. 18	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	TBA
Stuart Corridor, NT	GA	GA	SkyTEM Australia	6 Jul 2017	9832	Variable	Traverses	12 Aug 2017	Nov 2017	188: Jun 2017 p. 22	TBA
Olympic Domain	GSSA	GA	SkyTEM Australia	14 Nov 2017	3181	1.5 & 3 km E–W	33 200	21 Nov 2017	Preliminary final data received by GA 16 Mar 2018	190: Oct 2017 p. 27	TBA
Fowler Domain	GSSA	GA	SkyTEM Australia	Early Dec 2017	3057	5 km NW–SE	15 000	5 Dec 2017	Preliminary final data received by GA 16 Mar 2018	190: Oct 2017 p. 27	TBA

TBA, to be advised.

Table 4. Magnetotelluric (MT) surveys

Location	State	Survey name	Total number of MT stations deployed	Spacing	Technique	Comments
Northern Australia	Qld/NT	Exploring for the Future – AusLAMP	150 stations deployed in 2017	50 km	Long period MT	The survey covers the area between Tennant Creek and Mount Isa. The 2018 field season commenced in May 2018.
AusLAMP NSW	NSW	AusLAMP NSW	34 stations deployed in 2018 to date	50 km	Long period MT	Covering the state of NSW with long period MT stations at approximately 50 km spacing.
Olympic Domain	SA	Olympic Domain	320 total	Varied 1.5 to 10 km	AMT and BBMT	The survey area extends west of Lake Torrens and covers mineral prospects such as Carrapateena, Fremantle Doctor, Red Lake, Punt Hill, Emmie Bluff and Mount Gunson. At the end of May 100 sites have been collected.

Table 5 Seismic reflection surveys

Location	State	Survey name	Line km	Geophone interval	VP/SP interval	Record length	Technique	Comments
South East Lachlan	Vic/ NSW	SE Lachlan	Approx. 450	10 m	40 m	20 seconds	2D – Deep Crustal Seismic Reflection	The survey covers the South East Lachlan Orogen crossing the Victorian–New South Wales border. The data acquisition phase of the survey commenced on 5 Mar 2018 near Benalla in Victoria. The survey completed data acquisition south of Eden in NSW on 29 Apr 2018.
Kidson	WA	Kidson Sub-basin	Approx. 900	TBA	TBA	TBA	2D – Deep crustal seismic reflection within the Kidson Sub-basin of the Canning Basin extending across the Paterson Orogen and onto the eastern margin of the Pilbara Craton. The survey commenced acquisition on 18 Jun 2018.	

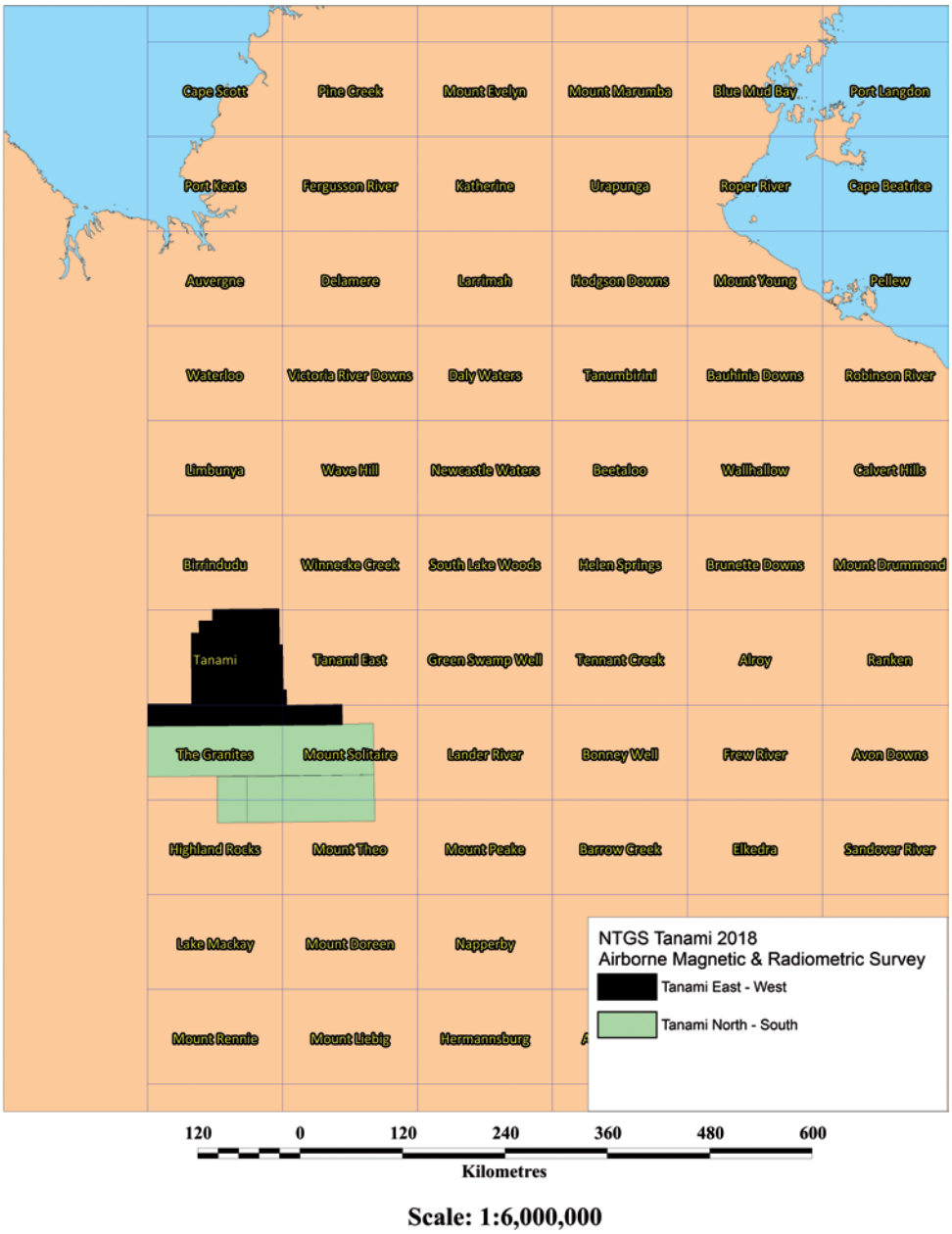

Figure 1. *Location of the Tanami airborne magnetic and radiometric survey area.*

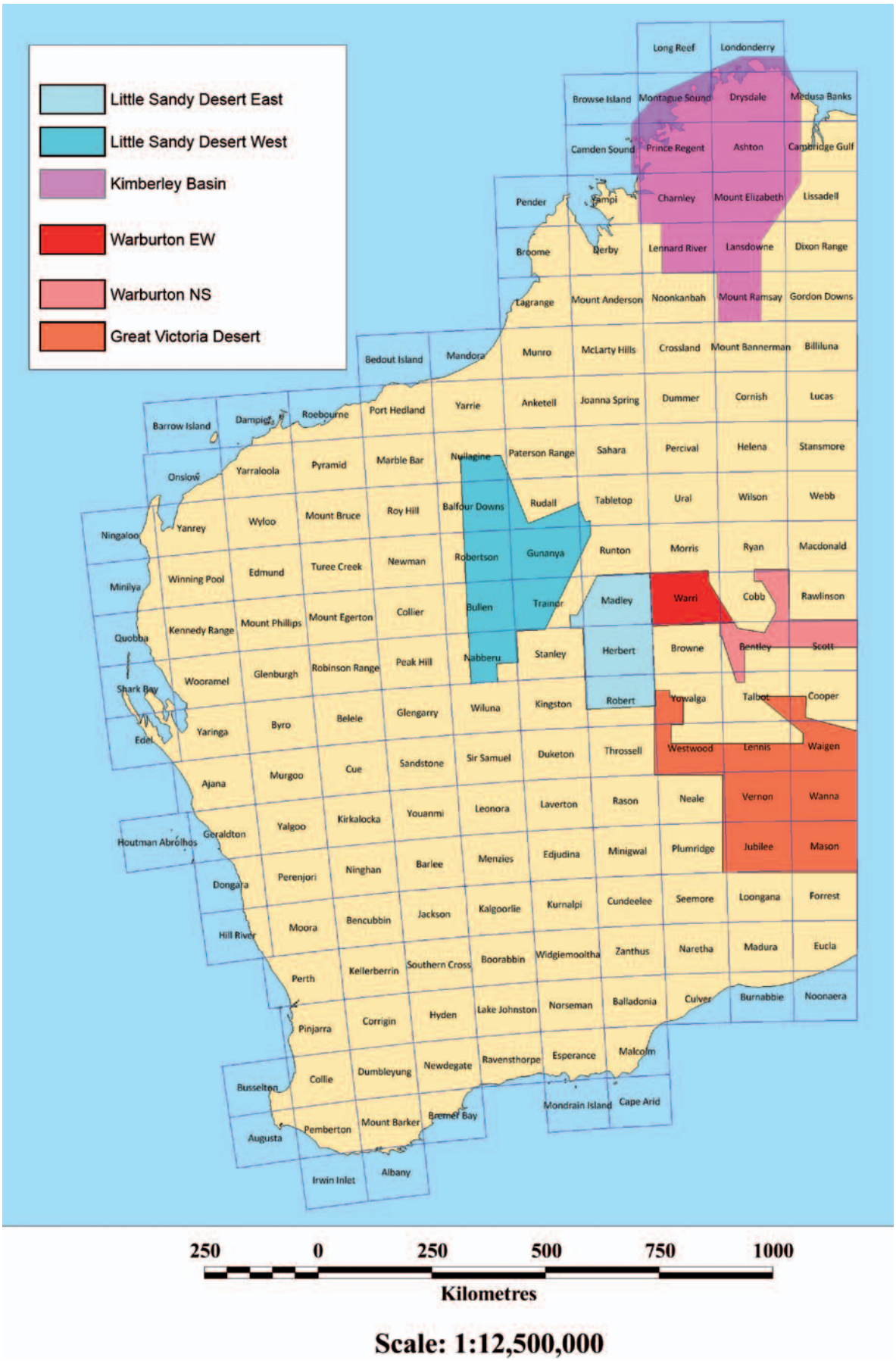

Figure 2. *Location of the Western Australian aerogravity surveys.*

Mineral Resources Tasmania: 3D geophysical model launch

Another semi-regional 3D geological and geophysical model is being released by Mineral Resources Tasmania, as part of its ongoing program of precompetitive geoscience initiatives. The Alberton-Mathinna 3D model was launched on 26 July by the Minister for Resources, the Hon. Guy Barnett, in Burnie. The Alberton-Mathinna area in north-east Tasmania (Figure 1) has historically been one of the most gold-rich in the State, with total production exceeding 330 000 ounces. Virtually all of this has been within a NNW-oriented linear trend known as the 'gold lineament', 'gold belt' or 'gold corridor' encompassing the eponymous townships, but the macroscopic details of structural or other controls on the primary quartz vein-hosted mineralisation are not well understood.

The modelling process began with structural interpretation and synthesis on a series of E-W cross sections by MRT geologists (Figure 2). These were extended to 3D fault surfaces and major unit boundaries, and subsequently volumes (Figure 3). Initial estimates of subsurface unit contacts were derived mainly from previous 2D gravity and magnetic modelling, particularly that of Roach (1994).

3D modelling of gravity (Figure 4) and magnetic (Figure 5) signatures proceeded via discretisation of geological unit volumes into voxets for calculation of model responses, using a comprehensive compilation of local physical property data. The starting geological volumes were modified by constrained stochastic inversion with respect to magnetic and gravity data maintained by MRT. The resulting range of statistical measures indicating the robustness of model components has been included in the 3D model package.

Both initial and post-inversion geological unit volumes are represented in the 3D model package (Figure 6), enabling ready inspection of how the 3D magnetic and gravity modelling has modified geometries. Among the new features to emerge is a small cupola in the vicinity of the Mathinna goldfield. Sensitivity analysis results are also incorporated in the model (e.g. Figure 7), so that the robustness of such features can be estimated.

Full details of the 3D geophysical modelling and sensitivity analysis

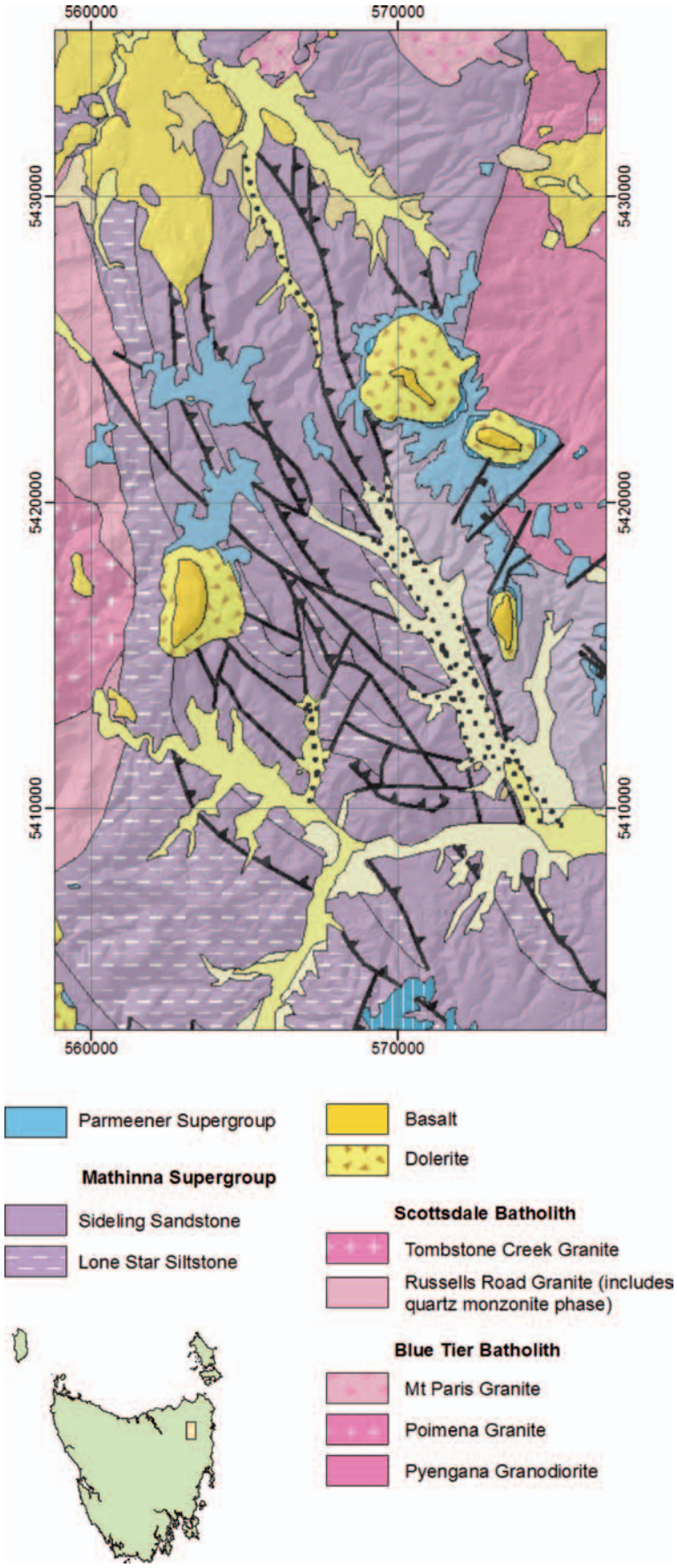

Figure 1. *Geology and location of the Alberton-Mathinna area.*

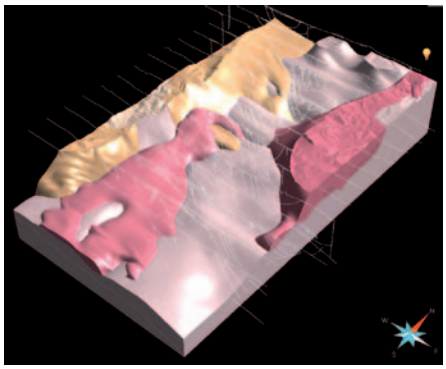

Figure 2. *Cross sections employed to initiate model construction, amongst granitoid pluton volumes derived from geophysical modelling.*

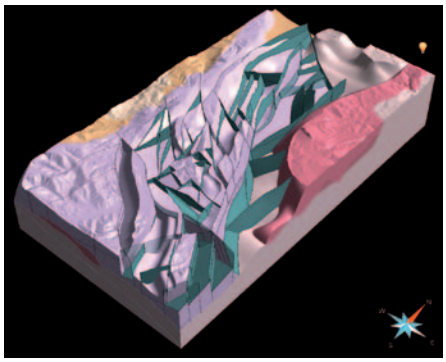

Figure 3. *Geological volumes, with one country rock unit (Sideling Sandstone) removed to reveal 3D fault surfaces.*

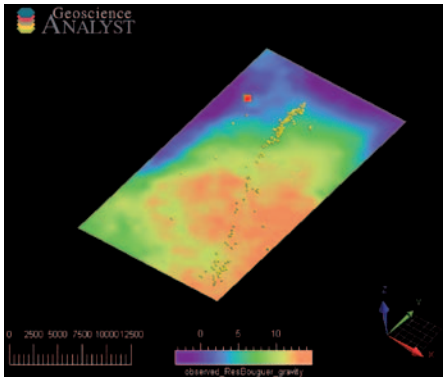

Figure 4. *Gridded observed complete Bouguer gravity (mGal) with gold occurrences superimposed (yellow spheres). Most historic gold production came from the Mathinna field, in the SE corner.*

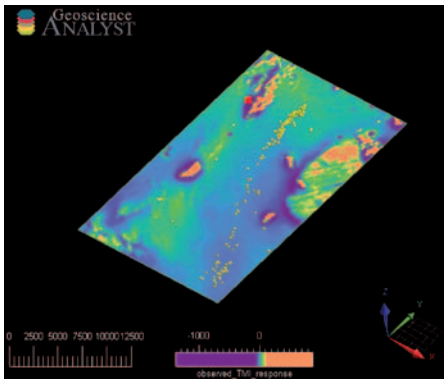

Figure 5. *Observed total magnetic intensity (nT) with gold occurrences superimposed (yellow spheres).*

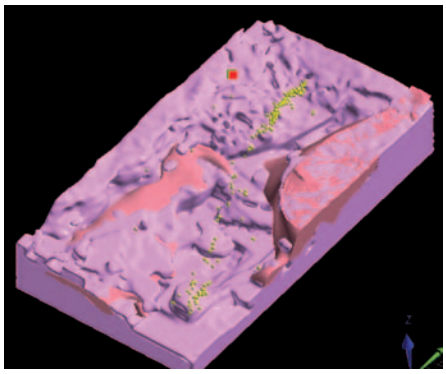

Figure 6. *Post-inversion granitoid volume (all plutons, pink) with superposed magnetic plutons from initial model (salmon) and historic gold occurrences plotted at the ground surface (yellow spheres). Granitoid depth below gold deposit points is generally 1–3 km.*

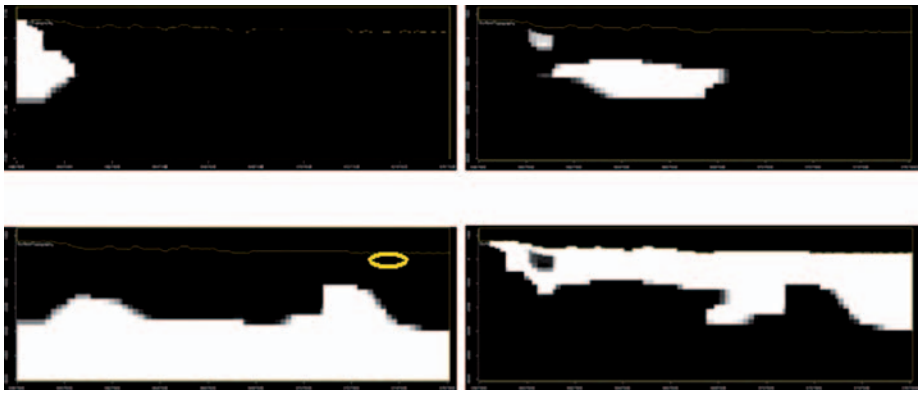

Figure 7. *Example of ensemble inversion-generated sensitivity metrics hosted within the 3D model package. Section from 5408000N (southernmost shown in Figure 2) indicating for each voxel the proportion of 2.64 million acceptable models containing a particular unit, via shading from <1% (black) to >99% (white). Clockwise from bottom left: undifferentiated granite, Russells Road Granite (granite-monzonite), magnetic granodiorite, Mathinna Supergroup metasediments. ~5500 m from surface to base of model. Approximate location of Mathinna goldfield indicated by yellow ellipse in lower left (undifferentiated granite) panel.*

methodology may be found in Bombardieri et al. (in prep.). The model package contains a range of other components not shown here including surface geology, elevation (40 metre cells), current exploration tenements and drillholes as well as details of the Golden Gate Mine at Mathinna. It is being distributed principally as a Geoscience Analyst (free viewer) project, which permits user import of other spatial data from their own sources, and is also available from MRT in native modelling software formats.

References

Bombardieri, D., Duffett, M., Vicary, M., McNeill, A., in prep., 3D geophysical modelling of the Alberton–Mathinna gold corridor, NE Tasmania.

Roach, M., 1994, The regional geophysical setting of gold mineralisation in northeast Tasmania. PhD thesis, University of Tasmania.

Mark Duffett and Daniel Bombardieri
Mineral Resources Tasmania
mark.duffett@stategrowth.tas.gov.au
daniel.bombardieri@stategrowth.tas.gov.au

Geological Survey of South Australia: The Woomera Prohibited Area, open for exploration (as always!)

The media reported recently that the WPA (Woomera Prohibited Area) has been 'opened up' for exploration (e.g. http://www.abc.net.au/news/rural/2014-07-17/woomera-mining/5605062). In reality, the WPA has always been open for exploration. The recent change has been the adoption of a time-share zone management system known as the 'Coexistence management framework'.

The WPA is an area of South Australia roughly the size of England, which is used as a military testing area. It is divided into four zones, each zone being used at different times of the year and for different purposes. The four zones are shown in Figure 1: the large green area, split down the middle by the long yellow area, an orange area, and the red zone. The red zone is the continuous use zone; an area used all year round by the military.

Figure 1 also shows the current (as of June 2018) South Australian Exploration Licences (ELs) in blue. ELs are held in all portions of the WPA except the red zone. The world-class Olympic Dam deposit sits to the east of the WPA. The geology under the WPA is therefore important in understanding the prospectivity of the wider area.

To help stimulate exploration – and ultimately the South Australian economy – the SA Government has been proactive in acquiring ground and airborne geophysical data over the entire WPA, including the red zone. The Gawler Craton Airborne Survey (GCAS) is touted as the world's largest airborne geophysical survey run by a government agency. Over 1.6 million line km of magnetic, radiometric and laser DEM data are being acquired over the region at 200 m line spacing. The figure shows the extent of the survey, covering much of the WPA.

In 2013 the SA Government contracted Daishsat Geodetic Surveyors to undertake a helicopter-assisted ground gravity survey in the central-north-eastern WPA. This survey acquired gravity readings at 2 km spacing in the red zone with 2 km, and 1 km spacing over many of the major mines in the area, including Prominent Hill, Cairn Hill, and Peculiar Knob. Figure 1 shows the extent of the survey. These surveys, as well as the Australia-wide AusLAMP magnetotelluric survey (see below) are a vital part in unlocking the mineral wealth under the WPA.

In early 2018, the Federal Government announced it intended to undertake a Review of the WPA Coexistence Framework, which triggered the establishing of the WPA Review Team. The Team is being led by Dr Gordon de Brouwer, former Secretary of the Commonwealth Department for Environment and Energy (2013–2017) and is supported by a Review Team composed mostly of officials from the Department of Defence and Department of Industry,

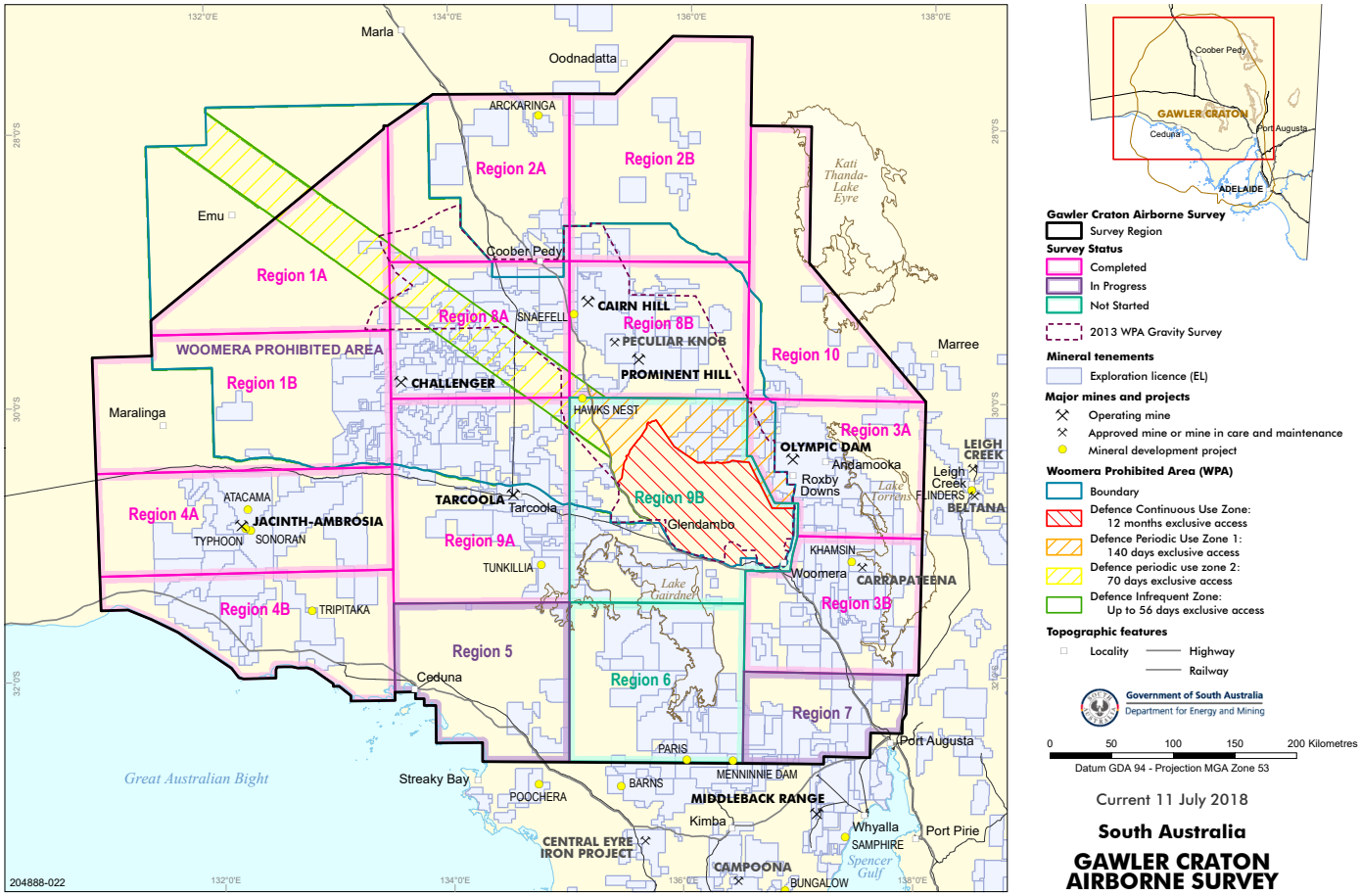

Figure 1. *Map showing the location of the Woomera Prohibited Area (WPA), major mines and projects, current Exploration Licences (ELs) and the status of Gawler Craton airborne surveys.*

Innovation and Science. Mark Carroll, First Assistant Secretary seconded from the Department of Home Affairs, heads the Review Team. Dr Paul Heithersay and Richard Price (Defence SA CE) have also met with the WPA Review's Commonwealth Interdepartmental Steering Group. The Steering Group is composed of deputy-secretary level reps from Air Force and Commonwealth Departments for Defence, Industry, Foreign Affairs, Home Affairs, and Prime Minister and Cabinet.

Cathy Lacar, Senior Project & Policy Officer of the Mineral Tenements and Exploration Branch has played an important role helping to coordinate the information sessions for State Government agencies. As project coordinator/lead, Cathy is also responsible for keeping Pru Freeman, Paul Heithersay and Defence SA up to date with all the activities of the Review Team particularly with the regional stakeholder consultations currently underway.

The Review aims to deliver a contemporary coexistence framework that maintains the primacy of Defence use of the WPA while maximising its significant value to South Australia's resources sector, pastoral operations, Aboriginal communities, and other stakeholders. The Review includes an extensive consultation and regional meetings with all WPA stakeholders throughout May until July, and a public submission process through the Commonwealth Department of Industry, Innovation and Science Consultation Hub.

Full details of the review of the WPA Coexistence Framework, including contacts, can be found online: http://minerals.statedevelopment.sa.gov.au/land_access/defence_land/woomera_prohibited_area.

Phillip Heath
Geological Survey of South Australia
Philip.Heath@sa.gov.au

New magnetotelluric surveys in South Australia

The Olympic Domain broadband and audio magnetotelluric (MT) in-fill survey completed data acquisition end of June 2018. The array of 320 MT stations have been collected across the Stuart Shelf, covering prospects such as Carapateena, Emmie Bluff, Red Lake, Punt Hill and Maslin. The array covers an area of ~100 km with site spacing ranging from 1.5 km – 8 km (Figure 1). Data processing is in its final stages, and preliminary models will be presented at the Australian Geoscience Council Convention in Adelaide in October this year. Data release will occur to coincide with the Geological Survey of South Australia's Discovery Day, to be held at the Adelaide Convention Centre on 6 December 2018.

In addition, the AusLAMP program in South Australia is very close to completion, with a further 23 long-period MT stations collected across the Musgrave Province in northwest South Australia in June (Figure 2). This brings the total number of long-period magnetotelluric AusLAMP sites close to 400 in South Australia. We anticipate having the AusLAMP data publically available on SARIG by Discovery Day. Stay tuned for details about an AusLAMP workshop day later this year.

Stephan Thiel and Kate Robertson
Geological Survey of South Australia
Stephan.Thiel@sa.gov.au
Kate.Robertson2@sa.gov.au

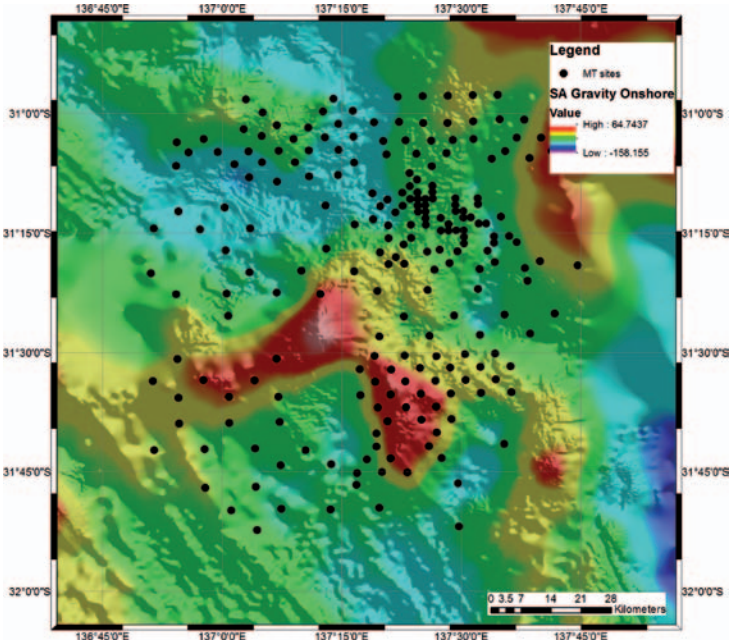

Figure 1. *Olympic Domain broadband and audio magnetotelluric (MT) in-fill survey sites.*

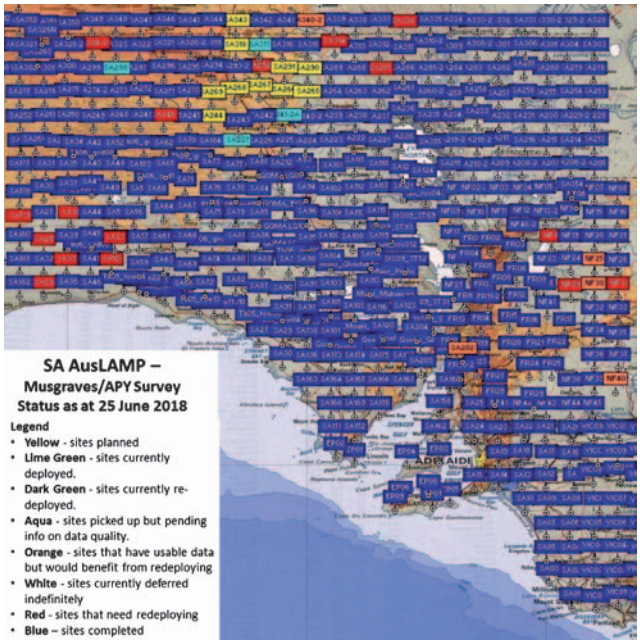

Figure 2. *South Australian AusLAMP survey status as at 25 June 2018.*

Geological Survey of New South Wales: New 3D models and statewide Seamless Geology of NSW released

The Geological Survey of New South Wales (GSNSW) has been using statewide geophysical imagery and other available data to interpret, map and model the geology of NSW. 3D modelling of the state's geology has been underway since 2014. The modelling program is developing a series of interlocking province-scale models, with a current focus on NSW sedimentary basins. The data used to generate the models includes drill-holes, seismic sections, geophysical imagery and the seamless geology geodatabase.

Most recently, the Sydney–Gunnedah 3D model has been completed and a GSNSW report published (Oliveira and Davidson, 2018). The 3D geological model for the Sydney–Gunnedah Basin (Figure 1) was created to provide insights into the sub-surface geology of the region and add detail to the consolidated cover volume created in the NSW depth to basement model (Robinson, 2017). It also delivers a geological framework for future detailed modelling, by highlighting regional and basin-scale features, mapping the geometry of geological structures under cover, and refining the stratigraphy of major units in areas with limited information. The model highlights distinct changes in sea level and depositional environment, as well as the structural architecture and fault movements experienced by the basins. The modelled features will provide context and information to support resource exploration and land-use planning.

The seamless geology of NSW will be released as a complete statewide product in August 2018 (Figure 2). The seamless geology geodatabase is a compilation of the best available geological mapping in an internally consistent format and was generated using many disparate datasets, including geophysical imagery. The methodology of the Seamless Geology can be found in Phillips et al. (2015).

Geophysical images were used to check geological boundaries and map faults and stratigraphy under cover. NSW has excellent coverage of magnetic, radioelement and gravity data, all available to the public via MinView (https://minview.geoscience.nsw.gov.au). Approximately 88% of the state has been covered at 400 m line spacing or closer with airborne magnetic and radiometric surveys. About 73% of the state is covered by 4 × 4 km or closer gravity stations.

The geophysical images primarily used in the interpretation of the seamless geology were the merged statewide products:

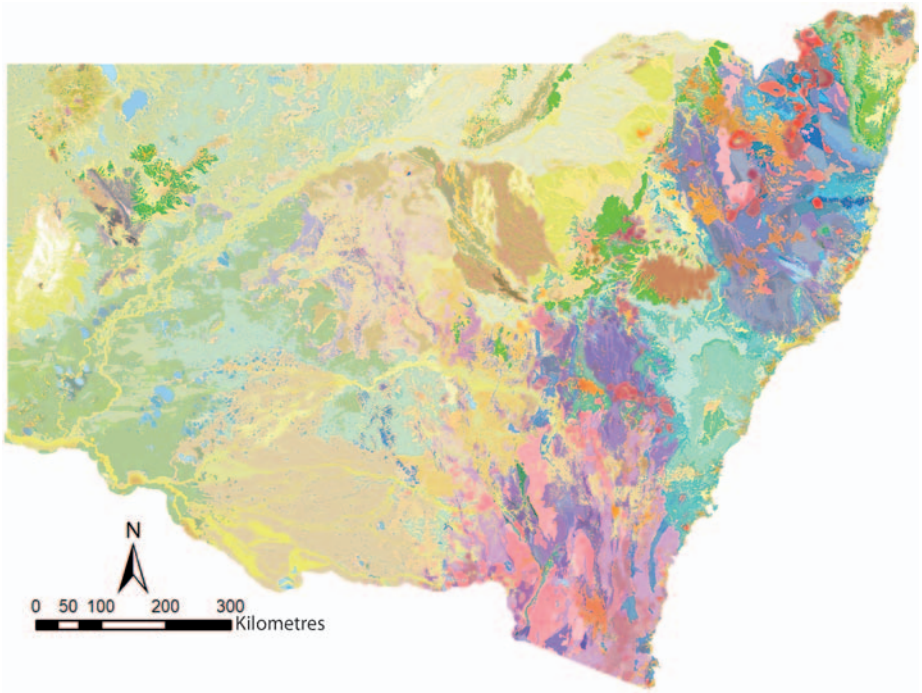

Figure 2. *Statewide seamless geology of NSW.*

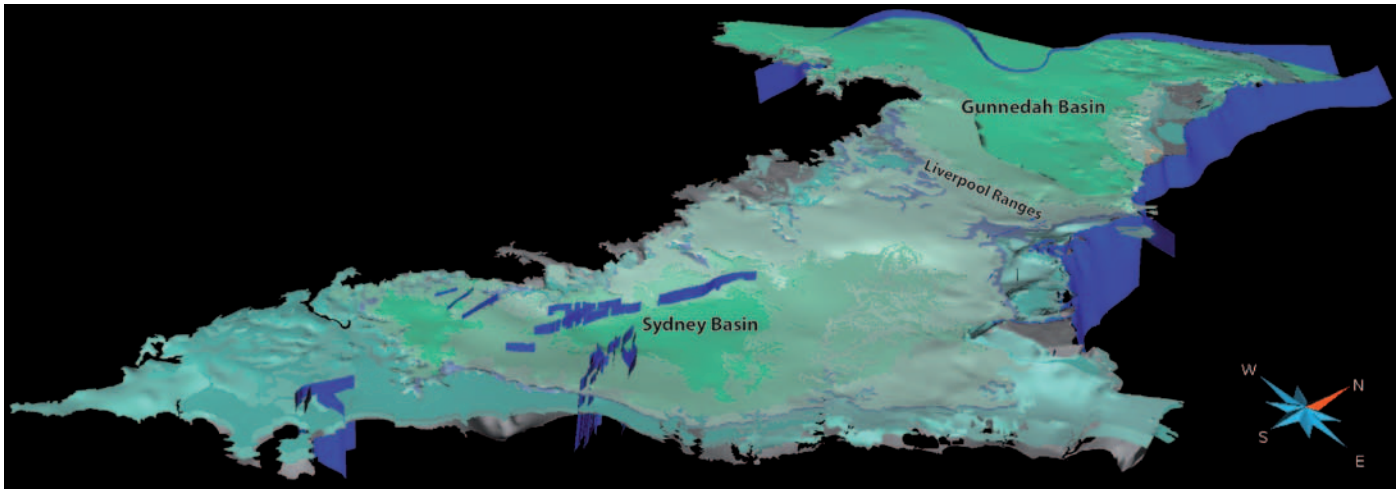

Figure 1. *Location and extent of the Sydney–Gunnedah Basin 3D geological model. The geological layer is an extract of the GSNSW Seamless Geology Zone 56 map (Colquhoun et al., 2015), with overlying cover removed. The 3D model is based on the outcropping portion of this map.*

- greyscale 1VD TMI RTP image for crystalline basement interpretation
- K Th U ternary radioelement image for Cenozoic soil related units and near surface intrusions
- pseudocolour isostatic gravity for deeper basins
- semi-transparent pseudocolour isostatic gravity image over greyscale tilt-filtered TMI RTP image
- semi-transparent pseudocolour TMI RTP image over greyscale tilt-filtered TMI RTP.

Fine geological detail was mapped using smaller images generated from statewide magnetic, radioelement and gravity grids. The statewide grids have been clipped to each standard 1:250 000 map sheet area. Each 250k grid has its own colour stretch applied to best enhance subtle geophysical features not readily visible in the statewide images. The 250k sheet clipped images can also be downloaded from MinView.

Another product recently developed as part of the 3D mapping of NSW is a 3D model of the structural architecture of the Eastern Lachlan Orogen. This research project adopted a multidisciplinary approach and used integrated analysis of surface mapping, seamless geology, drilling data, gravity and magnetic data, existing 2D forward models, and reflection seismic profiles. The model comprises a series of 3D surfaces, 2D derivative maps and modelled cross-sections.

The 3D model highlights the regional fault architecture and delivers a geological framework for future detailed modelling. The project contributes to advances in the understanding of the crustal nature, tectonic setting and geodynamic evolution of the Eastern Lachlan region.

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Ned Stolz
Geological Survey of New South Wales
ned.stolz@planning.nsw.gov.au

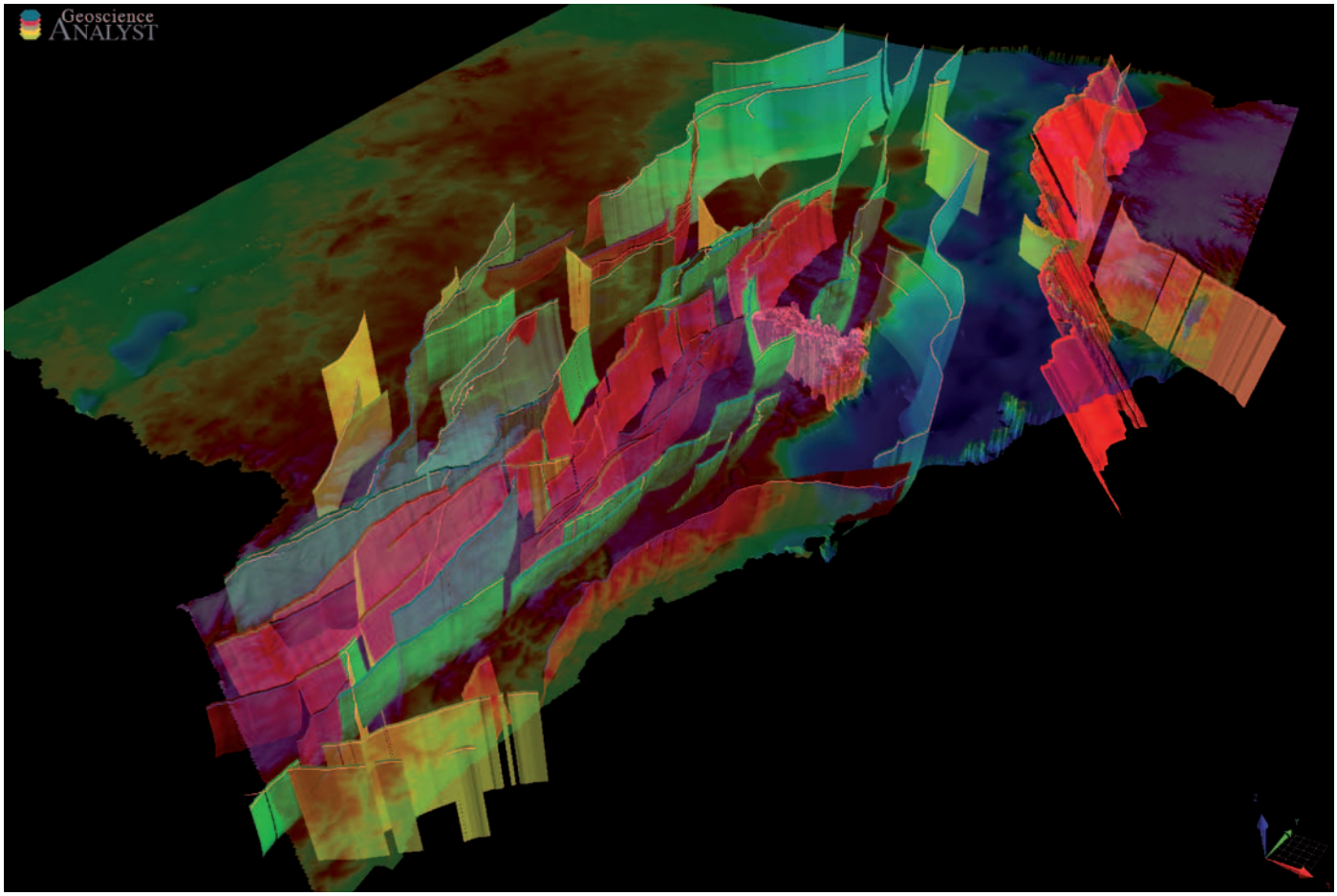

Figure 3. *3D fault model of the Eastern Lachlan Orogen with the statewide depth to basement in the background, from Geoscience Analyst©. The green arrow indicates north.*

Canberra observed

David Denham AM
Associate Editor for Government
denham1@iinet.net.au

New sea-floor data released from MH370 search area

Geoscience Australia has released the sea-floor data collected during the second phase of the search for missing Malaysia Airlines flight MH370. See: http://www.ga.gov.au/news-events/news/latest-news/the-data-behind-the-search-for-mh370-phase-two-data-released.

The search for MH370 involved collecting large amounts of data in a remote part of the southern Indian Ocean (see Figure 1). It was conducted in two phases – the first phase was a survey to collect bathymetry data to develop maps of the sea floor topography in the search area. These maps were then used to safely guide the second phase of the search – underwater.

Phase One data were released in July 2017, and Phase Two were released in June 2018.

As we all know the missing aircraft was not located within the 120 000 km^2 underwater search area, and in January 2017 the search was suspended until 'further credible evidence is available that identifies the specific location of the aircraft'.

The Phase Two data were collected using sidescan and multibeam sonar mounted on towed and autonomous underwater vehicles. During the search, points of interest were identified and investigated in more detail (see Figure 2). An underwater vehicle descended to each of these locations, where higher resolution sonar, photographic or video imagery was acquired to identify the features. This imagery revealed geological features

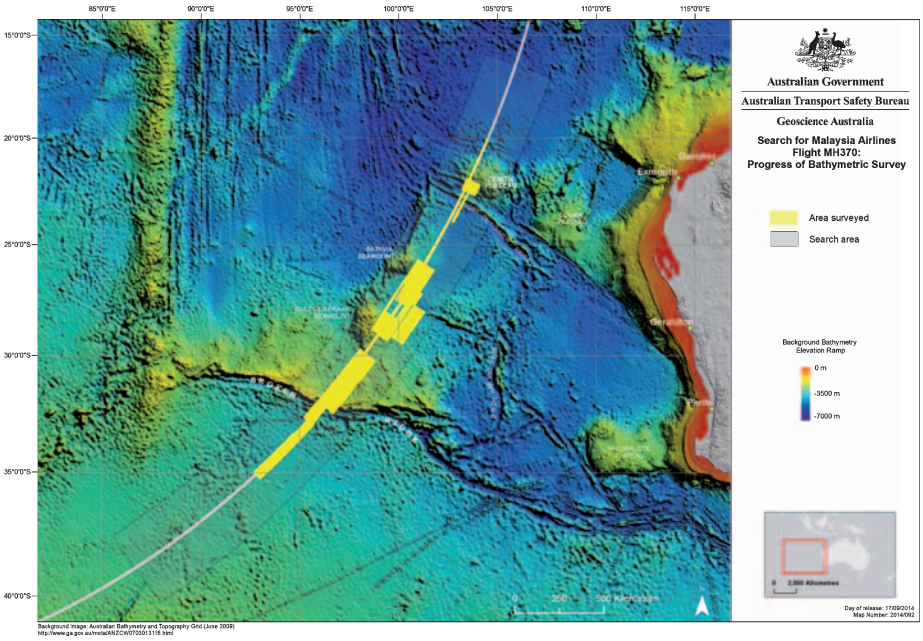

Figure 1. *Search area for MH370 shown in yellow. Source: https://www.atsb.gov.au/mh370-pages/the-search/maps/.*

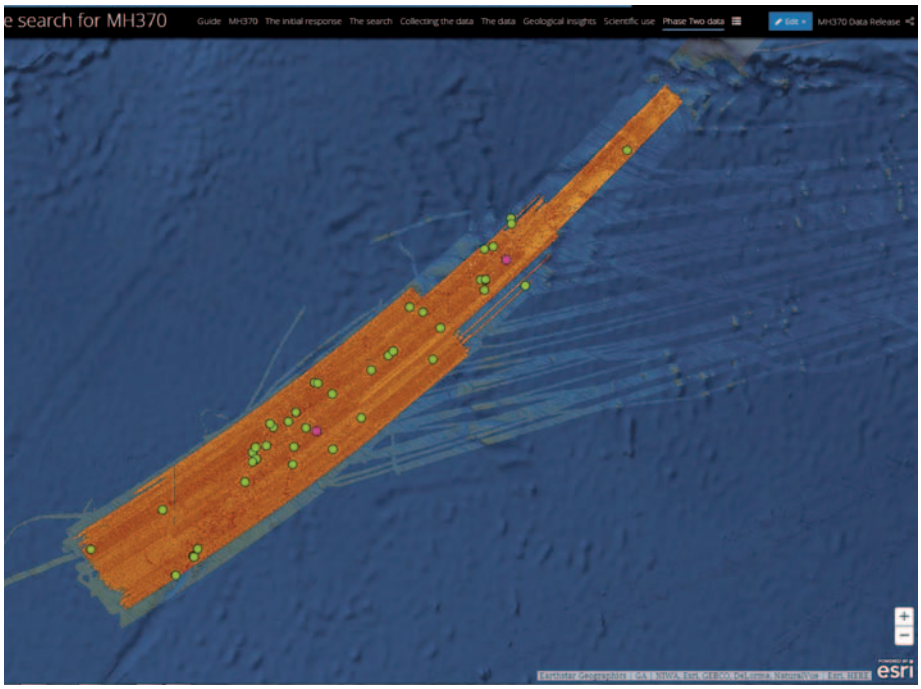

Figure 2. *Sites selected for sidescan and multibeam sonar data in the search for MH370. The green circles were sites of interest but unlikely to be significant in the search. The red circles were on high interest and warranted further investigation. Image provided courtesy of Geoscience Australia, see: https://www.atsb.gov.au/mh370-pages/the-search/maps/.*

of the ocean floor, and a range of items including whale bones and the remains of several ship wrecks.

Although the search for the aircraft was unsuccessful, the Phase One data show the sea floor in never-before-seen detail, revealing ridges 6 km wide and 15 km long that rise 1500 m above the sea floor, and fault valleys 1200 m deep and 5 km wide.

Together, these datasets contribute to a greater understanding of the geology beneath the deep ocean and the complex processes that occurred there. Geoscience

Australia has produced *an interactive story map about the search for MH370, exploring the data that has been collected.*

Figures 3 and 4 show the before and after images for the sea floor and more detail obtained over the Diamantina fracture zone.

The following URL makes compelling viewing: https://geoscience-au.maps.arcgis.com/apps/Cascade/index.html?appid=038a72439bfa4d28b3dde81cc6ff3214.

It is possible to watch the whole story of the search for MH370 evolve, starting with flight paths of the aircraft and finishing with shipwrecks on the floor of the Indian Ocean – and you can appreciate the difficulty of finding the missing aircraft in such a vast rugged terrain.

Geoscience Australia has done a wonderful job in carrying out this work and in making the data sets available.

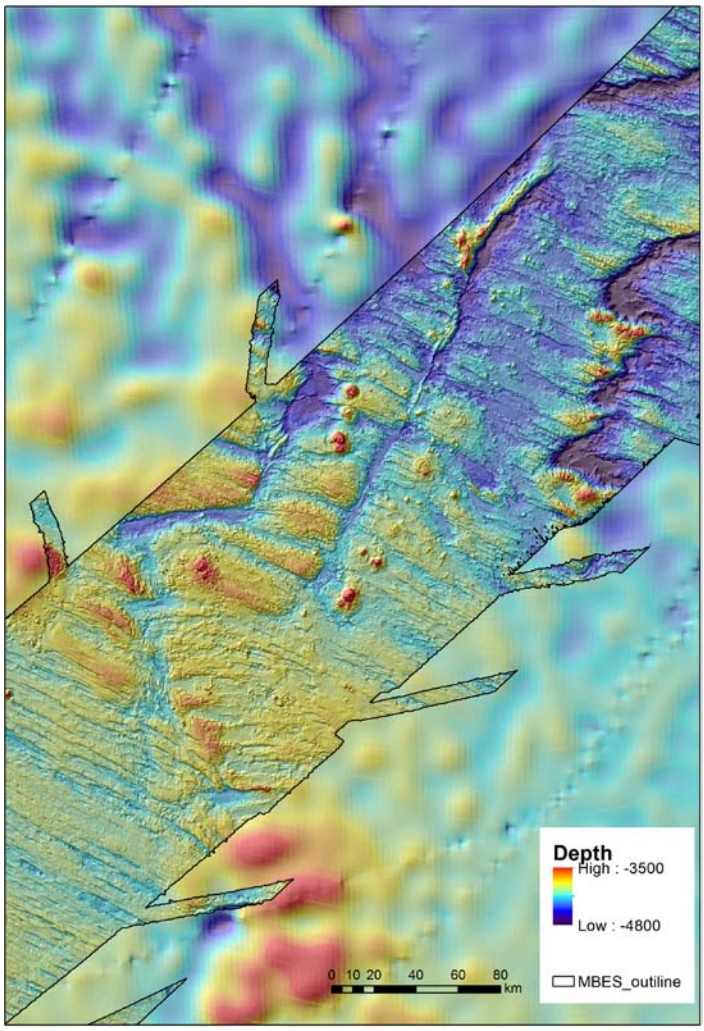

Figure 3. *Before and after MH370 data. The image shows the difference between the Phase One data and the data that existed before the search for MH370. The Phase One bathymetric data is seen through the middle of the image, compared to the satellite-derived data that was available before the search. Image provided courtesy of Geoscience Australia.*

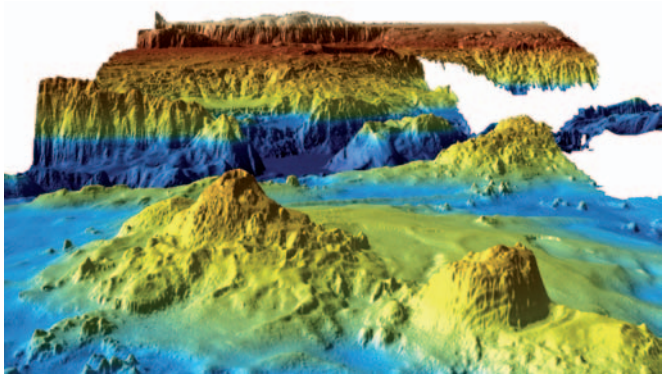

Figure 4. *Diamantina Fracture Zone: A 3D image of the bathymetry looking northeast into the Diamantina Escarpment. Image provided courtesy of Geoscience Australia.*

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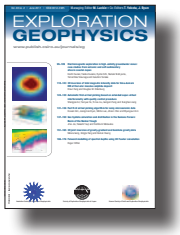

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A national disgrace: the decline continues in government investment in R&D

According to a report released on 6 July 2018 by the Australian Bureau of Statistics, the government investment in R&D decreased by 2% between 2014–15 and 2016–17 (http://www.abs.gov.au/ausstats/abs@.nsf/mf/8109.0). The ABS, unlike similar agencies in other OECD countries, only analyses these parameters every two years. Presumably because of resource constraints.

During the 2016–17 financial year, expenditure on R&D by Australian government organisations was $3279 million. Commonwealth government organisations contributed $2139 million (65%), and state and territory government organisations $1140 million (35%). Figure 1 shows the breakdown of these numbers for the period 1992–2017.

The most disturbing aspect of these numbers is the steep decline in investment, as a proportion of Gross Domestic Product (GDP), during the last four years; from 0.24% in 2012–13 to 0.19% in 2016–17. As you can see, this parameter peaked in 2008–09 and has declined ever since. A very unfortunate trend, to say the least. Some commentators hoped that with Malcolm Turnbull replacing Tony Abbott in September 2015 the trend would be reversed, but this has not happened.

As the then OECD Secretary-General Angel Gurría said in 2016, when he launched the OECD's 2015, Science, Technology and Industry Scoreboard in Korea:

'Public funding has underpinned many of the technologies driving growth today, from the digital economy to genomics. We must continue to lay the technological foundations for new inventions and solutions to global challenges like climate change and ageing and must not let investment in long-term research wane'. (http://www.oecd.org/newsroom/governments-must-step-up-rd-in-frontier-technology.htm).

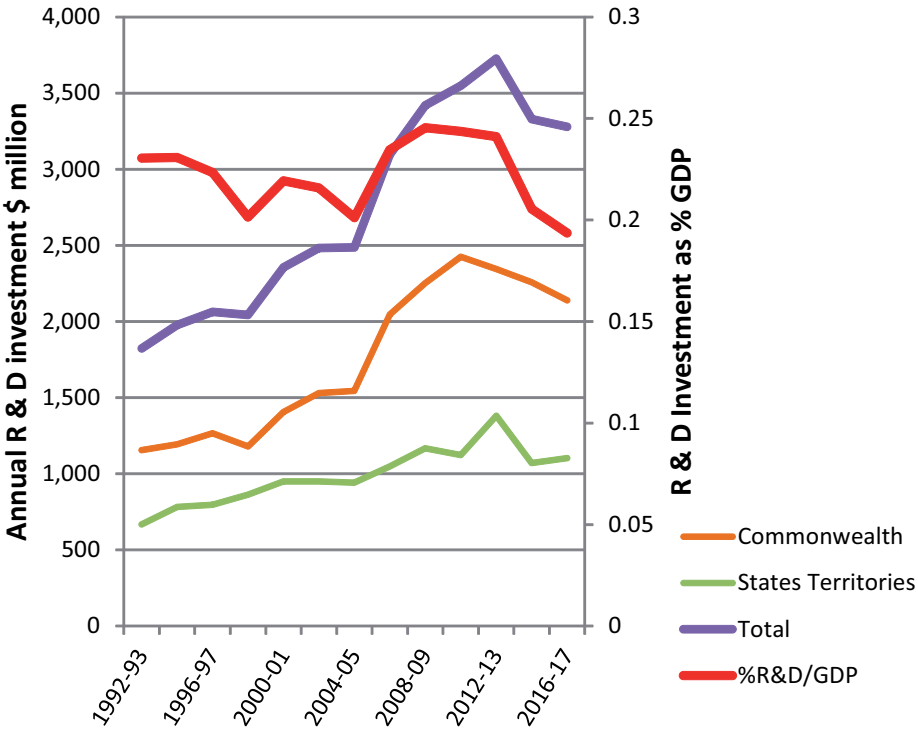


Figure 1. *Government investment in R & D from 1992–2017. The red curve shows the investment as a percentage of GDP. Notice that this peaked in 2008–09 and has declined ever since. Source: http://www.abs.gov.au/ausstats/abs@.nsf/mf/8109.0.*

This statement is still true today. And while we need a strong business R&D effort for the shorter-term challenges, we need governments to fund the longer term basic research and maintain the national data bases. That is why agencies such as the Australian Bureau of Statistics, Geoscience Australia, CSIRO and the Bureau of Meteorology should have their funding allocation coupled to GDP and not be part of the death-by-a-thousand-cuts inflicted annually to all government departments and agencies.

We do not want to be left behind as a nation of baristas, cooks and house-maids relying on tourists visiting the largest island resort on the planet or, as a nation of quarry-operators exporting the most basic of raw materials to the rest of the world.

Hot off the press: A paper by Graham Heinson, Yohannes Didana, Paul Soefy, Stephan Thiel and Tom Wise has just been published in *Nature's* Scientific Reports. The paper is called 'The crustal geophysical signature of a world-class magmatic mineral system' and reports on the use of magnetotellurics to image the fluid delivery pathways of the Olympic Dam mineral system. This work was proudly supported by the ASEG Research Foundation. Take a look for yourself, https://www.nature.com/articles/s41598-018-29016-2.pdf.

Education matters

Michael Asten
Associate Editor for Education matters
michael.asten@monash.edu

In this issue of *Preview* it is my privilege to introduce an article by Professor Dietmar Müller and Associate Professor Patrice Rey and their team, bringing us an overview of work in progress by the Basin GENESIS Hub at the University of Sydney on plate tectonics and the evolution of sedimentary basins. There is an interesting historical antecedent here; in the 1930s it was a University of Sydney student, Sam Carey, who developed a fascination with the concept of continental drift, and completed a PhD and DSc on tectonics of the Sydney Basin and basins of Papua New Guinea. His fascination with geology was interrupted by war service as a commando (1942–45) but, from the start of his appointment as Professor of Geology at the University of Tasmania in 1946, he was a powerful advocate for continental drift for two decades, a time when 'drift' was a derided concept in geosciences of the western world. The theory of plate tectonics became respectable in the academic world during the 1960s.

Professor Carey's trademark was to teach his students to question published work (even that of supervisors!), and if he were to look down at his old Department in Sydney from wherever he may be now, he would nod with approval, and remind today's students of his favourite motto regarding established scientific wisdom, 'disbelieve if you can'.

Carey was famous in the 1950s for deforming plastic sheets in boiling water to create earth-shell segments for tracing and moving continental margins on a globe. Researchers of the Hub may be remembered in 2080 for their use of super-computers available within the National Computational Infrastructure. We can't guess what advances the five post-doc researchers who contributed to this article will see in the next 60 years, but we wish them well in a branch of geoscience that progresses as much by iconoclastic change as by evolution.

The ARC Basin GENESIS Hub: connecting solid Earth evolution to sedimentary basins

Dietmar Müller[1], Patrice Rey[1], Romain Beucher[2], John Cannon[1], Rohitash Chandra[1], Claire Mallard[1], Sara Morón[2] and Sabin Zahirovic[1]

[1]EarthByte Group, School of Geosciences, The University of Sydney

[2]School of Earth Sciences, The University of Melbourne

Dietmar Müller (right) and Patrice Rey (left).

dietmar.muller@sydney.edu.au
patrice.rey@sydney.edu.au

The ARC Basin GENESIS Hub (BGH) is a 5-year Industry Transformation Research Hub supported by the Australian Research Council (ARC) and 5 industry partners, aimed at developing and applying next generation computer models to fine-tune our understanding of the structure and evolution of sedimentary basins. The Hub is based at the University of Sydney's EarthByte research group (www.earthbyte.org), led by Dietmar Müller and Patrice Rey, with additional nodes at the University of Melbourne (led by Louis Moresi), Curtin University (led by Chris Elders), the California Institute of Technology (led by Michael Gurnis) and Geoscience Australia (led by Karol Czarnota). The Hub's unique strength is in connecting global plate tectonic and geodynamic models to models of the evolution of individual basins and their hinterlands. This requires linking disparate geological and geophysical data sets with several simulations and modelling codes and their outputs. A central theme in the Hub is understanding the origin, and destruction, of topography. Surface topography represents the source of sediments that ultimately end up in sedimentary basins. Therefore, we are trying to understand how surface topography or accommodation space is created or destroyed via combinations of lithospheric deformation, mantle convection, erosion and sedimentation, constrained by a range of observations. This article portrays the software and new basin modelling workflows being developed in this research centre, with particular emphasis on the Hub's early career researchers.

For this, we first need well-constrained solid Earth models, driven by mantle and plate tectonic processes. The global tectonic reconstructions created in our EarthByte group are a key to understanding this system. The basic rules of plate tectonics theory, first defined formally in the 1970s, describe first order surface lithospheric motions, but these rules are mostly kinematic and do not explain the time-dependent interaction between the convecting mantle and the tectonic plates. As a consequence, the increasing uncertainties in the geological record back in time make it difficult to constrain plate reconstructions before Pangea breakup.

One way to deal with these uncertainty estimates is to better understand the physics behind plate motions. Although it is generally agreed that convection in the mantle and plate motions are inextricably

interconnected, the relationships between deep Earth dynamics and surface tectonics are still poorly understood. To make progress in this direction, BGH research fellow Claire Mallard uses recently-developed fully-dynamic global models using the code StagYY (https://github.com/the-life-tectonic/xsede/wiki/StagYY), which self-consistently generate Earth-like mantle currents together with plate-like surface tectonics. The virtual planets produced this way (Figure 1) provide access to a range of different evolving parameters representing plate-mantle evolution (Mallard et al., 2016).

Claire Mallard.

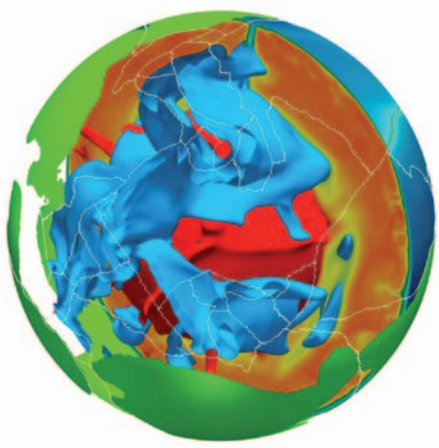


Figure 1. *Mantle temperature field and surface expression (in white) of a fully dynamic convection model, highlighting modelled plate boundaries. The Earth's interior shows hot up-wellings in red and sinking slabs in blue. At the surface, continents are shaded green.*

We are now able to qualitatively and quantitatively compare these virtual planet computations, such as their plate boundary evolution and reorganization, and estimate dynamic topography resulting from mantle flow, applying the rules of plate tectonics and geological observations. For instance, the definition and number of plates, as well as the length and evolution of past subduction zones, in the tectonic reconstruction is biased, and implies an increasing uncertainty of dynamic topography estimates deeper in geological time.

Our development of the open-source and cross-platform GPlates plate reconstruction software (Müller et al., 2018) is the enabling engine of our efforts to build and improve global plate tectonic reconstructions that we also share with the community. These plate reconstructions are typically constructed using a synthesis of continental geological constraints (e.g. palaeomagnetic, sedimentary/fossil evidence of prior tectonic affinity, metamorphic/volcanic chronologies, etc.) and marine magnetic anomalies and fracture zones (where they are preserved). To better understand the influence of the deep Earth on surface processes, we use our plate tectonic reconstructions as surface constraints for numerical models of mantle convection, using the well-established CitcomS code (https://geodynamics.org/cig/software/citcoms/). Recently, the capability to deform plates has also been added to GPlates (Gurnis et al., 2018), allowing us to use deforming plates as surface boundary conditions for geodynamic models and in basin modelling.

Sabin Zahirovic.

Our evolving 4D solid Earth models help us track the evolution of the mantle, as well as how convection influences vertical motions of the Earth's surface. All geologists are well-versed in tectonic topography (mountain-building in collisional settings, basin formation during rifting, etc.), but the role of the convective mantle in shaping regional topographic signals has been somewhat under-appreciated. A key observation is that plates move across different mantle domains, and so the dynamic topography acting on continents (and the basins they host) changes through time. For example, Australia's northward motion towards Southeast Asia in the last 50 million years has resulted in the northern margin of the continent overriding subducted slabs from Asia and the Pacific, leading to broad subsidence of the Arafura Shelf and New Guinea, leading to north-eastward tilting of the Australian continent at present-day. In addition, dynamic topography likely dominated the regional uplift of Southeast Asia in the Eocene, which was followed by broad regional subsidence towards the present, despite falling long-term sea levels. However, the influence from mantle flow is superimposed by tectonic and flexural topography in such complex regions, and work is under way to better quantify the relative roles of these signals. These global models, applied to the Southeast Asian and Papua New Guinea regions by Sabin Zahirovic and his students and collaborators (Figure 2), are an essential component of the infrastructure that helps track basin evolution across a wide range of spatio-temporal scales. More importantly, these modelling approaches help us better understand global and regional tectonics, as well as help us link global mantle flow to surface processes in frontier basin exploration areas.

GPlates is designed to visualize the outputs of mantle convection models with plate reconstructions and observational data attached to moving plates. To achieve this we had to explore and prototype various ways to render 2D raster data and 3D volume data with past configurations of tectonic plates, an effort led by John Cannon, the GPlates lead developer whose previous experience with graphics programming in the computer games industry comes in handy. Eventually we adopted an approach based on so-called hierarchical cube maps, accelerated by GPU graphics hardware. The cube map approach combined with a programmable ray-tracing capability of modern graphics hardware can be used to visualize arbitrary 3D geophysical data and geodynamic model outputs (Figure 2) together with plate reconstructions (Müller et al., 2018).

John Cannon.

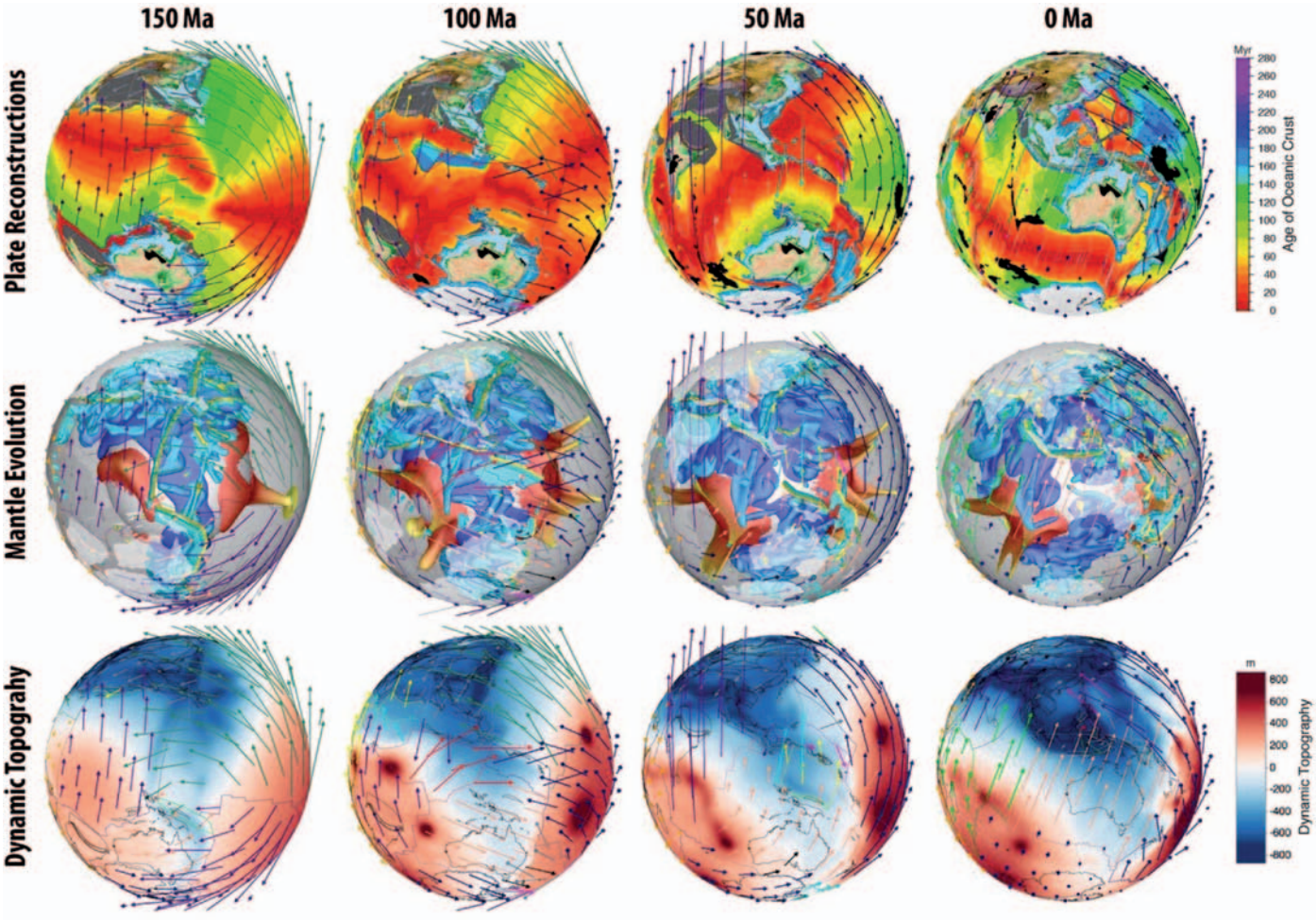


Figure 2. *Global plate tectonic reconstructions since the Jurassic in GPlates (www.gplates.org) (Zahirovic et al., 2016) with an Orthographic view of the Tethyan-Indian Ocean region. The plate motions (top row) from GPlates are used as surface boundary conditions for mantle convection models (middle row) in the CitcomS code, which help us estimate the dynamic topography (bottom row) acting on continental and oceanic basins as a result of mantle flow. This spatially- and temporally-evolving dynamic topography is typically regional in scale, with an amplitude of only several hundred metres, but is crucial in explaining the inundation or emergence of continents that may be out of sync with eustasy, as well as helping understand anomalous basin subsidence and uplift.*

Tristan Salles.

Our surface process models, driven by tectonic forcing of topography via mantle convection and plate deformation using the Badlands software (https://github.com/badlands-model/pyBadlands) (Salles, 2016), depend on a range of uncertain driving forces that we are exploring by experimenting with a range of input parameters (Figure 3). For instance, the erodibility coefficient of rocks at the surface is not well known and needs to be determined empirically, while the total uplift or subsidence rates through time are equally ill-constrained. Therefore, we run numerous forward models exploring parameter combinations to find the best-fit models constraining erosion and sediment accumulation (Figure 4).

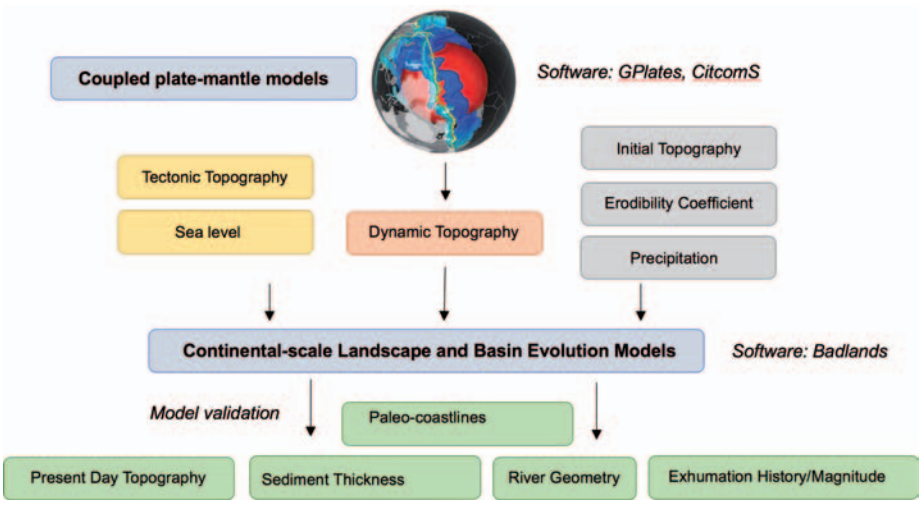


Figure 3. *Workflow to link geological and geophysical data to landscape and basin evolution models, constrained by tectonic and dynamic topography modelled via coupled plate-mantle geodynamic models.*

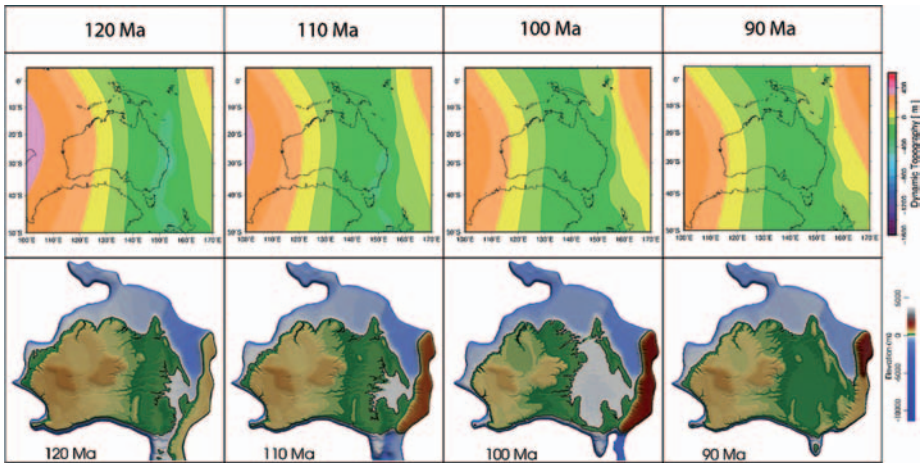


Figure 4. *Influence of change in mantle convection-driven dynamic topography (top row) on the transgression and regression of the Eromanga Sea from 120 to 90 Ma in the Cretaceous (Harrington et al., 2017). As Australia moves eastwards during this time period (not shown here) it overrides the East Gondwanaland "slab burial ground" drawing down eastern Australia and causing extensive flooding long before the Late Cretaceous global sea level high. Subduction becomes extinct around 100 Ma, resulting in slab material progressively sinking into the lower mantle, dimishing its effect on the surface, causing topographic rebound. Our Badlands surface process models can be used assess the effect of this westward wave of dynamic subsidence on landscape evolution. We can model the evolution of sediment fill in the Eromanga Basin, followed by uplift and exhumation after retreat of Australia's epicontinental sea. How deep Earth and surface processes interact, depends also on the interplay between rock erodibility, precipitation and global sea level change through time.*

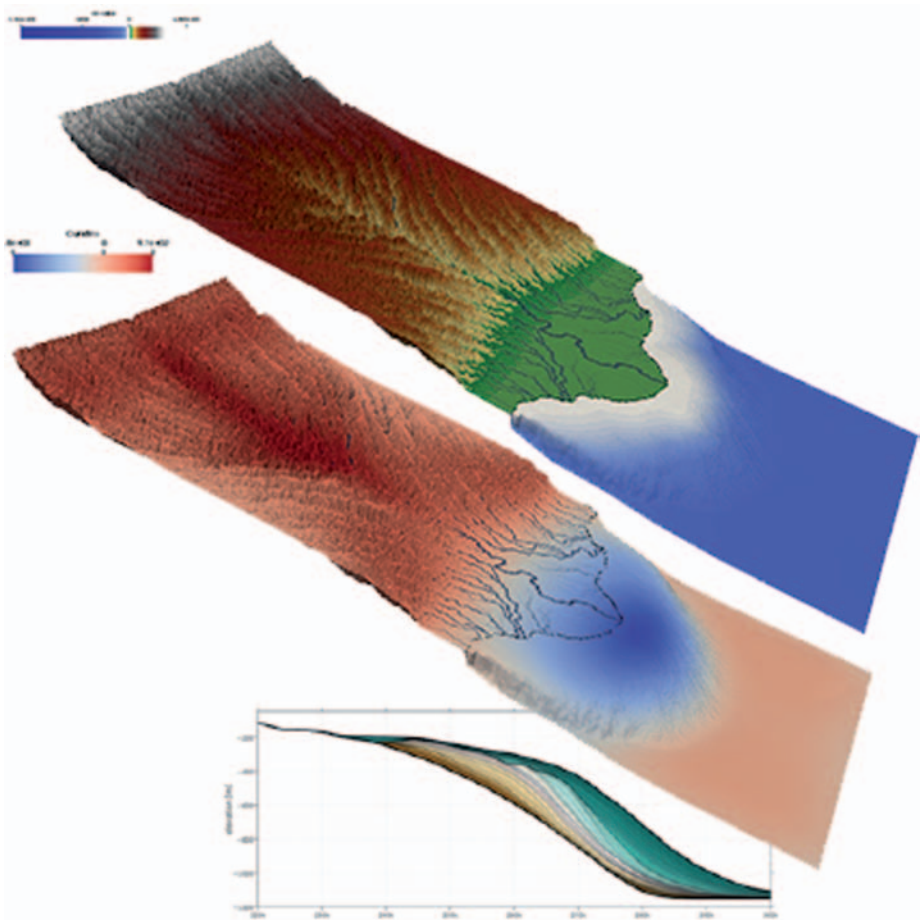


Figure 5. *Output of cutting-edge deltaic simulations generated in Badlands showing elevation and bathymetry, cumulative flexure and synthetic stratigraphy. Simulations are used to better understand the first-order controls that generate the sedimentary patterns we observe in ancient deltas. Improvements in understanding of fluvio-deltaic sequences are needed to unlock the vast amounts of hydrocarbons hosted in these types of reservoirs.*

These models have been applied to understand the interplay of the formation and disappearance of the Cretaceous Eromanga Sea and the subsequent uplift of the eastern highlands of Australia (Salles et al., 2017).

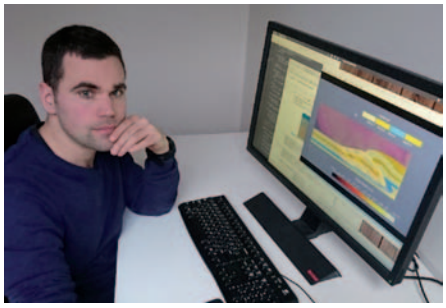
A particular emphasis of the Hub is the development of detailed models of the formation, preservation, and economic significance of deltas. Significant resources such as hydrocarbons and water are accumulated in deltaic deposits; prime examples are the Ceduna and Mungaroo deltas in Australia and the Paleo-Mississippi in the Gulf of Mexico. Improvements in understanding of fluvio-deltaic sequences are needed to unlock the vast amounts of hydrocarbons hosted in these types of reservoirs. Numerical modelling offers a cutting-edge process-based approach for unraveling controls in facies distribution and stratigraphic architecture in fluvial systems. In the Hub's team, Sara Morón uses the Badlands software to better understand the first-order controls that generate the sedimentary patterns that we observe in ancient deltas, by combining seismic, biostratigraphic, geochronological and thermos-chronological data to provide boundary conditions for our numerical simulations (Figure 5).

Sara Morón.

To formally evaluate model uncertainty, we have developed Bayeslands, which was created jointly with the recently established Centre for Translational Data Science at the University of Sydney. Bayeslands uses a Bayesian statistical framework to estimate model parameters by evaluating the outputs of thousands of forward models (Badlands) against observational data and prior knowledge. This approach, led by Rohit Chandra, has been successfully tested on simple basin models dependent on just three parameters (rock erodibility coefficient, annual rainfall and sediment thickness). This is being extended towards more complex models using high performance computing resources (https://www.earthbyte.org/bayeslands-resources/).

Rohitash Chandra.

Even though the resolution of our virtual planets allows us to better understand the mantle-lithosphere interaction processes as drivers of sedimentary basin evolution at the first order, a finer resolution is needed to capture faulting and crustal flow, as well as surface processes like river erosion and sediment transport. This additional challenge involves including our evolving understanding of mantle-lithosphere interaction in the feedback between mantle flow, crustal deformation, erosion and sediment transport at the scale of sedimentary systems. Patrice Rey, Tristan Salles, and research fellows Romain Beucher, Sara Morón, Claire Mallard and the Underworld/Badlands software teams have developed a range of different 3D thermo-mechanical models for different tectonic contexts using the Underworld (http://www.underworldcode.org/) numerical modelling framework. It is now possible to link these models with surface process models in order to model basin stratigraphy via our Badlands software (Figure 6a and Beucher et al., 2018). This 4D simulation of surface processes, enabled by a high-performance parallel computing approach, allows us investigate the effect of lithospheric rheology and extension speed/obliquity on the removal of up to several kilometres of material during rifting (Mondy et al., 2017) (Figure 6b), as well as associated sedimentary deposits. These models are starting to be applied to basins in a variety of tectonic settings around the world.



Romain Beucher.

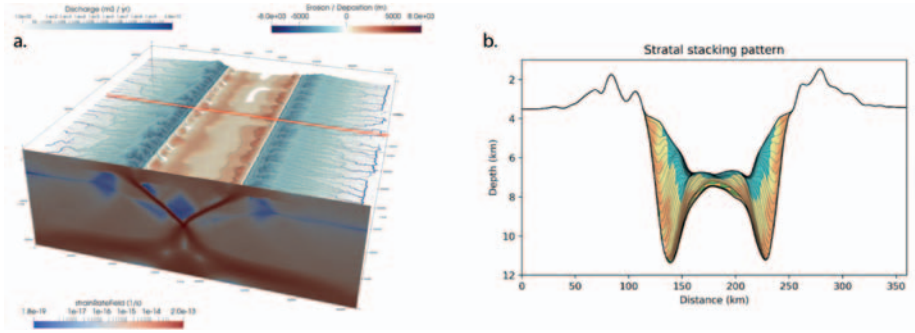


Figure 6. *Example of an Underworld thermo-mechanical model coupled with the surface process code Badlands. (a) The left panel shows a snapshot of the strain-rate in an extensional basin after 5 million years of rifting, while the surface illustrates the total erosion and sedimentation. (b) The right panel is a cross section of the stratal stacking pattern (along the red profile across the model), which can be compared to seismic reflection profiles.*

Figure 7. *Graduated and current Basin GENESIS Hub PhD students. From top left to bottom right: Xuesong Ding, Wenchao Cao, Amy I'Anson, Michael Tetley, Rhiannon Garrett, Ben Mather, Maelis Arnould, Carmen Braz, Sarah McLeod, Luke Mahoney, Amanda Thran, Omer Bodur, Luke Mondy, Nick Barnett-Moore, Andrew Merdith and Rakib Hassan.*

The Hub's PhD projects (see Figure 7 for past and current PhD students) cover a large range of spatial and temporal scales in solid Earth and surface processes. Examples include modelling syn-rift sequence stratigraphy using coupled thermos-mechanical and surface process models (Xuesong Ding), determining the role of asthenospheric flow and major plate motion speed changes on anomalous uplift and subsidence on sedimentary basins on leading and trailing edges of continents (Omer Bodur), and constraining upland erodibility in catchments delivering sediment to the Gulf of Papua (Rhiannon Garrett).

The work of these students will be described in more detail in the annual review of research by Australian students in geophysics that will appear in the December issue of *Preview*.

The Basin GENESIS Hub is enabled by the AuScope National Collaborative Research Infrastructure, Simulation project, whose Simulation and Modelling project, led by Louis Moresi, has supported software development since 2007. Another critical building block of the Hub is the Australian National Computational Infrastructure; without their high-performance computer Raijin we would not be able to execute our models. Lastly, we thank our industry partners, Statoil, Chevron, Oil Search, Intrepid Geophysics and 3D GEO, who support the development of open-source software for resource exploration. Our development of community software is a key aspect of the Hub, as it ensures that our software and workflows will

live on long after the Hub's 5-year lifetime. All end-users, including industry, are able to access our software at no cost, and an open-source philosophy allows us and a network of global collaborators to educate the next generation of exploration geoscientists who are all able to use, and be trained on, the same software, share their experiences and contribute to improving these community codes; updates on progress appear regularly on ResearchGate and the EarthByte research group page on Facebook: https: //www.facebook.com/earthbyte/.

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Environmental geophysics

Mike Hatch
Associate Editor for
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michael.hatch@adelaide.edu.au

Low induction number approximation revisited

Welcome readers to this issue's column on geophysics applied to the environment. Back in the December 2017 issue I diatribed about the use and misuse of the Low Induction Number (LIN) approximation in Terrain Conductivity Meters (TCM) like the Geonics EM31 and various other instruments like the GF Instruments CMD devices. I mentioned that there was some code that James Reid had written that corrected the LIN approximation when data were collected under conductive conditions. I then mentioned that I have been working with inverting the data, as an alternative to LIN correcting it, and that I liked the results. Well I have been working on some data provided by Andrew Telfer from Australian Water Environments (AWE), to evaluate the use of a TCM for work with the Murray Darling Basin Authority and the results of this inversion are not as good as hoped. So, in this article, I am going to present the results that bothered me, and I am hoping that someone out there has some insight as to why this isn't working as well as it seems it should.

It all started with some shallow TEM (not TCM) data that I collected in 2005 with AWE on a small section of Murray River floodplain as part of a larger project to look at strategies to rejuvenate some of the drought affected floodplains on the river. The data set was interesting as it clearly showed a conductive (salt affected) floodplain and a nice wedge of relatively resistive river water on the river bank (Figure 1 shows data collected at the same site in 2011). These data were collected using a 'standard' Zonge Engineering NanoTEM system, utilising 20 m × 20 m transmitting loops and a 5 m × 5 m centred receiving loop; data were collected at 20 m intervals along the transect. We have collected data in this area a number of times over the years.

In 2016 AWE collected data roughly along the same traverse using a GF Instruments CMD Explorer, and then collected soil and groundwater conductivity data from shallow bores at set intervals along this traverse to provide 'ground truth'. Remember that with the CMD Explorer run in the high moment mode, data are collected using vertical coaxial transmitter and receiver coils at three 'dipole' lengths to get information from approximately 2 m depth to about 7 m depth. I inverted the data using the *Aarhusinv* program (Auken et al., 2015; http://hgg.au.dk/software/aarhusinv/); in fact all of the data shown in this article were inverted using *Aarhusinv*. This program is available for academic projects, but is also the engine that drives AarhusGeoSoftware's Workbench inversion platform and is commercially available from AarhusGeoSoftware. *Aarhusinv* is very flexible, allowing, for example, the data to be inverted to produce both blocky, discrete layered inversions, as well as smooth-model inversions. Smooth model results are shown here, but I generally test both inversion styles when inverting EM data.

For the CMD data, to get as much depth information as possible, I inverted data collected from all three of the transmitter/receiver separations available. I tested inverting just the quadrature data (derived from the recorded conductivities), as well as both the quadrature and the in-phase data together. Figure 2*a* shows the results when only the quadrature data were inverted (the approach that I suspect is most often used) and Figure 2*b* shows the result when the quadrature and in-phase data were inverted together. Figure 3 shows the NanoTEM inversion for the data collected in 2011; this is the same data set as shown in Figure 1 – only the top 10 m are shown here so as to make comparison with the CMD data easier. The depth of investigation (DOI) as reported by *Aarhusinv* for the CMD data ranged from about 3.5 to 5 m for the quadrature-only results shown in Figure 2*a*, with inversion residuals that ranged from about 0.1 to 1.1 (higher values over the more complicated structure at the west end of the line). For the inversion of the in-phase and quadrature CMD data shown in Figure 2*b* the DOI's ranged from 6 to 9 m, while the inversion residuals ranged from 0.8 to 5 (again the

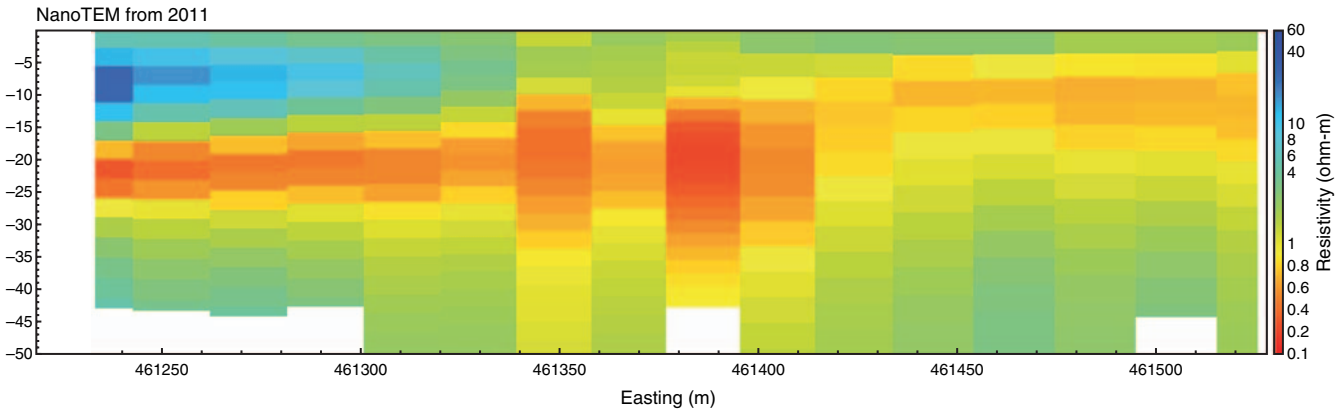

Figure 1. *Resistivity-depth section of NanoTEM data collected in 2011. These data were inverted using Aarhusinv and the whole depth range of the inversion is shown. The river (for all of these sections) is only 10 or 20 m from the left end of the plot. There is an obvious wedge of resistive fresh groundwater sitting over the more conductive, saline groundwater at that left edge of the section.*

higher residuals were observed at the river end of the line where the structure is more complicated). For the NanoTEM data, the DOIs were on the order of 25 m, and the inversion residuals ranged from 0.55 to 1.5.

Figure 4 graphically compares the results from the CMD and NanoTEM data sets at one of the sample locations near the river; the CMD and NanoTEM data are shown in units of mS/m (everywhere else the inversion results are shown in ohm-m) while the soil conductivity and groundwater data are shown as TDS (in mg/litre); this comparison of conductivity and TDS explains some of the obvious difference between the two sets of results. The explanation for differences are undoubtedly more involved than just the difference in units – Archie's Law type factors must also be in play. Interestingly, it appears that the response from the CMD is just too shallow (and looks that way when Figures 2*b* and 3 are compared as well), and assuming that the two sets of units scaled properly, the shallow TEM response appears to at least track the ground variation better. Obviously this isn't a perfect comparison as the TEM data were collected in 2011, while the CMD and ground data were collected in 2016. Nevertheless, the two data sets collected at the same time (the CMD and ground data) just don't match very well. Or am I expecting too much?

Thinking a little more about the results, part of me wants to 'like' the results when the in-phase data are included, as there appears to be more information, but I am just not sure about that, and need to keep testing that at more locations (and in different conductivity scenarios). Maybe I'm just trying to get too much out of these simple data sets and should be satisfied with the results from the quadrature- only inversions. Nevertheless, it seems to me that the quadrature-only inversion does not match the ground data

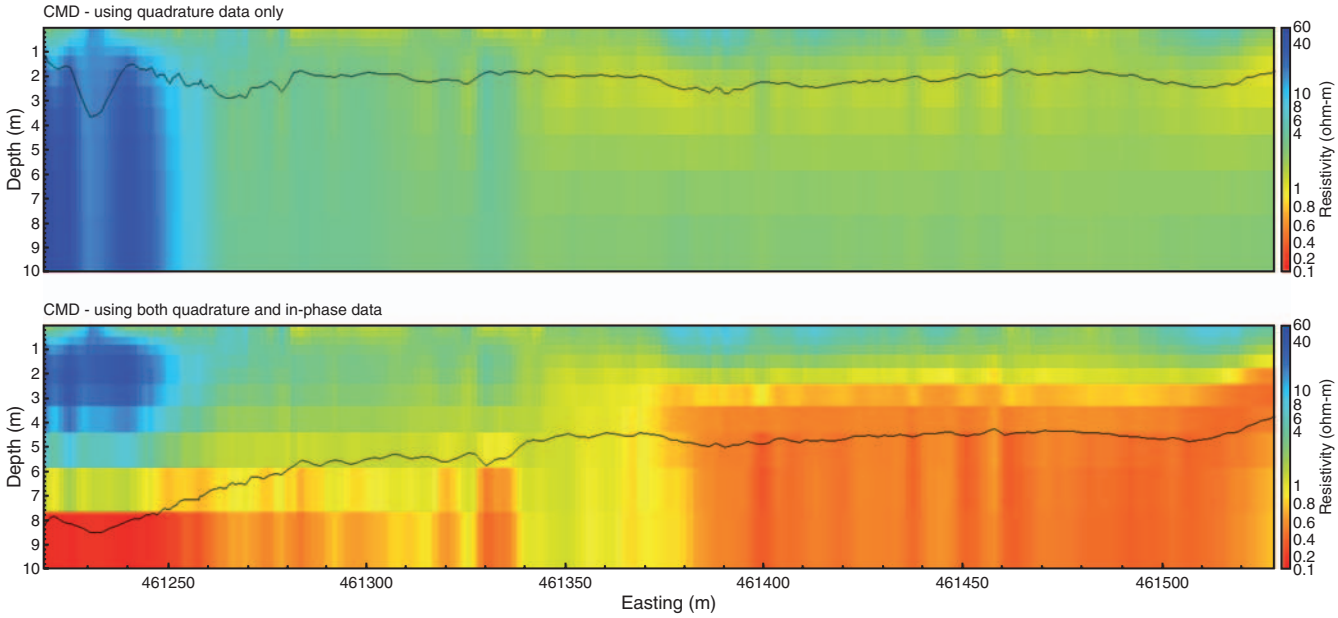

Figure 2. *Resistivity-depth sections of inverted CMD data comparing results using only quadrature data in Figure 2a, while both in-phase and quadrature data were inverted together for the results shown in Figure 2b. Note that the approximate DOI is indicated with the thin black line. The approximate location of the test bore shown in Figure 4 is indicated with the vertical black line.*

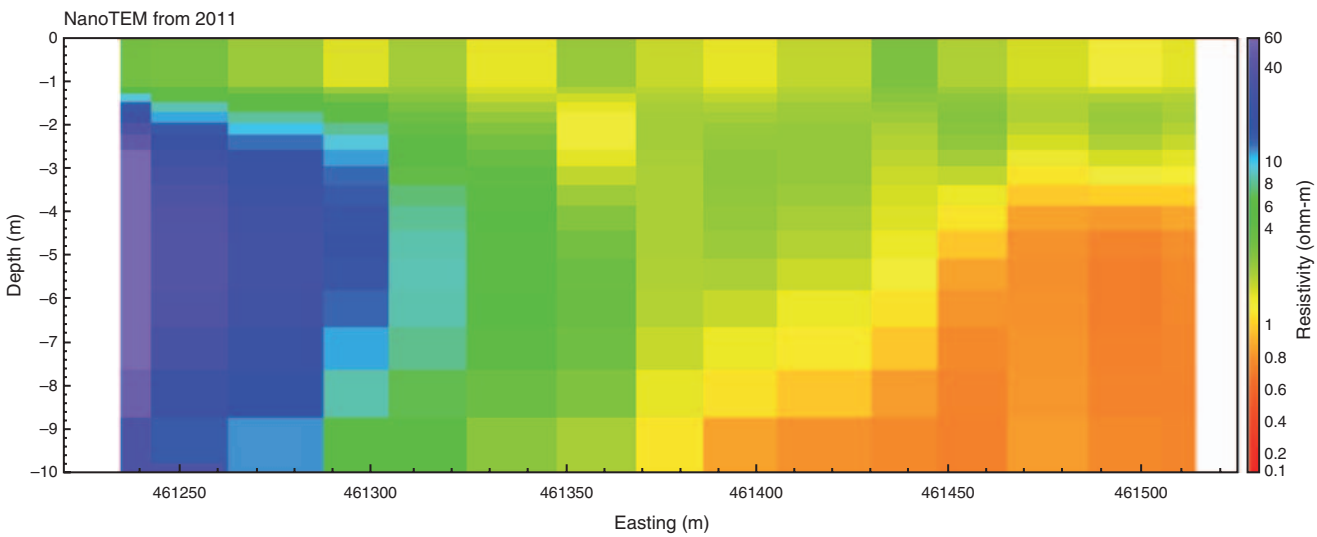

Figure 3. *This figure shows just the top 10 m of NanoTEM inversion shown in Figure 1. Note that DOI is deeper than 10 m for all stations. The approximate location of the test bore data shown in Figure 4 is indicated with the vertical black line.*

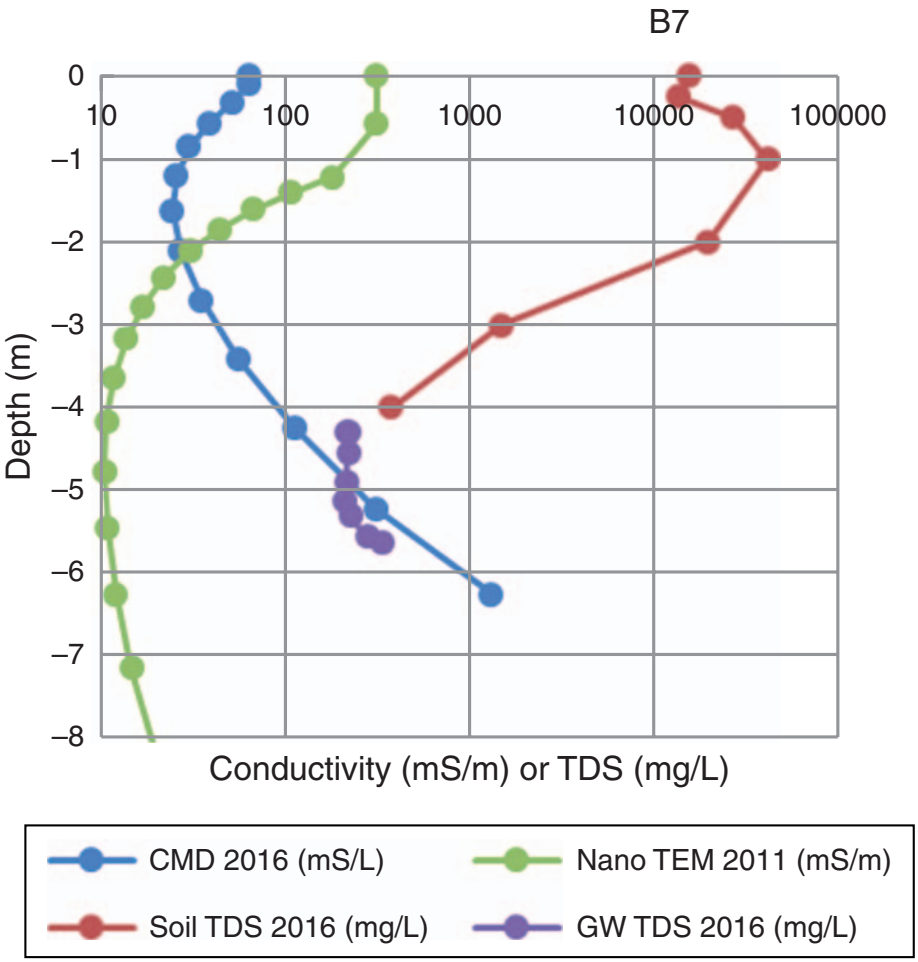

Figure 4. *Comparison between soil and groundwater TDS data against the inverted NanoTEM and CMD data at the test bore indicated with black line in Figures 2 and 3. The pattern of response between TDS and NanoTEM are quite similar, while the CMD response appears to be too shallow.*

any better, and the results just don't look as 'good'.

Has anyone else experimented with other inversions and had better (or worse) results? Overall, I am not satisfied when I see data from these TCMs that purport to provide information at a number of depths and then the data are plotted in Excel (or contoured onto a plan view), with only 'arm waving' depth information. We should be able to do better than that!

Acknowledgements

I gratefully acknowledge and appreciate permission, given by the Murray Darling Basin Authority (MDBA) in conjunction with River Murray Operations (MDBA-RMO), to use the data shown here. I would also like to thank Australian Water Environments for providing me with the opportunity to work on this project.

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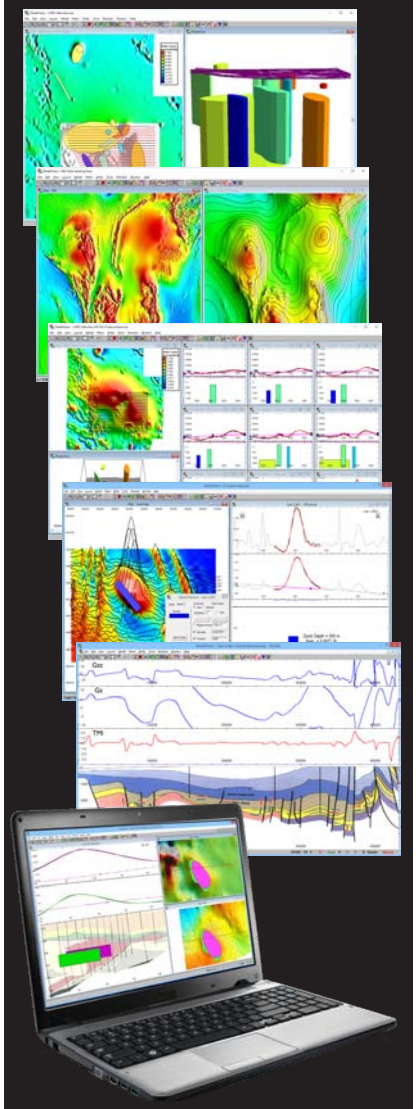
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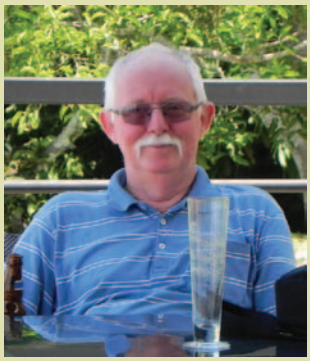

Terry Harvey
Associate Editor for Minerals geophysics
terry.v.harvey@glencore.com.au

Banes and mantras, learning never stops

Those of you who have read some of my previous pieces may have deduced that I'm middle-of-the-road when it comes to choosing between alternatives. Uncharitably this may be called fence-sitting, but I prefer to see it as taking the considered approach – cherry-picking the better aspects that different options might have to offer. There's something good to be had out of most things. And so it is with those sometime banes of galvanic electrical geophysics – pyrite, graphite and pyrolusite.

Pyrite: pyrite may not be the most electrically conductive mineral, nor have the strongest induced polarisation (IP) response, but it is so darn common. How many promising low-resistivity IP-anomalous base metal targets have been drilled only to find the source material is predominantly pyrite? Pyrite is no longer an economic source of iron or sulphur, so it's not the target you seek. However, pyrite detection can have indirect applications in mineral exploration. The silica-pyrite that accompanies some styles of gold mineralisation may provide a realistic electrical geophysics target – resistive IP-anomalism, and the intense pyritisation in the phyllic alteration zone peripheral to porphyry copper deposits can be the lead-in to the somewhat lower magnitude IP-anomalous copper mineralisation with which it is associated.

The inability to discriminate between the IP responses of different sulphides (and of graphite) was the original driving force for investigations into spectral IP. In the time domain this led to the Cole–Cole mathematical model, and in the complex resistivity domain to the Zonge classification system. That the measurable differences in spectral IP appeared to relate more to mineral grain size and distribution styles rather than mineral species was disappointing. The Holy Grail of sulphide species identification using IP remained unrealised, but out of these investigations came a much better understanding of the IP effect and improvements in IP instrumentation.

Graphite: graphite is strongly conductive and strongly IP anomalous. Graphite, particularly in faults and shears, is frequently mentioned as an unwanted anomaly source in Canadian electrical geophysics case histories. Of course, if you're looking for graphite itself with electrical geophysics, its conductive IP-anomalism provides the ideal target. Otherwise graphite's response can be an unwanted distraction, unless you are using it to trace structures or map out a prospective formation.

Put the two (graphite, or at least higher grade carbonaceous material, and pyrite) together, as in many carbonaceous rock types, and you have a nightmare situation for electrical geophysics. A decent base metal sulphide deposit should generate a detectable electrical geophysics response, but it won't be recognisable in this environment of intense electrical anomalism. Perversely, if silica and/or carbonate flooding accompany the mineralisation, a locally resistive, less IP-anomalous zone might be the target – good luck with that!

Pyrolusite: pyrolusite (manganese dioxide) has long been the bane of geochemists' lives because of its ability to scavenge other base metals. But pyrolusite, surprisingly (to me, at least), can be electrically conductive and strongly IP-anomalous, so much so that IP-resistivity is now an accepted geophysical technique in manganese exploration. Apparently manganese dioxide is (nearly) a semiconductor.

I originally subscribed to the mantra 'only metallic sulphides (except sphalerite) and graphite were really IP anomalous' and I hadn't even considered pyrolusite. To those who proposed magnetite as IP-anomalous, I had examples where disseminated magnetite had failed to respond to IP-resistivity. My mantra changed with the publication of geophysical data from the iron oxide copper gold mineralisation (IOCG) with its associated massive concentrations of iron oxides – particularly haematite – in the Stuart Shelf deposits such as Olympic Dam, Prominent Hill, etc. Here was a new (at least to me) class of IP anomalous minerals – metallic iron oxides. These were not necessarily as IP-anomalous as metallic sulphides and graphite, but capable of generating intense low resistivity IP-anomalous responses if there was enough material present.

So my new mantra is 'metallic sulphides (except sphalerite), graphite, pyrolusite and iron oxides (if there are enough of them), can all generate significant IP anomalies'.

But what of the other metallic oxides? What about pitchblende (uraninite), for example? Is that IP-anomalous? Could we use IP-resistivity to search directly for buried uranium deposits? What about cassiterite (in the rutile group with pyrolusite), chromite (in the spinel group with magnetite), and ilmenite (in the haematite group)? Is anyone using IP-resistivity to search for these minerals? I don't know, but I'd be interested to find out. Learning never stops.

Seismic window

Michael Micenko
Associate Editor for Petroleum
micenko@bigpond.com

Rock physics: past and future

In the 60s and 70s it was bright spots, then AVO in the 80s and 90s, and now it is rock physics. Let's take a look at this progression and make a prediction about where it is heading.

Bright spot technology simply involved searching for high amplitude anomalies on stacked seismic sections after it was observed that quite often gas discoveries in the Gulf of Mexico were associated with high amplitudes. Of course this was backed up with some sound mathematics, but really the only requirement was good eyesight. Success rates improved but, despite being drilled into bright events, many wells failed to find economic accumulations of hydrocarbons. Igneous rocks, coals, carbonates and low saturations of gas can all produce a brightening of the seismic amplitude. Today we can easily recognise carbonates and igneous rocks by the reflection polarity, but that was not so well understood 50 years ago.

The industry needed something better and moved on to the pre-stack method – Amplitude Variation with Offset (AVO). AVO measures the changes in reflector amplitude across a number of offsets to estimate the type of rock and its fluid fill. Again, there are pitfalls such as low gas saturation, highly porous sandstones, thin bed tuning (Figure 1), and poor processing, which create false anomalies and a dry hole results. However, a well's chance of success is often undermined by misuse of the technique by explorers that should know better – this lack of understanding (or is it?) is often displayed on the steady supply of farm-out brochures I receive.

So now we have rock physics. An AVO study is only as good as the rock physics behind it, and this is dependent on the quality and relevance of the supporting data used to create models of the expected response. For instance, a common blunder is to apply learnings observed at a shallow depth to a deeper situation. Figure 2 explains why this may be wrong. Because the relative changes of velocities with depth are different in sands and shales, there becomes a depth where the sand and shale trends cross over and the AVO response is completely different. What was successful at shallow depths will not be successful with an extra kilometre of burial.

Where is this all leading? It's a bit of a buzz word, but machine-learning is making inroads and in the future I suggest seismic data will be compared to a database of millions of prospects and outcomes. Seismic interpreters and dry holes will be a thing of the past.

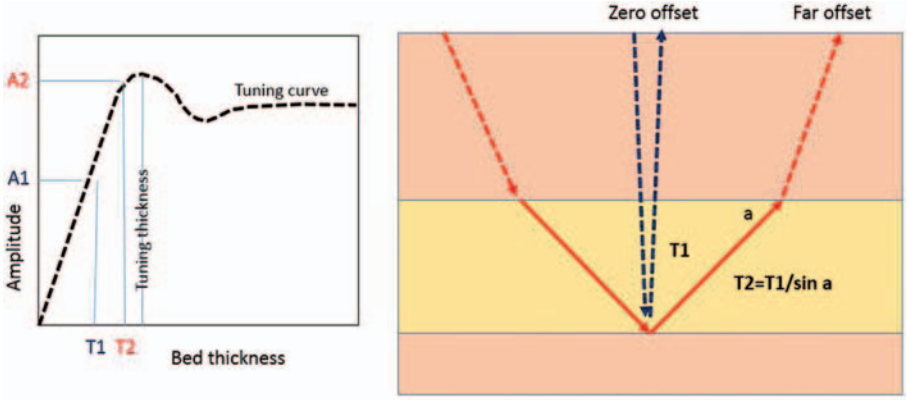

Figure 1. *Tuning curve (left). Thin beds can produce a false AVO response when the thickness (T1) is below tuning thickness. With long offsets the apparent thickness (T2) is larger and produces a larger seismic amplitude (right).*

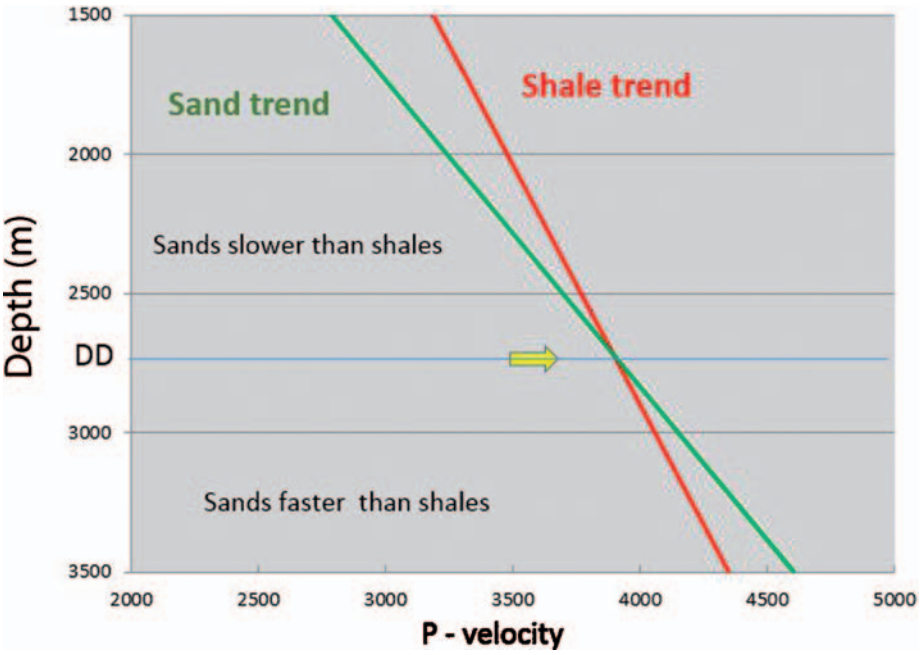

Figure 2. *Example P wave velocity versus depth of burial. At shallow depths (about 2000 m in this example) the sand has a slower velocity than shale, and replacing brine fill with gas will increase the difference creating a bright spot. But below a certain depth (DD) the shale becomes slower. In this case adding gas will reduce the difference between sand and shale and the reflection amplitude becomes close to zero. In the past this would be referred to as a 'dim spot'.*

Data trends

Tim Keeping
ASEG Technical Standards
Committee Chair
Tim.Keeping@sa.gov.au

A perennial topic at the ASEG Technical Standards Committee meetings is the status of grids for archiving. ERS continues to serve us well, but compression licensing changes and the coming of 3D and 4D file formats prompts consideration of the future of file formats for our open datasets. ERMapper(TM) has undergone several changes in ownership since its native binary file format was adopted as a *de facto* open standard for raster files. The ECW(TM) compression license and API has changed too, with the current iteration allowing unlimited reading but no writing. Meanwhile, software races towards integration with 3D and 4D datasets. So, what are the new file types on the block?

One format mentioned several times has been a new format from Pitney Bowes. On behalf of the Committee, I (t)asked Pitney Bowes software developer, Sam Roberts, to describe the new file type in prose aimed at those with a passing interest in the topic, but with enough detail to satisfy the technically minded. Please read on for his response – which successfully answers my challenge.

MRR: a new, soon to be freely accessible, raster storage format

Sam Roberts
sam.roberts@pb.com

Pitney Bowes has developed a new raster data storage format called Multi-Resolution Raster (MRR). MRR is a key enabling technology in the GIS platform *MapInfo Pro* and *MapInfo Pro Advanced*. Free libraries to read and write MRR files via the open source Geospatial Data Abstraction Library (GDAL) platform will become available later this year. They will also be available through the Pitney Bowes APIs. In time this will allow MRR to be utilised across all major platforms such as *ArcGIS* and *QGIS*.

Background

Rasters contain grid based spatial information. This includes imagery of all varieties – photographic, scanned, aerial or satellite, true colour, thermal and multi-spectral. It includes digital surface models (DSM) and digital terrain models (DTM) and grids of any other observable property of the Earth; like atmospheric pressure or the gravitational field. It includes thematic (or classified) raster data that might represent land use or urban infrastructure classifications. It includes the output of any analysis or interpolation operation where computations or estimations are performed on a grid based spatial pattern. Raster data is continuously variable spatially, and often temporally. Over the last decade the amount and variety of raster datasets - available to professionals and non-professionals alike – has exploded.

MRR is a unifying and enabling technology that provides a flexible solution for the entire spectrum of raster consumer requirements. It unifies the storage of all kinds of raster data – imagery, spectral imagery, continuous gridded data and thematic data – and removes the barriers to working with different kinds of raster data in the same context. It enables the highest quality visualisation and processing of raster data – at any scale and for a raster of any size. MRR provides a new storage and management solution for customers. It minimises storage requirements using industry standard data compression codecs and is a storage vessel for all varieties of raster data.

The MRR format distinguishes itself from other raster formats in the following ways:

- contained within a single file on disk
- supports image data, classified (or thematic) data and continuous and discrete data
- stores one or more multi-banded fields
- supports local registration for each field, and tile decimation
- supports raster datasets of virtually unlimited size
- extends the concept of a raster from a simple 2D array of cells to an extensible sparse matrix of tiles of cells
- provides efficient access to data at any scale. Contains a data overview pyramid and supports underview generation
- supports the temporal dimension, allowing data to be accumulated and accessed by time
- contains high quality summary and spatial statistics
- achieves efficient storage using lossless and lossy compression techniques via industry standard compression codecs
- supports a wide and extensible number of data types

Physical structure and access

A MRR is a single binary file, so it is easy to manage and transport. A MRR file is actually a ‘file system inside a

file', which provides flexibility to change raster properties, edit raster cell values and extend the raster spatially, temporally or structurally. This flexibility comes at the expense of simplicity – consequently a MRR can only be read, written or edited via the use of a supporting API from Pitney Bowes. We currently ship an API as a part of *MapXtreme*, our .NET software toolkit for developers. Pitney Bowes also plans to provide open source Geospatial Data Abstraction Library handlers (GDAL) for the MRR format and have already done so for a few customers. Further interoperability developments are likely as Pitney Bowes sees no advantage in restricting access to the MRR format. In the meantime, your main point of contact with the MRR format will be in the *MapInfo Pro Advanced* product.

Fields and bands

A MRR contains one or more fields of a designated type. Data in different fields are related in that they will share the same coordinate system, but they may not share the same cell size or spatial location. There are four field types – image, image palette, continuous and classified.

An image field contains raster imagery. It will contain a single concrete data band of any supported colour data type. If the colour data type has multiple components (such as RGB) then the individual components are exposed as virtual bands. Image fields can use image compression codecs such as JPEG or PNG.

An image palette field contains raster imagery that draws from a colour palette. It will contain a single concrete data band that records the palette index of the colour in each cell. The colour palette is a table that contains a single column with a supported colour data type. The cell colour and colour data type components are exposed as virtual bands. Image palette fields can use any supported lossless data compression codec like ZIP.

A continuous field contains continuous or discrete grid data. It will contain one or more bands, each of which can use any supported data type. Bands are continuous by default, meaning the value for each cell is an estimate acquired at the centre of that cell. Bands can also be declared discrete, meaning the value for each cell is an average value over the spatial extent of the cell. The individual components of multi-component data types (like colour or complex numbers) are exposed as virtual bands. Continuous fields can use any supported lossless data compression codec like ZIP.

A classified field contains thematic information drawing from a classification table. It will contain a single concrete data band that records the class index in each cell. The classification table can contain multiple columns of information in any supported data type and typically contains information like colour, labels and other information. All columns in the table and the individual components of multi-component data types are exposed as virtual bands. Classified fields can use any supported lossless data compression codec like ZIP.

Cell validity is recorded for all cells using a flag. There are no 'null values' in an MRR. Validity can be stored for each band in a field or for all bands collectively. The value of an invalid cell can then be used to identify why that cell is invalid. We reserve the values 0 and 1, corresponding to 'empty' (there is no value) and 'null' (there can be no value). Cell validity is stored using lossless compression.

Spatial structure

A MRR is not a simple rectangular array of cells (what could be called a tile). It is an extensible sparse matrix of tiles of cells. The size of a MRR is not defined by some number of columns and rows – it is defined by the size and extent of the tiles in the matrix. A MRR is not limited to some pre-determined size – it can be extended by adding new tiles anywhere, anytime. There is virtually no theoretical limit to the size of a MRR. The limitations, instead, are practical - such as the maximum size of a file in your operating system file system.

A tile of cells is generally some reasonable size such as 1024 × 1024 cells. You can quickly access a tile and mount the data contained therein. We refer to this data as the 'base level' data and assign it resolution level 0. To support high performance visualisation and processing at different scales, a MRR contains a complete overview data pyramid in addition to the base level data. In the overview pyramid the cells of each higher resolution level are 2× larger than the cells of the level below it. The API will also return data from 'underview' levels. This data is constructed from the base level data on the fly using well known methods such as bilinear or cubic interpolation.

A field in a MRR has a defined cell size that applies to all bands and to all tiles in the base level. You can, on a tile by tile basis, break this rule. For each tile you can specify a decimation factor (with limitations) that effectively increases the cell size within that tile. We refer to this as multi-resolution tiles.

Temporal structure

Changes to a raster over time can be recorded in a MRR. When raster data is added to a MRR we record this as an 'event' and the 'time' of the event can be specified. Unlike an edit operation that may permanently overwrite data, an event is always cumulative. The API then allows you to acquire data from any place and at any time, or over any time range at any scale.

Statistics

A MRR contains accurate and high quality statistics. This includes cell count and extent data, summary statistics (such as minimum, maximum, variance etc.), distribution histograms and other information that can aid visualisation and processing. Histograms in a MRR are designed to be as robust as possible and tolerant of outliers and other anomalies. Statistics are gathered in a single pass with no a-priori information.

Storage efficiency

A key goal of the MRR design was to maximise storage efficiency and minimise file size, whilst giving the user total control over the quality of the data stored therein. This starts with the sparse tile matrix. In a MRR, tiles only exist where data exists. So, it is possible to build rasters of unusual shape (such as a raster of near shore bathymetry that follows a convoluted coastline) and not have to store vast quantities of nulls.

We offer a large range of data types. The careful selection of an appropriate data type can do much to reduce both in-memory storage requirements and on-disk storage.

We offer a variety of encoding schemes. For decimal data types, you can elect to restrict the number of decimals of precision – do you really need six decimals of precision in your terrain data? You can use scaling and transformation to transform decimal data prior to storage so that you can store it in

an integer data type. You can record cell validity for each cell, rather than for each band of each cell. You can use a variety of predictive encoding schemes, which encode the data prior to writing it to the tile and can improve compressibility.

Finally, when the data is written to the file (on a tile by tile basis), you can (and should) use a compression codec to compress the data. The compression codec can be loss-less (for most field types and data types) or loss-y (for imagery, if desired). MRR currently uses a variety of standard codecs such as LZ4, ZIP, LZMA, PNG and JPEG. We have experimented with others and I have no doubt new codecs will be added over time if they prove useful, especially for imagery.

Data types

MRR supports a rich variety of data types including:

- unsigned integers – 1/2/4/8/16/32/64 bit
- signed integers – 8/16/32/64 bit
- reals – single and double precision
- complex numbers – 16/32 bit signed integers, single and double precision reals
- date and time
- strings – fixed and variable length ASCII, variable length UTF-8, UTF-16, UTF-32
- colour Grey – 1/2/4/8 bit (minimum is black or minimum is white)
- colour components – Red, Green, Blue, Alpha
- colour components – Hue, Saturation, Intensity/Lightness/Value
- colour – RGB/RGBA/BGR/BGRA/HSI/HSIA/HSL/HSLA/HSV/HSVA
- colour – RA/GA/BA/GyA
- BLOBS – fixed and variable length

Comparison with ECW, JPEG2000 and MrSID

ECW was designed to store compressed imagery and, although the scope of the format has been expanded over the years, imagery is still the main game. ECW uses a loss-y wavelet based compression codec. In comparison, MRR offers the JPEG loss-y codec or loss-less codecs like PNG or LZMA. Whether you prefer JPEG or wavelet based compression is up to you, and mainly depends on how you like your noise. Wavelet compression does result in smaller files and, to my eye, has a more attractive noise signature than JPEG. However, wavelet compression introduces noise pervasively throughout the entire image whereas JPEG compression generates less (or no) noise in areas of low variability – which can be a real advantage. If you want to store highly compressed imagery in the smallest possible file, then ECW remains a very good solution. Otherwise, MRR provides a useful alternative. JPEG2000 and MrSID are both very similar solutions for raster imagery to ECW.

Comparison with TIFF

TIFF stands for 'Thousands of Incompatible File Formats'. No really, it does. The format has been around for many years and has grown organically. TIFF can do just about everything that a MRR can do – it stores imagery (optionally using a palette), continuous data and classified data via extensions, and it can access an overview pyramid. It has compression codecs – lots of them – and uses predictive encoding. BigTIFF supports large rasters, but trying to read a TIFF file is now an art, and while it remains a vitally important format it inspired the development of MRR.

Comparison with ERS, Imagine, BIL and ESRI formats

ERMapper ERS format has been a useful and flexible workhorse over many years, especially amongst geophysicists. BIL, BIP, BSQ and ESRI ArcFloat formats are very similar in practice. Probably the biggest criticism of all these formats is that they quickly become impractical as the size of the raster increases.

The ERDAS Imagine format is a pre-cursor to MRR. It supports continuous and classified data, but does not have direct support for imagery. It supports concepts like the overview pyramid to enable high performance rendering. The major issue with this format is that it does not support efficient data compression. It is currently used by some organisations to distribute GIS raster data.

ESRI ArcASCII format suffers from various problems, although it has the one advantage that it can easily be read by anyone with a text editor or a simple programming capability. ESRI Arc format is able to store large rasters yet it generates a large number of files with fixed filenames, so you need to store the raster in a dedicated file directory. MRR avoids tracking multiple files with its single file storage.

Example: Merging many TIFF files to a MRR

The British Ordnance survey makes topographic imagery of the UK available at a variety of scales. It is downloadable as a collection of TIFF files. For example, the 1:50 000 scale imagery consists of 1634 TIFFs (3.07 GB) and the 1:5000 scale imagery consists of close to 10 600 TIFFs (39 GB). In both cases, it is difficult to consume the imagery. *MapInfo Pro Advanced* can be used to merge the source rasters into a single MRR. The MRR contains a data pyramid, so it can be instantly rendered at any scale. For example, the 1:50 000 scale TIFFs merge to a single MRR that is somewhat smaller than the source data (2.65 GB).

Example: Terrain grids

MRR is great for visualising large terrain rasters. As an example, consider the SRTM (Shuttle Radar Topography Mission) data made available by CGIAR (Consultative Group for International Agricultural Research). The data is downloadable as almost 900 ZIP archives (14.2 GB), each of which contains a 205 MB raster in ESRI ArcASCII format. It goes without saying it is hard to consume this data. But it is easily merged into a single MRR (11.5 GB) that can then be used for global or local terrain analysis.

Example: Multispectral satellite imagery

Consider multispectral data acquired from the ESA (European Space Agency) Sentinel-2 satellite. For each scene, there are 13 spectral bands of data to download as well as a colour imagery band. Each band is provided as a separate raster in JPEG2000 format. The rasters come in three different resolutions – 10 m, 20 m and 60 m.

All of this data for a scene, or for multiple scenes, can be combined into a single, multi-field, multi-banded MRR. It is necessary to separate data with different field types (imagery or continuous) and different resolutions. You end up with a MRR that contains four multi-banded fields as shown below:

Field 1 – 60 m resolution data
– Bands 1,9,10
Field 2 – 20 m resolution data
– Bands 5,6,7,8A,11,12
Field 3 – 10 m resolution data
– Bands 2,3,4,8

Field 4 – 10 m Total colour imagery – RGB

Satellite imagery from other platforms such as Landsat have similar properties and can be treated in a similar way.

Summary

In summary, MRR is an efficient vehicle for raster storage and raster data querying, and is flexible enough to be used in almost all raster usage environments. At the present time it is a feature of *MapInfo Pro Advanced* and its use is largely confined to that platform. But, Pitney Bowes plans to make free libraries available to read and write MRR files this year via the GDAL platform, and through our own API's, and in time this will allow MRR to be utilised across all major platforms such as *ArcGIS* and *QGIS*. Big, complex rasters? No problem, just use MRR!

Sam Roberts is a Principal Software Development Engineer at Pitney Bowes with an Honours degree in geophysics from the University of Adelaide and has previously worked as a geophysical field technician and exploration geophysicist.

Webwaves

Dave Annetts
ASEG Webmaster
david.annetts@csiro.au

Password hygiene

Q: What is the next number in the sequence 123456, 123456789, 111111, 12345678?

Internet security has been a common feature of the past few *Webwaves* columns, and this one is no exception.

A recent news story (ABC, 2018) concerned common passwords recovered from data breaches. Surprisingly, after widespread internet use and warning about secure passwords, the most common password in a database of over 500 million records was '123456', with nearly three times the frequency of the second most common ('123456789'). Wikipedia's (2018*a*) page on common passwords shows many commonalities over different compilations since 2011, and has been reproduced and augmented as Table 1. Other equally cryptic sequences recur in Table 1, some of which (with variations) are 'qwerty', 'zxcvbn', 'abcde', as well as the standby, 'password'.

The choice of a secure account password is something over which users have control. Users have no control over how their data are stored, and one reason that compilations such as Table 1 are possible is that passwords are stored as plain texts instead of being encrypted. Another effect of plain text storage is that lists can be used as dictionaries as a first pass in attempts to hack into accounts. A table lookup, even using a large table, takes no effort compared to decryption. Weir and Aggarwal (2009) describe other methods of decoding passwords. ASEG Members' passwords are encrypted.

Strong recommendations for password maintenance are:

1. Unique password for each account – password managers can help keep track of these; Wikipedia (2018*b*) maintains a list of password managers.
2. Passwords – longer passwords containing more unique characters are stronger than shorter passwords with repeated characters.
3. Enforced multi-factor authentication – one-time keys must be entered even after a successful logon.

Table 1. Comparison of most common passwords retrieved from data breaches (after Wikipedia, 2018*a*). Entries under 'Keeper' were taken from the password manager Keeper's 2016 compilation, while entries under 'ABC' were taken from the haveibeenpwned.com (2018) compilation.

	2011	2012	2013	2014	2015	2016	2017	Keeper	ABC
1	password	password	123456	123456	123456	123456	123456	123456	123456
2	123456	123456	password	password	password	password	password	123456789	123456789
3	12345678	12345678	12345678	12345	12345678	12345	12345678	qwerty	qwerty
4	qwerty	abc123	qwerty	12345678	qwerty	12345678	qwerty	12345678	password
5	abc123	qwerty	abc123	qwerty	12345	football	12345	111111	111111
6	monkey	monkey	123456789	123456789	123456789	qwerty	123456789	1234567890	12345678
7	1234567	letmein	111111	1234	football	1234567890	letmein	1234567	abc123
8	letmein	dragon	1234567	baseball	1234	1234567	1234567	password	password1
9	trustno1	111111	iloveyou	dragon	1234567	princess	football	123123	1234567
10	dragon	baseball	adobe123	football	baseball	1234	iloveyou	987654321	12345
11	baseball	iloveyou	123123	1234567	welcome	login	admin	qwertyuiop	1234567890
12	111111	trustno1	admin	monkey	1234567890	welcome	welcome	mynoob	123123
13	iloveyou	1234567	1234567890	letmein	abc123	solo	monkey	123321	0
14	master	sunshine	letmein	abc123	111111	abc123	login	666666	iloveyou
15	sunshine	master	photoshop	111111	1qaz2wsx	admin	abc123	18atcskd2w	1234
16	ashley	123123	1234	mustang	dragon	121212	starwars	7777777	1q2w3e4r5t
17	bailey	welcome	monkey	access	master	flower	123123	1q2w3e4r	qwertyuiop
18	passw0rd	shadow	shadow	shadow	monkey	passw0rd	dragon	654321	123
19	shadow	Ashley	sunshine	master	letmein	dragon	passw0rd	555555	monkey
20	123123	football	12345	michael	login	sunshine	master	3rjs1la7qe	123456a
21	654321	jesus	password1	superman	princess	master	hello	google	dragon
22	superman	michael	princess	696969	qwertyuiop	hottie	freedom	1q2w3e4r5t	123321
23	qazwsx	ninja	azerty	123123	solo	loveme	whatever	123qwe	654321
24	michael	mustang	trustno1 batman	passw0rd	zaq1zaq1	qazwsx		zxcvbnm	666666
25	Football	password1	0	trustno1	starwars	password1	trustno1	1q2w3e	homelesspa

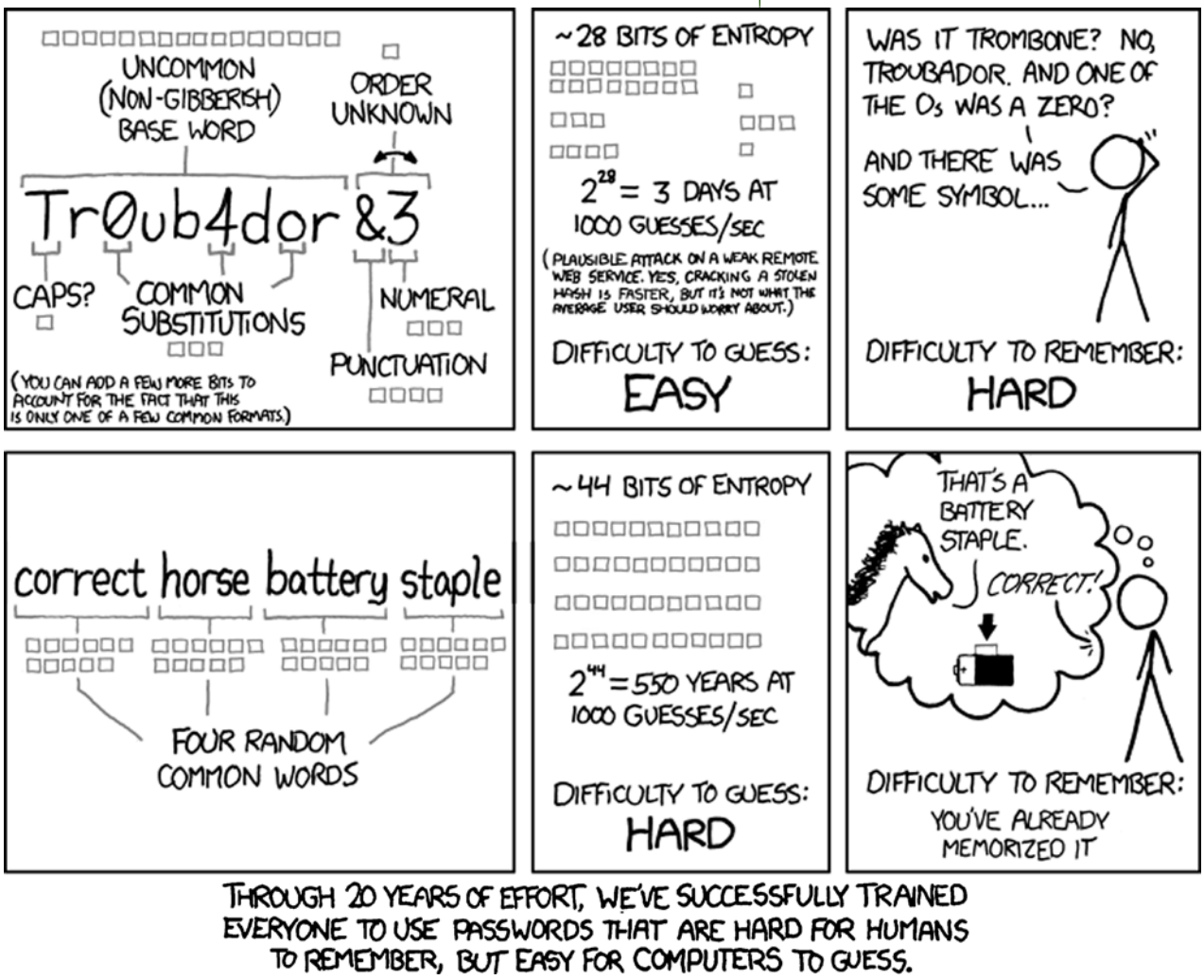

Figure 1. *Password strength and ease of use (XKCD, 2018).*

It is noteworthy that one of NIST's (2017) current guidelines are not to force users into periodic password changes. In fact, passwords were often weakened by the requirement for regular changes because, invariably, only a few characters are changed so that users can more easily remember them. In contrast to NIST, CERN (2018) recommends changing passwords frequently, and also offers the following guide for password choice:

1. Choose a line or two from a song or poem and use the first letter of each word. For example, 'In Xanadu did Kublai Khan a stately pleasure dome decree!' becomes 'IXdKKaspdd!'. XKCD (Figure 1) recommends a similar approach.
2. Use a long passphrase like the sentence 'InXanaduDidKublaKahn AStatelyPleasureDomeDecree!', itself or mathematical formulas like 'sin^2(x)+cos^2(x)=1'.
3. Alternate between one consonant and one or two vowels with mixed upper/lower case. This provides nonsense words that are usually pronounceable, and thus easily remembered. For example: 'Weze-Xupe' or 'DediNida3'.
4. Choose two short words (or a big one that you split) and joining them together with one or more punctuation characters between them. For example: 'dogs+F18' or 'comP!!UTer'.

Password managers (Wikipedia, 2018*b*) can usually indicate password strength, as do sites such as https://howsecureismypassword.net/. Such sites can also be used to check whether an email address has been included in one of the many reported data breaches (see *Preview 191*). Affected users can then make a decision about whether to change passwords on compromised accounts. Weir and Aggarwal (2009) have noted that after data from around 20k accounts (passwords and credit card details) were leaked in a 2009 breach of the Web Hosting Talk Forum, only 0.6% changed their passwords even though 34% of passwords could be recovered.

And the answer to this column's initial question? Table 1 shows the answer to be 1234567 from the 2018 compilation.

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A new experimental extractive technology trial for Cooper Basin unconventional resources: alignment flow technology

Professor Raymond L. Johnson, Jr
Professor of Well Engineering and Production Technology
The University of Queensland
r.johnsonjr@uq.edu.au

Unconventional reservoirs in Australia's Cooper Basin consist of three main types of reservoirs: tight or basin-centred gas, shale gas reservoirs, and deep coal gas accumulations. Tight and basin-centred gas ('BCG') reservoirs are unlike conventional reservoirs.

Conventional reservoirs exist in traps or accumulations requiring exploration tools (e.g. drilling and seismic) to define reservoir boundaries or explore their presence. They have well interconnected porosity and high permeability, and have been pursued across Australia for oil and gas extraction since the 1950s. BCG reservoirs are a type of tight sandstone; gas reservoirs that have been stratigraphically or hydro-dynamically trapped and charged to pressures beyond normal hydrostatic pressures. This occurs either by internal maturation, unearthing or uplifting, or charging from underlying sediments. Tight or basin-centred gas reservoirs possess lower interconnected porosity and permeability and require hydraulic fracturing to be successful.

Shale gas reservoirs are highly layered, clay-rich, low permeability reservoirs that are generally self-sourced, have extremely low permeability, and require a horizontal wellbore and multiple-staged, hydraulic fracturing treatments to be successful. Deep coals are similar to coal seam gas reservoirs, deriving their gas from adsorbed gas and permeability primarily through natural fracturing in the coal. Whilst coals and shales in the Cooper Basin are not directly addressed by this paper, these interbedded coals and shales within sandstones, targeted for hydraulic fracturing, affect hydraulic fracture propagation (i.e. coals and shales have differing stress and rock-mechanical properties as compared to targeted lower permeability sandstones and siltstones in Cooper Basin reservoirs).

All of the above unconventional reservoirs were initially successfully developed in North America using vertical wellbores, and became highly profitable based on the successful experimentation and development of horizontal well technology, including multiple staged hydraulic fracture treatments, staged in clusters along the horizontal wellbore. Similar applications of North American technologies in Australia have had lesser success largely because of lower permeability values and a less favourable stress conditions (i.e. stress regime). North America is generally in an extensional, normal stress regime (i.e. vertical stress is much greater than the maximum horizontal stress, which is greater than the minimum horizontal stress). The Cooper Basin is in a compressional, strike-slip stress regime where the maximum horizontal stress is much greater than the vertical stress and greater than the minimum horizontal stress. In deeper sections of the Cooper Basin, the stress regime can become a reverse stress regime (i.e. vertical stress is less than or equal to the minimum horizontal stress and much less than the maximum horizontal stress).

A favourable stress regime is the predominant factor for the success of North America unconventional developments to date, and is particularly favourable to the hydraulic fracturing process. Conversely, the strike-slip to reverse stress environment adversely effects Cooper Basin hydraulic fracturing treatments. This is especially the case when such treatments originate from one of the less favourable well directions, being either vertical or horizontally oriented in the direction of the minimum horizontal stress (i.e. oriented to create fractures perpendicular to the wellbore orientation or 'transverse' fractures).

The Cooper Basin has a problematic stress environment that can be further complicated by the damaged stress cage resulting from wells drilled in a less favourable stress direction to the maximum horizontal stress and the presence of natural fracturing (Johnson et al., 2015). This complex stress environment can create a fracture complexity often manifested by a pressure differential associated with these fracture complexities in the near wellbore region, or near wellbore pressure loss (NWBPL). Developing an effective extractive technology to progress Cooper Basin unconventional resources has been elusive to date based on these complexities, and further research in this area was a key recommendation by the 2013 Chief Scientist and other ACOLA examination of the status and progress of unconventional resources in Australia.

Since the early 2000s, a number of experimental methods have been employed to counter high NWBPL observed during Australian hydraulic fracturing treatments. One experimental study showed that NWBPL in the Cooper Basin can be reduced by directionally perforating the well before fracturing in the maximum horizontal stress direction (Johnson and Greenstreet, 2003). Increasing fluid viscosity has cited by several authors as a means to manage NWBPL. However, increased polymer loadings can also severely impact post-treatment hydraulic fracture conductivity (Penny et al., 1996), leading to overall poor productivity. Others have used small mesh proppant slugs, acid spearhead treatments, and reducing the perforation length in Australian Basins where problematic NWBPL was encountered (Johnson and Greenstreet, 2003; Pitkin et al., 2012; Scott et al., 2013). Although achieving some localised success, these methods have proven ineffective at providing an overall solution to the development of an effective widespread extractive technology for Cooper Basin unconventional resources.

Recent published experimentation with wellbore orientation indicated that in two cases orientation of the drilled wellbore

in the maximum horizontal stress direction reduced fracture complexities in the strike-slip stress environment (Bentley et al., 2013; Johnson et al., 2015). This was based on numerous North American studies of horizontal wells showing the benefit of alignment in the maximum horizontal stress direction to create less complex, fracturing along the horizontal wellbore. Based on this, and past research, it is hypothesized that a combined strategy of deviating the wellbore and aligning the perforations in the maximum horizontal stress direction will improve the hydraulic fracturing process in the Cooper Basin in two upcoming fracs for an operator in the Windorah Trough area of SW Queensland (ATP 927P – see Figure 1) by:

- lowering NWBPL and fracture complexity as a result of better alignment of the perforations and the resulting hydraulic fracture with the wellbore (all should be aligned along the preferable maximum horizontal stress direction);
- allowing better fracture containment within lower stress bounding coals through the use of lower viscosity fracturing fluids
- allowing implementation of recently graded particle injection as a means to improve natural fracturing using cleaner, lower-polymeric fluid technology; and
- improving flow to the wellbore through higher concentrations of localised proppant in the primary hydraulic fracture through effective proppant 'banking'.

The last three bullet points above are only achievable by effectively lowering NWBPL and creating a less complicated

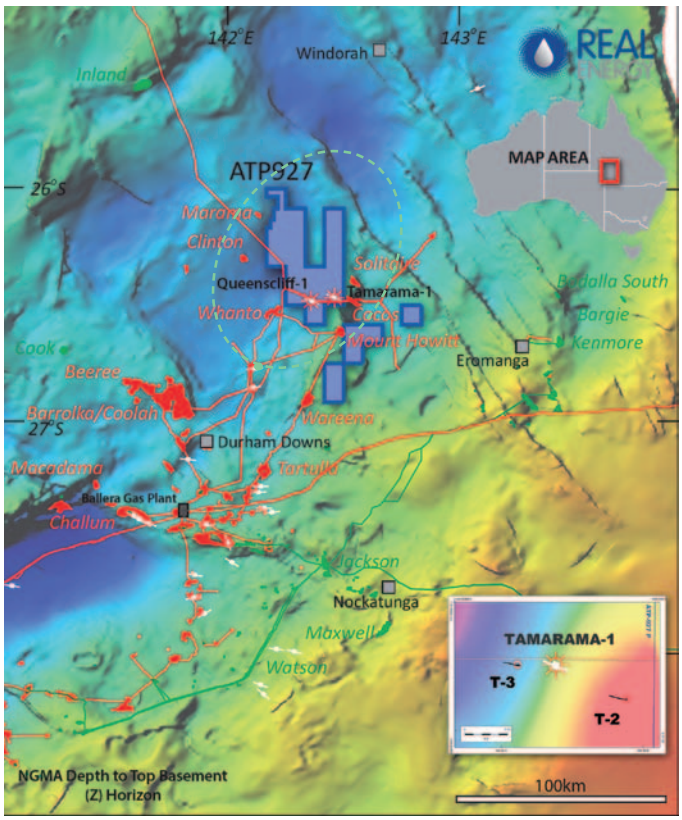

Figure 1. *Windorah Trough study area indicated in green dashed region with Tamarama 1 vertical and Tamarama 2 and 3 lateral wells (pictured insert) with well azimuth striking <10 degrees from the E-W trending maximum horizontal stress direction.*

hydraulic fracturing environment in Cooper Basin fracturing treatments.

This combined strategy, referred to as 'Alignment Flow Technology' or 'AFT', will be implemented in a series of experimental wellbores to be placed in an opportunistic area of the Cooper Basin – the Windorah Trough. It is believed that this area will benefit from this experimental technology based on past experiments demonstrating high stress, problematic wellbores, high NWBPL, and difficulty placing proppants (Johnson, et al., 2015, 2016). Further, this technology may provide a widespread solution for the Cooper Basin as an effective extractive technology for other unconventional resources in problematic stress environments.

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Edgar H Booth: was he the first Australian exploration seismologist?

Roger Henderson
rogah@tpg.com.au

The first exploration seismic survey planned by an Australian commenced in 1929, when E H Booth agreed to act as a consultant to the Imperial Geophysical Experimental Survey (IGES), and to establish its seismic section (Broughton Edge and Laby, 1931)[1].

In this paper, I expand on Booth's previously un-acknowledged geophysical interests and activities, and propose that, as a result, he was the first Australian exploration seismologist.

Existing published information on E H Booth (1893–1963)

The earliest published information on the life of Edgar Harold Booth that I have found is a standard, short, much abbreviated entry in *Who's who in Australia, 1950* (Alexander, 1950). Booth was born in Sydney, and studied engineering from 1911–13 at the University of Sydney, where he was awarded a BSc in 1914, and a DSc in 1935. He died at his home in Sydney. More information is provided in various biographies.

There are at least four biographies of Booth, however, all too little emphasis is given in them to his exploits in geophysics, which were considerable for the time. For example, the entry in the *Australian Dictionary of Biography (ADB)* for Booth (Mitchell, 1993), although over 650 words in total, has only 18 words on his involvement in exploration geophysics and then only refers to his association with the IGES. Mitchell states, "His major research on geophysical exploration stemmed from his association with the [IGES] in 1929–31". This statement does not recognise Booth's development of seismographs before the IGES, which was the reason he was asked to join the IGES. Nor does the statement recognise his involvement in geophysics outside of research, such as his practical field surveys, about which more follows.

The other three biographies, in reference to geophysics, state only that Booth was a "consultant physicist, [IGES] (1928–30)", except that *Physics in Australia to 1945* (Home, 1995) does add his several geophysical publications, which will be discussed below.

The entry on Booth in the *Australian Dictionary of Biography* (*op cit*), is by far the most comprehensive of the four available, and summarises his life as a "soldier, university lecturer and administrator", with no inclusion of 'research physicist', let alone 'geophysicist'.

Mitchell's description of Booth as a 'soldier' relates to his service in the Australian Imperial Force (of WW1) from June 1916, including action in France and Belgium for which he was awarded the Military Cross[2]. His activities during the war will be dealt with in the section on 'Booth and Pollock'.

The description of Booth as a 'university lecturer' relates to him being firstly, Assistant Lecturer and Demonstrator in physics at the University of Sydney in 1915 and, after his war service, a permanent Senior Lecturer until 1937. Booth was known for his imaginative and effective teaching, the production of two classic textbooks, and numerous other articles on physics subjects (see Home, 1995).

The description 'administrator' no doubt acknowledges, in part, Booth's position as President of the Science Teachers Association of New South Wales (1928–32). Such administrative experience may have been the reason Booth was chosen, in 1938, to be the inaugural Warden of the newly established New England University College (NEUC) at Armidale, a position he held until 1945[3].

The Encyclopedia of Australian Science (McCarthy, 1993) entry for Booth lists, for published resources, the above ADB reference, an obituary of Booth in the *Australian Journal of Science* (Somerville, 1964), and his item in '*Physics in Australia to 1945*' (Home, 1995). Another biography in *Trove*, National Library of Australia (Trove, 2009) repeats the same details.

Physics in Australia to 1945 (Home, 1995) lists 23 publications by Booth (only three with co-authors). Included in this list are nine papers in the *Journal and Proceedings of the Royal Society of NSW* in the period from 1922 to 1938, the last being his Presidential Address to the Society. Six of these papers deal with geophysical topics including the detection of vibrations by microphones, surface waves, regional magnetic surveys, and observations on magnetic diurnal variations. Thus, one quarter of his publications are very much on geophysical subjects.

Ever Reaping Something New, a history of the science faculty of the University of Sydney to 1985, has the following summary of Booth's research activities (Branagan and Holland, 1985, p. 95), "Booth's work displayed versatility with practical flair…. he investigated atmospheric dust and ionization, and followed it

[1]The first seismic refraction survey carried out in Australia was only one year earlier in Roma, Queensland, by the German survey company, Elbof (Thyer, 1979).

[2]Booth, like others at the time, continued to use his military rank of 'Major Booth' after the war and, according to Mitchell (1993), "much of his subsequent career had a military flavour".

[3]Booth is said to have run the College in somewhat of a military fashion, consistent, perhaps, with his continued preference for being referred to as 'Major Booth'. In 1954 the NEUC became the University of New England.

closely with seismic surveys with his newly developed hot-wire microphone as a detector of small vibrations" (see more on this in the section on 'Booth's research into the seismic method' below). "Principles of magnetic surveying for geological interpretation applied to a survey of the 'Gib' (Mount Gibraltar) at Bowral completed the geophysical side of his work" (this work will be examined further in the section on 'Booth as a field geophysicist' below).

Booth and Pollock

As we know from Broughton Edge and Laby (1931, p. 3), when organizing the IGES it was realized that there were "neither experienced operators nor the necessary equipment" even to test seismic methods. However, the Australian Branch of the Institute of Physics "drew attention to the fact that, following on their war [WW1] experiences of seismic methods, the late Professor J A Pollock FRS and Major (sic) E H Booth, [both] of Sydney University, had for some years been carrying out experiments by an electrical recording system which is very similar to that now being employed in geophysical investigations", and thus recommended that seismic methods be included in the IGES[4].

Branagan and Holland, (*op cit*), in regard to Pollock's war experience, add, "In November 1915 it was decided by the Federal Defence Department to form a Military Mining Corps… under the command of Edgeworth David." As part of this Corps, "Pollock devised a geo-telephone for underground listening…" (p. 91). Also, "At the time of his death [22 May 1922], Pollock was engaged in acoustical work related to the transmission of earth waves, based on his experience in France [during WW1]" (p. 92). Booth (1926*b*) acknowledged that Prof Pollock had encouraged him to continue on this work after his death.

Booth's research into the seismic method

Since existing biographies on Booth make no reference to his seismic research, information about this work has been compiled from his own geophysical publications and from references to his work in the Report of the IGES (Broughton Edge and Laby, 1931). Details of some of Booth's seismic experiments before the IGES are given in two papers in the *Journal and Proceedings of the Royal Society of NSW* (Booth, 1926*a*, 1926*b*).

In this first specifically geophysical paper in the Journal (Booth, 1926*a*), Booth described in 13 pages, with graphs, the various microphones used in WW1 to detect artificial earth disturbances. These included the French "Télégéphone" and other microphones, or "seismomicrophones". He showed laboratory results from examining the various types of detectors and, in particular, their sensitivities. He concluded that the 'Télégéphone" was the most satisfactory.

In the very next paper in the Journal (Booth, 1926*b*), he reported on detecting and examining "minute earth vibrations of microseismic nature by means of microphones". This is preceded by a theoretical examination of wave types, including Rayleigh waves.

The next insight into Booth's research, and in particular its use in the IGES, is given in Broughton Edge and Laby (1931), in the section on the Seismic Method written by Booth and R L Aston (of whom, more will follow). In this section they describe the electromagnetic seismometer used by the IGES, and also the hot-wire seismometer patented by "Major Edgar Booth" and first used in the IGES[5].

The electromagnetic seismometer was built at the University of Sydney to a standard principle whereby "the relative motion of inertia mass and framework is translated into relative motion of a coil of wire and a magnetic field". The resulting current produced in the electromagnet from cutting the field is proportional to the relative velocity of the frame, which may be due to seismic ground motion. This principle of operation is the same as still used today in seismic geophones (more typically now with a suspended magnet in an EM coil). Figure 1 illustrates a cut-away section of the seismometer showing its construction including the electromagnet and the coil.

"The hot-wire seismometer first makes use of hydraulic magnification, the inertia mass and frame being arranged as piston and cylinder respectively. Their relative motion forces air through a small orifice containing a grid of fine platinum wire … kept at a dull red heat by an electric current". The air flowing past the wire cools it and hence its resistance (constantly measured by a galvanometer) reduces in proportion to the velocity of the air and so too, the velocity of the ground movement[6]. Figure 2 shows the components of this seismometer, both in section and plan view. According to the way it is mounted it can detect not only the vertical component, but also the horizontal component if mounted vertically, and parts of both components if the mount is inclined to the vertical.

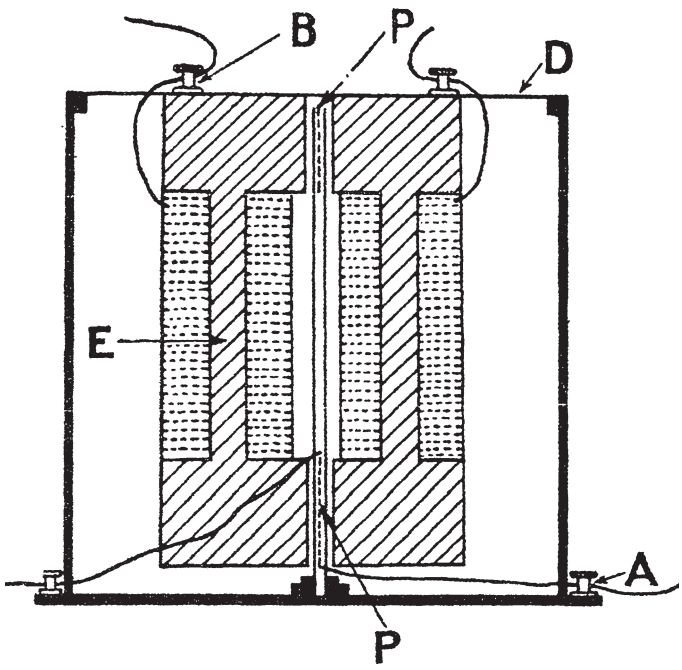

Figure 1. *The electromagnetic seismometer made at the University of Sydney, where E is the electromagnet suspended from the diaphragm, D and P is a thin flat coil passing between the poles of the electromagnet. B is the excitation circuit to E and A is connected to the recorder (from Broughton Edge and Laby, 1931, fig. 259).*

[4]Pollock was a co-inventor, with R Threlfall, of the first gravity meter built in the world, as recalled in Henderson (2015).

[5]That is, Australian Commonwealth Provisional Patent, No. 23,284, by Major Edgar Booth.

[6]How was this principle ever devised? Remarkably, it actually worked! See Figure 3.

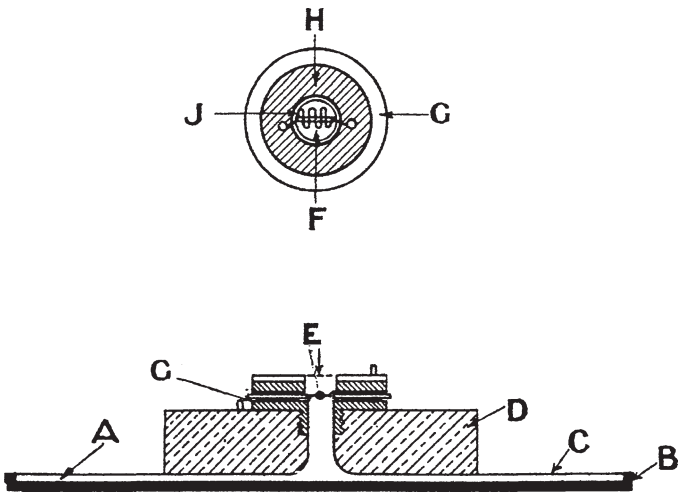

Figure 2. *The essentials of the construction of the hot-wire seismometer are illustrated first in section, where D is the inertia mass, G is a mica disc and then in plan, where F is the hot-wire microphone, J is a fine platinum wire on a porcelain rod (from Broughton Edge and Laby, 1931, fig. 260).*

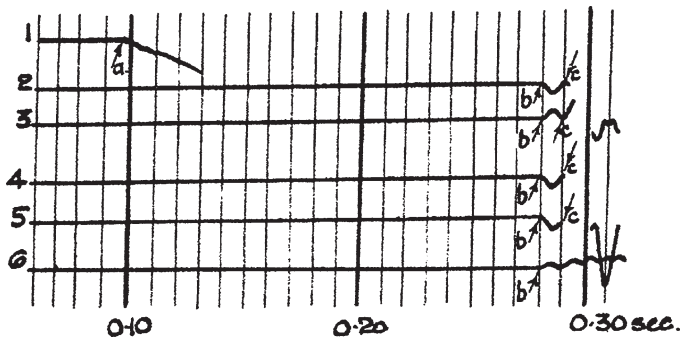

Figure 3. *A typical example of a seismic record from a hot-wire seismograph showing on trace 1 the shot firing time designated by 'a' and the first arrival is indicated by 'b' on each of the other traces (from Broughton Edge and Laby, 1931, fig. 261 (ii)).*

A typical example of a hot-wire seismograph recording as used in the IGES is shown in Figure 3. This must, therefore, be one of the first seismic refraction records produced by Australians.

Booth's involvement in the IGES

The Introduction to the report of the IGES (Broughton Edge and Laby, 1931, p. 4) states, "Major Booth …consented to act as consultant to the Survey in this branch [seismic methods], and on his recommendations the necessary microphones and electromagnetic recording apparatus were obtained". Some of this equipment was from Booth's own designs as described earlier.

Just how much Booth was involved in the field work of the IGES is not clear, as he was not the leader of the field party; although, as we shall see following section 'Booth as a field geophysicist', his activities after the IGES showed he was not averse to field work. The seismic section of the IGES Report (*op cit*, p. (x)) was written jointly by Booth and R L Aston making it one of Booth's 23 publications.

The list of personnel of the IGES (Broughton Edge and Laby, 1931, p. (ix)) has the field leader of the seismic section as the Australian Ronald Leslie Aston, BSc, BE, MSc, who appears to have had no prior experience in seismic methods[7]. This aligns with Booth's statement in his 1938 Presidential Address (Booth, 1938) in regard to the operation of the IGES: "No trained personnel, scientific or otherwise was available in Australia".

Aston was qualified in physics and engineering and, with guidance from Booth, he would have appreciated what was needed to be done in order to conduct a seismic survey. There is no indication of his having conducted any seismic surveys after the IGES or, indeed, engaging in any other geophysical activity.

The seismic method of the type used by the IGES (refraction) was not used by any other Australian crew for at least six years after the IGES. Certainly no surveys of that type were included in Booth's list of surveys, given at the end of his Presidential Address, conducted after the IGES and up until 1937 (Booth, 1938). Whether correct or not, Booth attributes this to seismic being "the most expensive [method] and consequently has regretfully been relegated to the background throughout the financially depressed period [the Depression] elapsing since…". By way of contrast, surveys by other methods, particularly magnetic, which were cheaper, were actively pursued immediately following the IGES[8].

Booth's promotion of geophysical exploration generally.

According to Butcher (1984), "In August 1928, the Australian branch of the Institute of Physics devoted a session to the subject of geophysical prospecting" at which Booth co-authored a paper. "The following year a session was included on 'Seismic Prospecting', at which Booth" was one of the contributors.

On 13 September 1929, Booth gave a "lecture (sic) on Geophysical Prospecting" at the Newcastle School of Arts under the headings of electrical, magnetic, gravity and seismic methods. (*Newcastle Morning Herald and Miners' Advocate*, 1929). "The lecture was illustrated by lantern slides and a short cinematograph film".

Booth's broader knowledge of non-seismic methods may have been gained from publications that were just becoming available, such as those in the possession of E C Andrews of the NSW Department of Mines and described by Henderson (2017).

Booth was President of the Royal Society of New South Wales in 1936-37, and for his Presidential Address chose to speak on the general topic of geophysical prospecting. This address was structured not unlike a series of lectures to students, with each method discussed in a separate section (Booth, 1938)[9]. The theory and instrumentation of all the main methods were outlined in 26 pages, and the surveys conducted since the IGES, in each of the methods (with the exception of the seismic method), were listed in another seven pages.

As Booth said in his introduction to this address, it was customary for the presidential address to be on a subject "with

[7]Aston's biography by Curdie (1993) indicates that for his MSc at Cambridge in 1925 he studied "the effect of boundaries on the deformation of single crystals of aluminium".

[8]These non-seismic surveys conducted after the IGES are detailed in Booth (1938, p. 32–38) and Thyer (1979, p. 247).

[9]This address is also available in book form in the National Library of Australia. https://catalogue.nla.gov.au/Record/2731558

which the retiring President has made himself especially familiar". However, "…my address will be on one not yet covered by a President and one, moreover, of interest and value…to our community". That is, "The subject of geophysical prospecting..."[10].

Booth as a field geophysicist

Three of Booth's papers to the Royal Society of NSW described field surveys, all using the magnetic method. Day (1966) suggests that Booth's forays into the field were "in connection with some purely geological research". However, I believe they were worthy geophysical investigations.

The first paper, which is 14 pages long and was published in 1933 with J M (Jack) Rayner, is titled a "A magnetic survey in the vicinity of a granite bathylith". Its purpose was "to delimit the possible gold-bearing areas" east of Gulgong, NSW (Booth and Rayner, 1933)[11]. It included fold-out plans and magnetometer results plotted as profiles over geological sections. One of the magnetometers used was from the IGES.

A second paper, which was 26 pages long and was published in 1935, reports on "a detailed regional magnetic survey" in the Mittagong-Bowral district "primarily to study the nature of the syenite mass" (known as the 'Gib' or Mt Gibraltar) (Booth, 1935). A third paper, which was five pages long and published in 1937, dealt with "some zonal discordances in diurnal magnetic variations" (Booth, 1937). In this study Booth observed the importance of the distance a local magnetometer recording base may be from the survey areas, a matter which is still of concern today.

Booth's promotion of geophysics teaching.

In his Presidential Address (Booth, 1938) Booth indicated, "one year, 1931, a course was conducted at the University of Sydney by myself, for the Extension Board"[12]. Alan Day (1966) adds that Booth gave on this occasion a "series of sixteen lectures, four demonstrations and three field days in geophysical prospecting". In planning the course at this time, Booth may have benefited from the existence of the detailed Report on the IGES (Broughton Edge and Laby, 1931). If so, was this the Report's first use as a textbook? Butcher (1984, p. 39) notes that "despite his [Booth's] claims that this was a successful exercise, it was not repeated". As we shall see below, that was not for want of trying on Booth's part.

In 1937, Booth wrote a proposal to accompany a letter from the Australasian Institute of Mining and Metallurgy (AusIMM) to the Registrar of the University of Melbourne in which he outlined a possible course in geophysics[13]. The proposed course had two schemes, one for a full-time Chair of Geophysics, both pure and applied, and another for a Professor teaching 'geophysical prospecting' for part of his time. The proposal gave estimated costs including the salary of a Professor (1100 pounds), plus the costs of suggested instruments including horizontal and vertical magnetometers, electrical resistivity and EM equipment, all amounting to 675 pounds[14].

I believe that all this demonstrated that Booth had a strong interest in seeing that geophysics was taught at tertiary level in Australia and took steps to achieve it. As he stated in his Presidential Address, delivered in May, 1937 – a few months before his above proposal for teaching, "no students had yet been trained" (Booth, 1938). The Address concluded with a plea for education in geophysics with, "we could train the students here … we have companies who want to employ them". The last sentence of his Address is, "We have no chair of geophysics at any Australian university".

Conclusions

Published biographies of Edgar Allen Booth suggest that he was a physicist that had a small involvement in geophysics, however, in reality, the teaching and practice of geophysics was a big part of his activities. His geophysical work commenced with his observations of the use of microphones to detect artificial ground motion during WW1, and continued with his subsequent investigations into the nature of seismic theory and development of instrument design. This work resulted in him being chosen to establish the seismic method in the IGES, and would not have happened otherwise. His several talks about geophysics, his own field surveys, and his many published papers on geophysical subjects all confirm his strong interest in the subject. An interest that culminated in his choice of exploration geophysics as the topic of his Presidential Address to the Royal Society of NSW. We can also see from this paper, and Booth's involvement with the AusIMM, that he had an interest in establishing geophysics as a subject in universities.

I suggest that Booth could be regarded as a pioneering geophysicist of some note, and certainly the first Australian to understand and organize the practice of the exploration seismology.

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[10]Butcher (1984) claims that this address was "in fact a long complaint about the lack of interest shown in the subject both at the theoretical and applied levels". Whether it was a "complaint", or not, it was, at least, drawing attention to the prevailing situation.

[11]Jack Rayner was, at this time, the sole geophysicist in permanent government service in Australia (with the NSW Dept. of Mines). He was seconded to the IGES and later became author of the Electromagnetic section of the IGES Report (Broughton Edge & Laby, 1931). Subsequently he conducted several surveys for the Department and various companies. (See Thyer, 1979, p. 247).

[12]The University of Sydney Extension Board provided courses to students unable to attend University.

[13]The letter from the AusIMM, dated 20 September 1937, was a result of its Council approving "of the proposal to establish teaching facilities for geophysics at an Australian University. That is, those "which confer degrees in mining". Melbourne had such a department of mining and metallurgy. (pers comm., Lindsay Thomas).

[14]Booth suggested in his proposal that, as AusIMM were primarily interested in the teaching of geophysical prospecting, the scheme for a part-time Professor should be initiated first.

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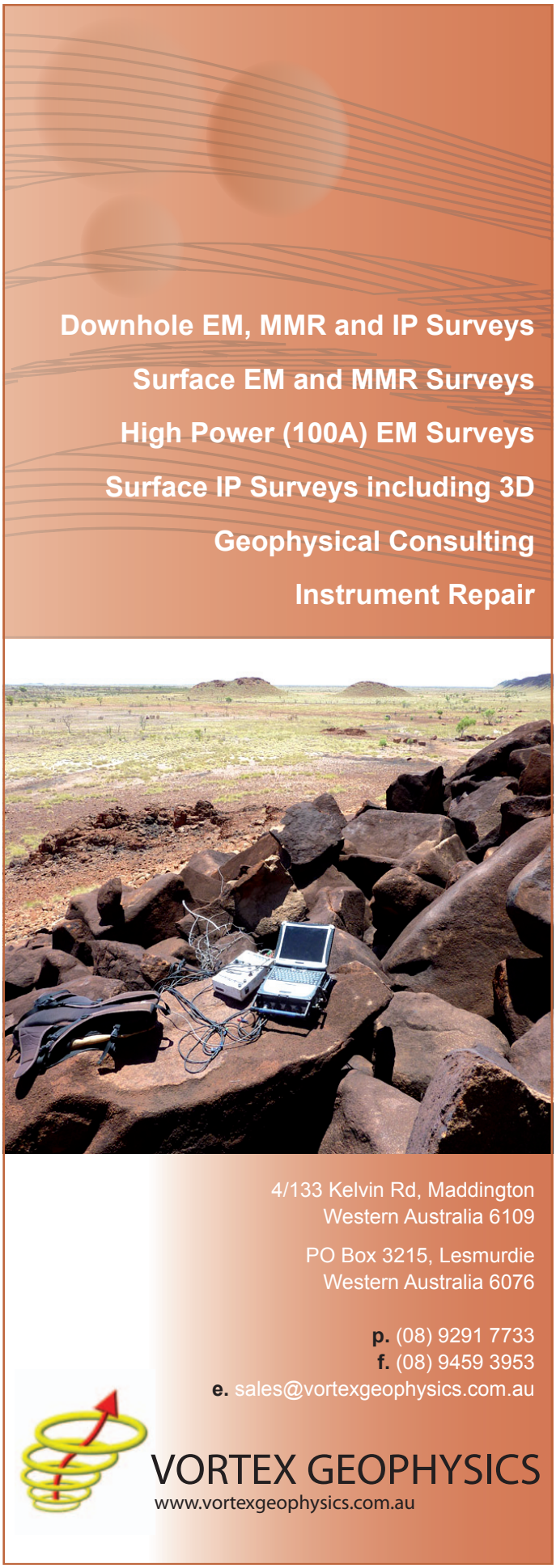

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M: +61 419 696 982
E: mcattach@gapgeo.com

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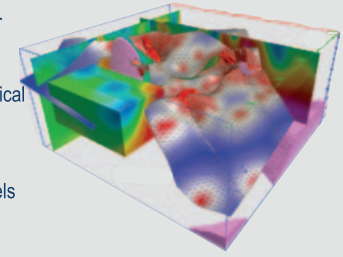

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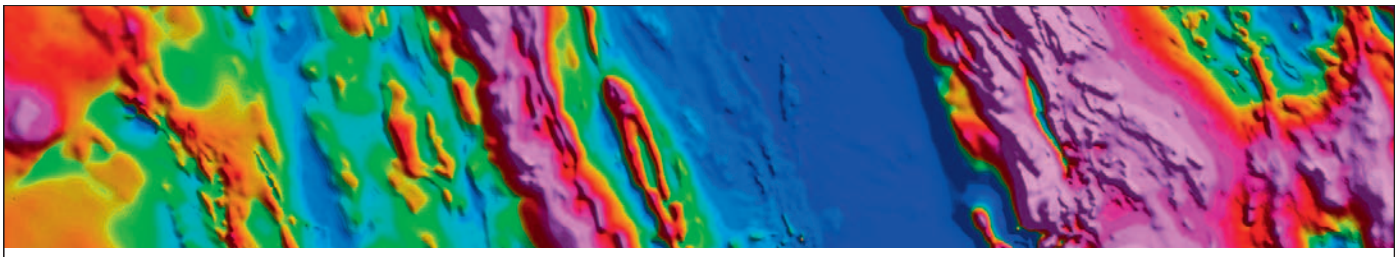

Exploration Geophysics

The Journal of the Australian Society of Exploration Geophysicists

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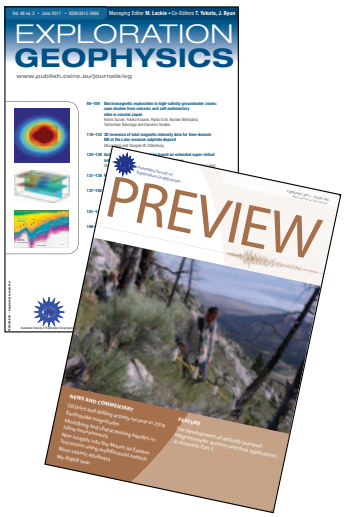

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International calendar of events 2018–20

August	**2018**		
5–7	2018 SEG Reservoir geophysics workshop https://seg.org/Events/Events-Calendar/Reservoir-Geophysics-Workshop	Daqing Oilfield	China
13–20	24th EM Induction Workshop https://emiw2018.emiw.org	Helsingør	Denmark
27–29	EAGE/SEG Workshop on Marine Multi-Component Seismic https://events.eage.org/	Kuala Lumpur	Malaysia
September	**2018**		
2–7	36th General Assembly of the European Seismological Commission http://www.escmalta2018.eu	Valletta	Malta
3	The International Conference on Magmatism of the Earth and related Strategic Metal Deposits http://magmas-and-metals.ru/	Moscow	Russia
10–12	Near Surface Geoscience 2018 https://events.eage.org/	Porto	Portugal
17–19	Maximizing asset value through Artificial Intelligence and Machine Learning https://seg.org/Events/Artificial-Intelligence-and-Machine-Learning	Beijing	China
23–25	SPE Annual Meeting http://www.atce.org	Dallas	USA
24–27	43rd HAGI Scientific Annual Meeting http://events.hagi.or.id/2018/	Semarang	Indonesia
October	**2018**		
1–3	Future Energy Africa 2018: Conference and Exhibition https://www.futureenergyafrica.com/	Capetown	South Africa
3–5	5th International Workshop on Induced Polarization https://ncas.rutgers.edu/academics-admissions/academic-departments/earth-environmental-science/research-initiatives/near-surface-geophysics/5th-international-workshop-induced-polarization	Newark	USA
10–11	EAGE Australasian Workshop on Continuous Improvement in 4D Seismic https://events.eage.org/en/2018/eage-australasian-workshop-on-continuous-improvement-in-4d-seismic	Perth	Australia
14–18	AGC Convention http://www.agc.org.au	Adelaide	Australia
14–19	SEG Annual Meeting https://seg.org/Annual-Meeting-2018	Anaheim	USA
November	**2018**		
4–7	2018 GSA Annual Meeting https://www.geosociety.org/GSA/Events/Annual_Meeting/GSA/Events/gsa2018.asp	Indianapolis	USA
4–7	AAPG International Conference & Exhibition 2018 http://capetown2018.iceevent.org/	Capetown	South Africa
12–14	13th SEGJ International Symposium http://www.segj.org/is/13th/	Tokyo	Japan
13–15	Fourth AAPG/EAGE/MGS Myanmar Oil & Gas Conference	Yangon	Myanmar
December	**2018**		
10–14	AGU Fall Conference	Washington, DC	USA
May	**2019**		
6–9	Offshore Technology Conference http://2019.otcnet.org/welcome	Houston	USA
19–22	GEM 2019 Xi'an	Xi'an	China
June	**2019**		
11–13	AGU/SEG Airborne Geophysics Workshop	Golden	USA
September	**2019**		
15–20	SEG International Exposition and 89th Annual Meeting	San Antonio	USA
October	**2020**		
11–16	SEG International Exposition and 90th Annual Meeting	Houston	USA

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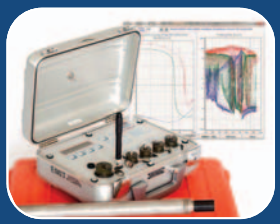

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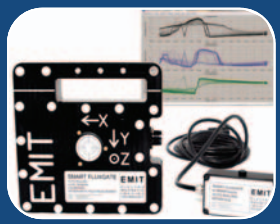

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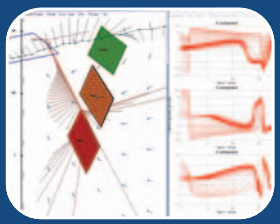

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