Australian Society of Exploration Geophysicists

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PREVIEW

AEGC2018 FIRST AUSTRALASIAN EXPLORATION GEOSCIENCE CONFERENCE

18-21 FEBRUARY 2018 | SYDNEY AUSTRALIA

EXPLORATION • INNOVATION • INTEGRATION

Australian Society of Exploration Geophysicists

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AUSTRALIAN INSTITUTE OF GEOSCIENTISTS

NEWS AND COMMENTARY

CONFERENCE HANDBOOK

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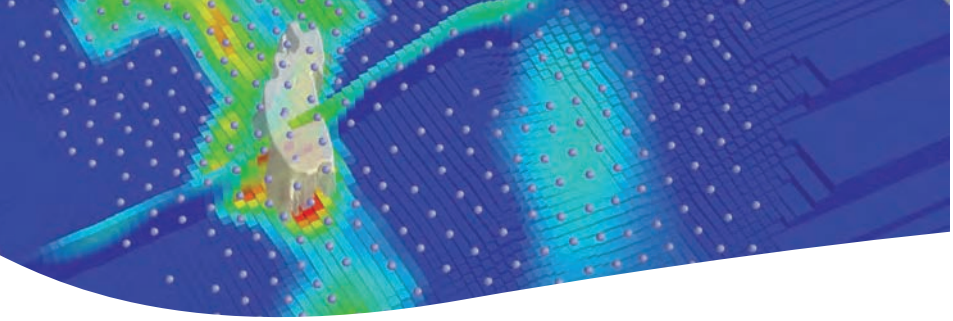

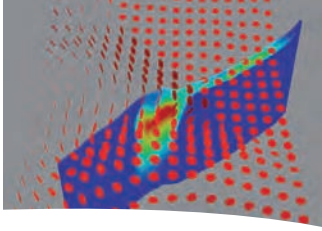

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Editor's desk

This issue of *Preview* features the Conference Handbook for Australasian Exploration Geoscience Conference 2018 (AEGC 2018). AEGC 2018 is an exciting new collaborative venture between ASEG, PESA and AIG. Like most new ventures it has had teething problems, and your feedback via ASEG, PESA or AIG will be important in terms of improving the organisation of any future conferences.

If you are not an ASEG Member you may be new to *Preview*, and it is my pleasure to introduce the magazine to you. *Preview* is published by the ASEG on a bimonthly basis and is freely available online (http://www.publish.csiro.au/pv). You can subscribe to a free email early alert or RSS feed via http://www.publish.csiro.au/journals/earlyalert. You can also follow the magazine on twitter using the hashtag #PreviewASEG. *Preview* contains news and commentary of interest to all geophysicists practising in the minerals, petroleum and environmental sectors. We also carry feature articles – which are less technical in nature than articles published in the ASEG journal, *Exploration Geophysics*.

As well as the Conference Handbook, this issue of *Preview* contains news from all the geological surveys in Australia and contributions from our usual commentators. David Denham (*Canberra observed*) reviews 2017 from the perspective of the resource sector, considers the future of coal and brings us up to speed with the latest news on acreage release for offshore petroleum exploration. Michael Asten (*Education matters*) takes us on board the *Joides Resolution*. Mike Hatch (*Environmental geophysics*) pulls one out of the hat with a piece on converting EM data into music. Terry Harvey (*Mineral geophysics*) contemplates the question of when enough is enough in exploration. Mick Micenko (*Seismic window*) takes a close look at acquisition footprints or anisotropy, and Dave Annetts (*Webwaves*) takes time out to introduce non-ASEG Members to the delights of the ASEG website.

Lots to enjoy in quiet moments during, or after, AEGC 2018!

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

President's piece

Andrea Rutley

It is with pleasure that I welcome you all to the first Australasian Exploration Geoscience Conference, incorporating the 26th ASEG Conference and Exhibition. Sydney is a fantastic city and a great location to host the conference. With the themes of Exploration, Innovation and Integration we will be treated to a fantastic few days of geoscience, which will no doubt stay with us for many years. The integration of all our geoscience disciplines is an ideal opportunity for us all to explore aspects of our professions that we may not have considered in detail. Not only will we have the opportunity to hear from experts in their fields, but we will also have networking opportunities that can only enhance our continual professional development.

The joint organising committee has excelled in providing a program of oral and poster sessions that cover a diverse range of disciplines, captured over three days. Additionally, the exhibition space will be filled with local and international exhibitors keen to promote their latest technology. These provide excellent opportunities to review the latest and greatest on offer, and to share an evening drink with colleagues and ponder how to implement all the innovations at once!

With so much on offer for the duration of the conference it is hard to imagine why you would want to stray from the Convention Centre, but should you feel the need, Sydney is a destination in itself to explore. There are quite a number of restaurants and bars all within close proximity to the Centre, providing ideal venues to continue the networking into the evening.

The conference program starts strong, with keynote addresses in Coal, Case Histories, the Western Australian Basins Symposium and geophysical streams. The diverse range and depth of knowledge that is being presented at the conference will surely keep everyone fully engaged for the three days.

On behalf of the ASEG, I thank the organising committee for their huge effort in putting together this conference, and as delegates, presenters and exhibitors, I welcome you all to Sydney and to the first Australasian Exploration Geoscience Conference.

Andrea Rutley
ASEG President
president@aseg.org.au

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INSTRUMENTATION FOR GEOSCIENCE APPLICATIONS

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MS2/MS3 Magnetic Susceptibility System for laboratory, field and borehole applications. Resolution down to $2x10^{-6}$ SI. Used in environmental magnetics and oil & gas exploration. Deep borehole tool, with operation to 6000m, for use in mineral exploration.

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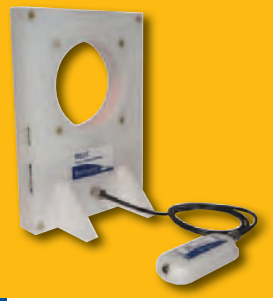

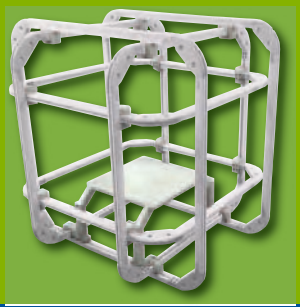

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ASEG Branch news

Australian Capital Territory

The ACT Branch was excited to begin 2018 by hosting guest speaker Dr **Carina Kemp** in January. Carina presented on *Leveraging New Technologies from the Web to Improve Data Delivery: Implications for Geophysical Data*. The presentation detailed the latest developments in data delivery for magnetics, radiometrics, gravity and AEM data for Geoscience Australia. These developments were made possible by leveraging technologies outside those used by the typical exploration geophysicist. Carina also highlighted the potential for these new technologies to be applied to delivery of 3D geophysical inversion models.

Also, the ACT Branch is looking forward to a number of events this year so keep an eye out for more details on the following:

- The ACT Branch Annual General Meeting with guest speaker **Simon van der Wielen** presenting on *The Geophysical Reference Model of South Australia* (15 March)
- SEG Workshop on *Seismic Anisotropy: Basic Theory and Applications in Exploration and Reservoir Characterisation* presented by **Professor Ilya Tsvankin** (5–6 April)
- SEG Honorary Lecturer **Mazin Farouk**i presenting on *Dense Sampling in Marine Seismic: Efficiency in Acquisition without Compromising Data Quality* (date TBA)

Wishing you all an enjoyable time at the AEGC 2018 conference this month!

James Goodwin
actpresident@aseg.org.au

New South Wales

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 last Queensland Branch meeting for 2017 enjoyed a UQ honours student presentation. **Mitchell Simpson** presented *Analysis of Azimuthal Anisotropy in Shallow-Target 3D-3C Seismic-Reflection Data*. The presentation was well attended and equally well received. We wish Mitchell success in his new role at Woodside in 2018.

We will be starting the year with a presentation by **Sylvia Michael** on February 6. We are currently looking for speakers to fill our calendar for 2018, if you would like to volunteer a talk please contact qldpresident@aseg.org.au or qldsecretary@aseg.org.au.

An invitation to attend Queensland Branch meetings is extended to all ASEG Members and interested parties. Details of all upcoming Queensland events can be found on the Qld Events tab on the ASEG website.

Fiona Duncan
qldpresident@aseg.org.au

South Australia & Northern Territory

Since the last edition of *Preview*, the SA/NT Branch has only held one event, our final one for 2017 and one that was a very relaxed and enjoyable lead-in to the Christmas and New Year period. This event was our November technical evening, Annual Student Night and Christmas Party. It was as popular as ever, with a great turnout in support of the local students who gave presentations on their recently completed honours projects. **Sam Jennings**, **Ania Manka**, and **Ben Kay** all did a fantastic job presenting the background and results of their chosen areas of study, with a very interesting variety of topics from identification of fluid pathways in the deep crust using magnetotellurics, to the importance of very shallow lithological effects on seismic depth conversion, with some compositionally based thermal conductivity modelling in between. Special congratulations go to Ben Kay, who was awarded the prize for the best presentation but, as only a handful of votes separated the three speakers, all the students should be congratulated on the quality and content of their projects and the enthusiasm with which they presented to the Branch.

After the official business of the evening was complete, all the attendees were invited to stay and celebrate the festive season. The Branch thanks each of the speakers for their efforts and willingness to present, and also all the Members who came along to support and vote for them and to make the evening a success.

The local Branch held a number of other successful technical talks, student events and other industry events in 2017, with numerous local, interstate and overseas guest speakers. The Branch also has a healthy social calendar. We would like to thank all of our 2017 sponsors, the Department of the Premier and Cabinet, Beach Energy, Minotaur Exploration, and Zonge. Without their support we would not be able to hold such full program of events for the local Members. We will be in touch with all our 2017 sponsors hoping they will return for 2018. Of course, if you or your company are not in the above list and would like to offer your support, please get in touch at the email address below.

I would also like to thank the 2017 Branch Committee, with special mentions to **Adam Davey** our Treasurer and **Mike Hatch** our Secretary for all of their hard work, especially given the amount of extra time some of our events require. Also thanks must go to **Phil Heath**, the continual driving force behind the SA/NT Branch Wine offer and our representative on the SAEMC committee. Every committee member's efforts are much appreciated by me and the local Branch Members alike. For everyone continuing, I look forward to working with you in 2018. We also welcome any interested Members to the local committee and any commitment, large or small, is appreciated.

Please keep an eye out for events in 2018 on the website and in your inbox. As usual, further technical meetings will be held monthly at the Coopers Alehouse on Hurtle Square in the early evening. We start in March with the AGM, date TBA but following AEGC 2018. If you are interested in joining the committee or holding a position on the Branch Executive, nomination forms will be sent out early next year.

We invite all Members, both SA/NT and interstate to attend any of our meetings and, of course, any new Members or interested persons are also very welcome

to join us. For any further information or event details, please check the ASEG website under SA/NT Branch events and please do not hesitate to get in touch at joshua.sage@beachenergy.com.au or on 8338 2833.

Josh Sage
sa-ntpresident@aseg.org.au

Tasmania

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

The Victorian Branch of the ASEG welcomes you to 2018 and, wherever you are, we look forward to bringing you another exciting calendar of events. Welcome, welcome, welcome!

We concluded 2017 with the traditional end of year joint ASEG-PESA Christmas technical meeting, which was held at the Kelvin Club on 13 December. Branch Members had the pleasure of hearing from two of the petroleum industry's most seasoned entertainers; Kevin Hill and Dave Moreton. Messrs Hill and Moreton presented *Turkey Talk Two: Geology and Ancient Civilizations in West Anatolia, Turkey* to a captivated audience.

As customary, we expect to kick off the year with the annual joint Summer Social. Date and venue are yet to be finalised so keep an eye out for further information. What's more, if you haven't already done so, your Committee Members encourage you to renew your ASEG membership for 2018. Your support is crucial to the on-going efforts of your Society and ensures we continue to remain at the frontiers of our industry!

Finally, the very first ever Australasian Exploration Geoscience Conference will be held in Sydney from the 18–21 February 2018. Early bird registrations have already closed but there's still ample time to get in! Don't miss out!

Thong Huynh
vicsecretary@aseg.org.au

Western Australia

The WA Branch finished 2017 having provided a good number of technical and social events for our Members, including eight tech night presentations, a SEG Distinguished Lecturer presentation, the ASEG-PESA Golf Day, a SEG DISC EM Workshop, and the Christmas Party.

The number of events was down during 2017 due to a shortage of SEG Honorary and Distinguished Lecturers and SEG DISC and OzSTEP workshops, however, we are hoping to see this situation reversed in 2018 with more workshops and lectures on offer.

The Annual General Meeting and Christmas Party was held in December 2017, with all statutory positions contested. Effective January 2018, the following people were elected to statutory positions:

- Heather Tompkins – President
- Matt Owers – Secretary
- Matthew Cooper – Treasurer

In 2017 the WA Branch received a strong level of sponsorship support for our Tech Night events. We would like to thank our annual sponsors: Platinum Sponsor; Globe Claritas, Gold Sponsors; Teck, HiSeis, Southern Geoscience, Western Geco, Geosoft, First Quantum, Resource Potentials, GPX Surveys, and NRG, and Silver Sponsors; Explore Geo, Atlas, CGG and NGI, as well as a private donor who made a contribution in memory of Marion Rose, a pioneering woman in geophysics who sadly left this world too soon.

Thanks to the generosity of all of our sponsors we have been able to bring Members a wide variety of free technical events throughout 2017. We look forward to maintaining strong relationships with our sponsors in 2018, and would welcome any new sponsors.

The calendar for 2018 is starting to be populated, including SEG Honorary Lecturer **Mazin Farouki** presenting on dense sampling in marine seismic in May. If you have any suggestions for presenters for 2018 please email either the WA Branch President or Secretary. The next ASEG Conference will be in Sydney in February, now a combined conference with PESA and AIG; the AEGC 2018. The program has now been released for this conference and it is looking like another excellent event!

I would like to take this opportunity to thank the WA Branch Committee and event volunteers who work tirelessly to bring you our diverse range of technical and social programs; specifically **Brett Adams, Brett Harris, Prue Leeming, Lianping Zhang, Carolina Pimentel, Emanuelle Frery, Cameron Adams, Shane Mule, Amir Hashempour Charkhi, Tim Dean, Andrew Fitzpatrick**, our outgoing Secretary **David Farquhar-Smith**, and our Treasurer **Heather Tompkins**. The activities of the Society would not be possible without these people!

Kathlene Oliver (outgoing President)
wapresident@aseg.org.au

ASEG national calendar: technical meetings, courses and events

Date		Branch	Event	Presenter	Time	Venue
18	Feb	National	YPN Presentation skills workshop	Doug Knight	0900–1600	TBA, Sydney
18–21	Feb	National	AEGC 2018	Various		International Convention Centre, Sydney
06	Feb	QLD	Tech night	Sylvia Michael	TBA	XXXX Brewery, Cnr Black Street and Patten Street, Milton, Brisbane
	Mar	SA-NT	AGM	TBA	1730	Coopers Alehouse, Hurtle Square, Adelaide
15	Mar	ACT	AGM	Simon van der Wielen	TBA	Sir Harold Raggatt Theatre, Geoscience Australia, Symonston, Canberra
	Apr	ACT	SEG HL	Mazin Farouki	TBA	Sir Harold Raggatt Theatre, Geoscience Australia, Symonston, Canberra
5–6	Apr	ACT	SEG workshop	Ilya Tsvankin	TBA	Sir Harold Raggatt Theatre, Geoscience Australia, Symonston, Canberra
18	Apr	ACT	ASEG AGM	TBA	1800	Sir Harold Raggatt Theatre, Geoscience Australia, Symonston, Canberra
	May	WA	SEG HL	Mazin Farouki	TBA	TBA

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

Notice of Annual General Meeting (AGM)

The 2018 AGM of the Australian Society of Exploration Geophysicists (ASEG) will be held at Geoscience Australia in Canberra on 18 April. The meeting will be hosted by the ACT Branch. Details to be supplied via email. Drinks will be available from 6:00 pm and the meeting will begin at 6:30 pm.

The business of the Annual General Meeting will be:

- To confirm the minutes of the last preceding general meeting;
- To receive from the Federal Executive reports on the activities of the Society during the last preceding financial year;
- To receive and consider the financial accounts and audit reports that are required to be submitted to Members pursuant to the Constitution and to law;
- To consider and if agreed approve any changes to the ASEG Constitution;
- To report the ballot results for the election of the new office holders for the Federal Executive;
- To confirm the appointment of auditors for 2018.

The AGM will be followed by a scientific presentation. The speaker and title will be advised closer to the event.

Invitation for candidates for the Federal Executive

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

In accordance with Article 8.2 of the ASEG Constitution '…The elected members of the Federal Executive are designated as Directors of the Society for the purposes of the [Corporations] Act'.

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

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

These officers are elected annually by a general ballot of Members. Marina Costelloe was elected as President-Elect in 2017 and as such will stand for the position of President.

The following officers are also recognised:

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

These officers are appointed by the Federal Executive from the volunteers wishing to serve the Society.

Nominations for all positions (except Past President) are very welcome. Please forward the name of the nominated candidate and the position nominating for, along with the names of two Members who are eligible to vote (as Proposers), to the Secretary:

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ASEG Secretary
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PO Box 576
Crows Nest
NSW, 1585
Tel: (02) 9431 8622
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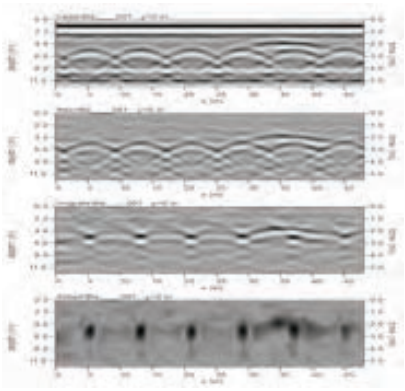
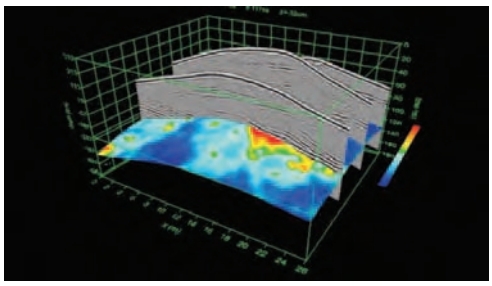
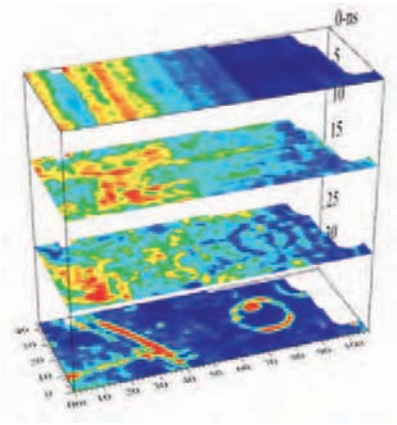
Email: fedsec@aseg.org.au

Nominations must be received via post, fax or email no later than COB Tuesday 7 March 2018. Positions for which there are multiple nominations will then be determined by ballot of Members and results declared at the Annual General Meeting.

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







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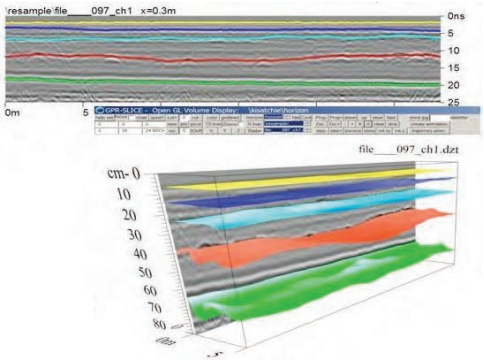

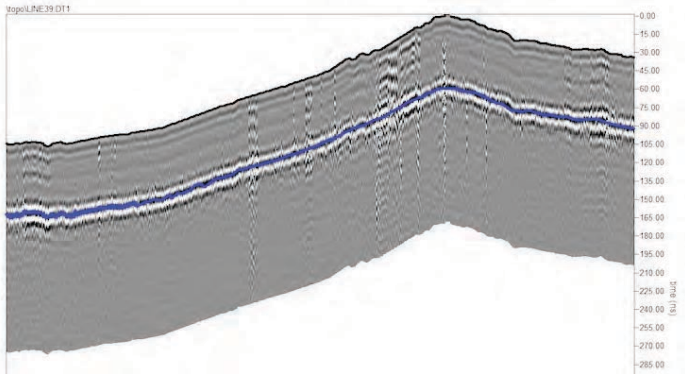

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Geophysics at Geoscience Australia: new data and innovation

Geoscience Australia (GA) exists to meet the geoscience information needs of the Australian Government. GA's strategic priorities are focussed on six key areas:

(i) building Australia's resource wealth;
(ii) ensuring Australia's community safety;
(iii) securing Australia's water resources;
(iv) managing Australia's marine jurisdictions;
(v) providing fundamental geographic information; and
(vi) maintaining geoscience knowledge and capability.

For more than six decades GA has been collecting geophysical datasets over the Australian region with the provision to the public of pre-competitive geophysical data a fundamental activity of the agency. Geophysical surveys have collected magnetic, radiometric, gravity, airborne electromagnetic, seismic (passive and active), nuclear magnetic resonance, induction, gamma and magneto-telluric datasets at various resolutions depending on the aims of the respective surveys. Through collaboration with governments at all levels, GA is the custodian of the largest publicly available geophysical databases in Australia. These geophysical databases can then be combined with other geoscientific datasets (e.g. geology, geochemistry, geochronology and hydrogeology) to enable GA to build and map the national geological and hydrogeological framework of the continent in order to inform resource exploration and development. This knowledge is publicly available to enable the development of new methods and tools, and new data interpretations to accurately assess the resource prospectivity of the Australian continent. This information enables industry to explore and invest in Australia with confidence.

In addition to the resources-aligned geophysics activities, GA continues to use geophysical methods to support the Australian Government in many diverse areas. These include the search for MH370 and other bathymetric mapping, maintaining the navigation and the geodetic reference frame, global positioning, hazard monitoring (such as bushfires, earthquakes, tsunami, floods), secular earth observation through remote sensing and monitoring for the Comprehensive Test Ban Treaty.

Onshore geophysical activity

Exploring for the Future is a $100.5 million program (2016–2020) to provide new pre-competitive data and knowledge in order to attract exploration investment into Northern Australia and parts of South Australia. The program is a collaboration between GA and the governments of Queensland, Northern Territory, Western Australia and South Australia. A large proportion of the budget is being spent on acquiring new geophysical datasets, including: large regional and transcontinental surveys of passive and active seismic, airborne electromagnetic, gravity, and magnetotelluric methods. These data will be complemented by more focussed geophysical studies such as ground magnetic resonance. These geophysical datasets will be released once they are processed and will be integrated with complementary geological, hydrogeological, geochemical, remote sensing and geochronological studies into a thorough understanding of the region's geology and prospectivity for minerals, energy and groundwater resources.

Exploring for the Future is a $100.5 million initiative by the Australian Government dedicated to:

Petroleum exploration

One of the major achievements by the Exploring for the Future Program was the completion, in early August 2017, of the acquisition of deep crustal seismic reflection data in the region between the southern McArthur Basin to the Mt Isa western succession (Figure 1), crossing the South Nicholson Basin and Murphy Province. Five seismic lines were acquired totalling 1100 line km with two of the seismic lines to the east linking with existing deep crustal seismic data in the Mount Isa western succession.

Other new data of the South Nicholson Basin has been released; this was collected by a gravity survey GA conducted in July 2017 across a 43 330 km^2 area over the basin. These gravity

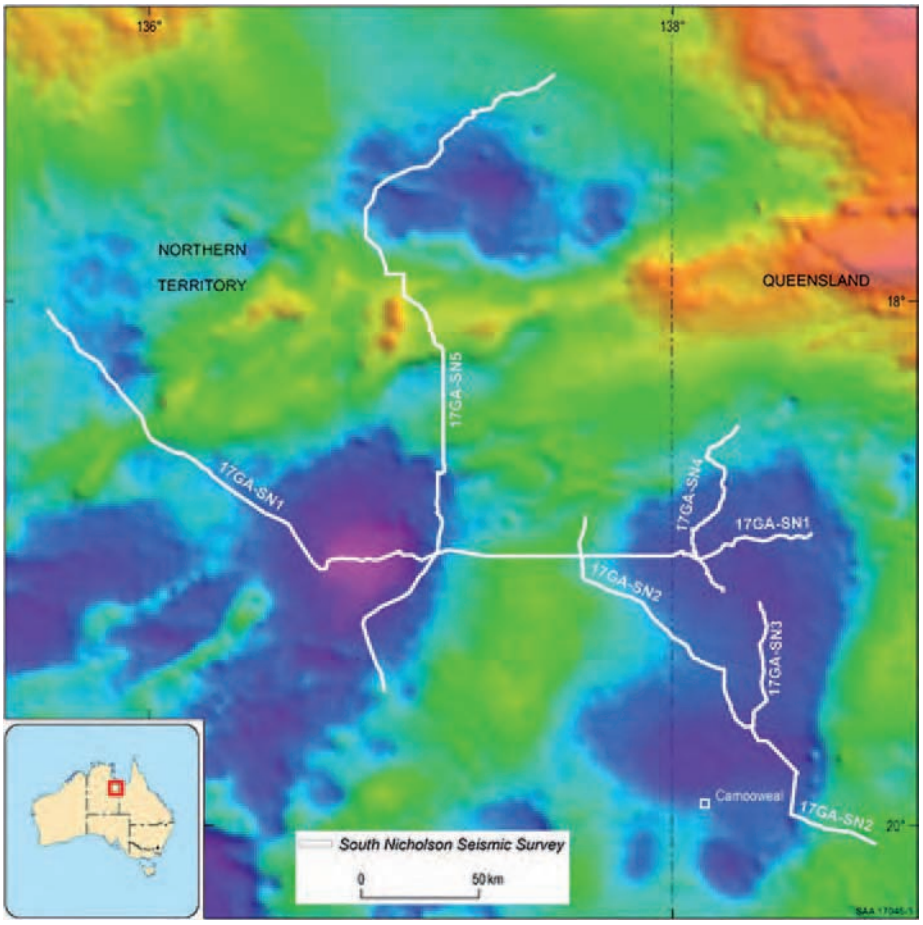

Figure 1. *South Nicholson Seismic Survey 2017 location with coloured Bouguer gravity image from the National Gravity dataset.*

data were the first data to be released through the Exploring for the Future Program. The public release of the final processed seismic data is expected in early-mid 2018.

Further information on the Exploring for the Future program is available in this edition of *Preview*.

Mineral exploration

The National Mineral Exploration Strategy was endorsed by the COAG Energy Council in June 2017. This strategy emphasises the importance of pre-competitive data and tools in reducing exploration risk to attract exploration investment in greenfields areas. The Strategy along with head agreements between GA and each of the state and the NT geological surveys allows excellent inter-jurisdictional collaboration and as such GA is a project partner in many of the large geophysical activities across Australia (Figure 2). GA manages the deeds, panels, contract and procurement process, QA/QC requirements and storage and delivery of the data. This is a significant part of our geophysical work and it ensures geophysical data are well maintained, consistent and seamless, high quality and available in the National databases.

Figure 2 shows the recent surveys and activities across the entire continent, which includes the significant injection of work from the Exploring for the Future program. The quantum of work to date at end 2017 includes >2 million line km of airborne magnetics and radiometrics, >300 000 line km of air gravity, 2000 ground gravity stations, almost 100 000 line km of airborne electromagnetics (AEM), 1100 km deep crustal reflection seismic, reprocessing of 5500 km of seismic, 180 long-period MT and 500 broadband MT sites acquired. In the first half of 2018 we expect to acquire a further 1 million line km of airborne magnetics/radiometrics, 100 000 line km of air gravity, 1530 line km of deep seismic and 40 000 line km of AEM. This data acquisition program is a tens of millions of dollars investment by Government in pre-competitive data and is a major contribution to revealing the prospective geology of Australia.

Of particular note in 2017 was the commencement of the AusAEM and AusARRAY surveys, which are wide-spaced airborne electromagnetic data (20 km nominal line spacing) across much of Northern Australia, and deployment of 120 new portable passive seismic recorders and 10 semi-permanent recorders respectively. A fleet of 35 new long-period magnetotelluric instruments were also purchased and these recorders are currently deployed as part of the ongoing AusLAMP project. These new national datasets will complement existing magnetic, gravity and radiometric datasets that have been instrumental in many mineral discoveries. Completion of these new national maps will position Australia as the best imaged continent on the planet, and will ensure Australia remains a highly desirable investment destination for minerals and other resource exploration and discovery.

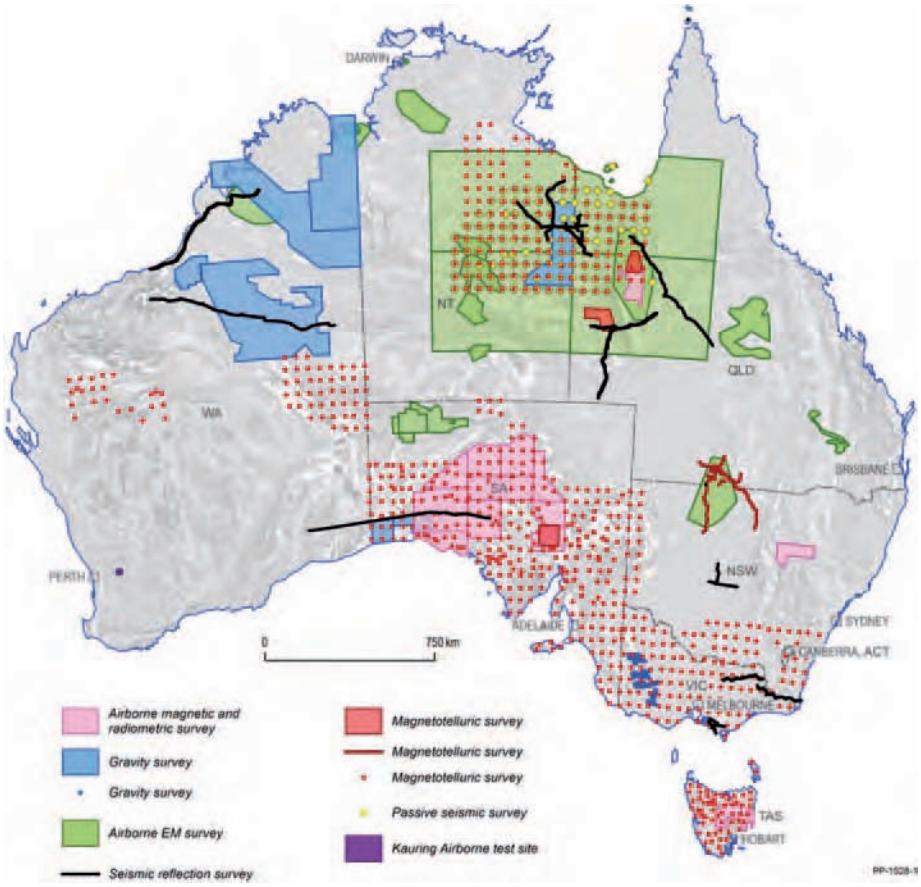

Figure 2. *Map of significant recent and current onshore geophysical surveys on grey-scale TMI that are led by GA's Mineral Systems Branch with funding from Exploring for the Future and Initiative funding from the states and Northern Territory governments.*

Many of the geophysical datasets are being collected on a scale not previously attempted. Data processing, modelling and interpretation on such a large scale requires innovative computing solutions. All code is being made available on the GitHub shareware site and will be incorporated into the Australian National Virtual Geophysical Laboratory (ANVGL). The first of these is the machine learning codes GA developed in collaboration with Data61 which are available at https://github.com/GeoscienceAustralia/uncover-ml. GA ran a successful workshop on *Inverse Methods for Cover Thickness Determination* in Perth in December 2017, which gave users the skills and codes to run passive seismic (trans-dimensional), MT and AEM inversions.

Groundwater exploration

GA uses airborne electromagnetics (AEM) to rapidly map and identify fresh groundwater resources and managed aquifer recharge (MAR) opportunities in 'frontier' areas of Australia and deliver sustainable management outcomes in a wide variety of landscapes and geological settings. In Australia, the application of electromagnetic methods for hydrogeological investigation is complicated by the highly salinised nature of many landscapes, and variable weathering and cementation that can significantly modify the hydraulic properties of sediments.

To overcome these issues, GA is using a novel multi-disciplinary, multi-physics, systems-based approach to map, characterise and assess hydrostratigraphic, structural and groundwater elements

in the shallow sub-surface in 3-dimensions. GA is also utilising new ground geophysical sensors such as ground magnetic resonance (GMR), complementing AEM and providing key aquifer and aquitard properties using non-invasive techniques. These non-invasive methods help reduce costs while enabling the production of a series of advanced hydrogeological information products that can be used to target more selective drilling and pump tests, and hydrogeochemical and hydrogeological investigations.

These approaches have been successfully applied in the Lower Darling Valley, New South Wales, and Fitzroy River and Ord Valley, Western Australia and are currently being applied as part of the Exploring for the Future program (see the Exploring for the Future article elsewhere in this issue of *Preview*).

Offshore geophysical activity

GA continues to acquire pre-competitive geophysical data on Australia's continental margin. Most recently data acquisition has taken place over the Lord Howe Rise as part of a collaborative project with the Japan Agency for Marine-Earth Science and Technology (JAMSTEC).

The objectives of the International Ocean Discovery Program (IODP) deep stratigraphic drilling are to:

- define the role and importance of continental crustal ribbons, like the Lord Howe Rise, in plate tectonic cycles and continental evolution;
- recover new high-latitude data in the southwest Pacific to better constrain Cretaceous paleoclimate and linked changes in ocean biogeochemistry; and
- test fundamental evolutionary concepts for sub-seafloor microbial life over a 100-million-year timeframe.

The aim of the project is to drill a deep stratigraphic well through a rift basin on the Lord Howe Rise, off eastern Australia. This seismic acquisition follows that performed in 2016 (GA0354) (Figure 3) for which the well site seismic reflection data is available for download via NOPIMS (http://www.nopims.gov.au/) or email (ausgeodata@ga.gov.au). This new site survey (GA0363) involved high-resolution seabed and shallow sub-sea floor mapping, collection of shallow (<20 m below-sea floor) sediment cores and underwater video at the sites being considered for drilling. Information from this detailed mapping and sampling will be used to understand the geotechnical properties of the seabed affecting drilling operations and contribute to the environmental permitting process for the drilling project. These data will also contribute valuable baseline environmental information describing deep-water habitats in a remote area of Australia's maritime jurisdiction (http://www.ga.gov.au/about/projects/energy/lord-howe-rise).

More information about Geoscience Australia's geophysical programs can be obtained from Murray Richardson: murray.richardson@ga.gov.au, (02) 6249 9229.

Please visit us at AEGC booth 75 and 76.

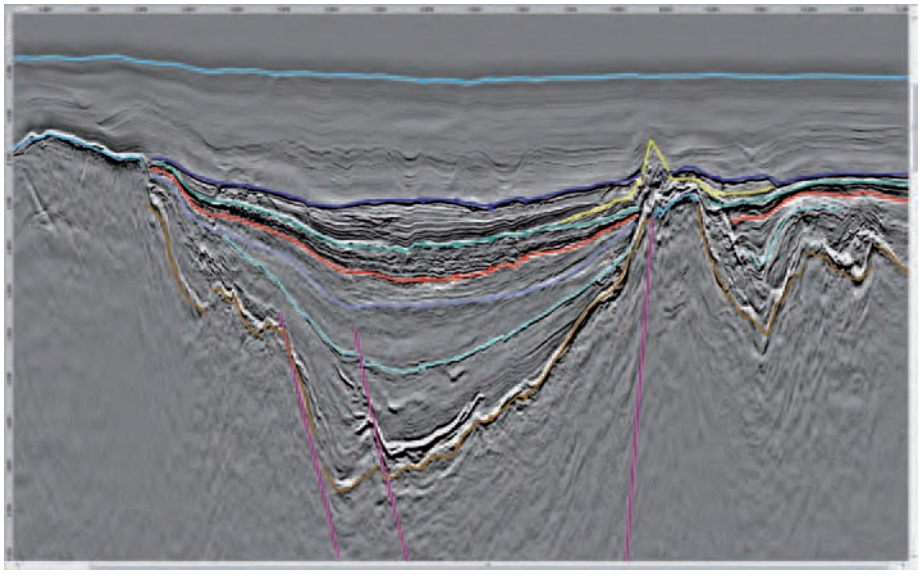

Figure 3. *GA0354 Lord Howe Rise Site Survey PreSTM.*

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News from the Geological Survey of South Australia

State images

In 2017 a new edition of South Australia's gravity grid was released. The new grid utilised a gridding methodology developed in the Geological Survey of South Australia, namely supervised variable density gridding. Approximately 530 000 ground gravity stations were used in the grid in a systematic, iterative process that combines GIS geoprocessing with minimum curvature gridding. A report book detailing the methodology has been released and is now available, along with grids and data package at https://goo.gl/zXQPok. The recently acquired Coompana gravity survey will be integrated into the next edition of the South Australian gravity grid.

Airborne Surveys

The Gawler Craton Airborne Survey commenced in January 2017 and will conclude in 2018 (Figure 2). The survey is currently the largest in South Australia's history, with 1.87 million line kilometres of magnetic, radiometric and elevation data collected at 200 m line spacing with a nominal terrain clearance of 60 m. The survey is setting new benchmarks in the way the South Australian government works with landholders and survey contractors resulting in high quality community information and data (Figure 3). The survey results display significant improvements in clarity and geological detail. Collaboration with CSIRO will add significant value to the data by producing a range of analytic and interpretive products, including magnetic depth-source models.

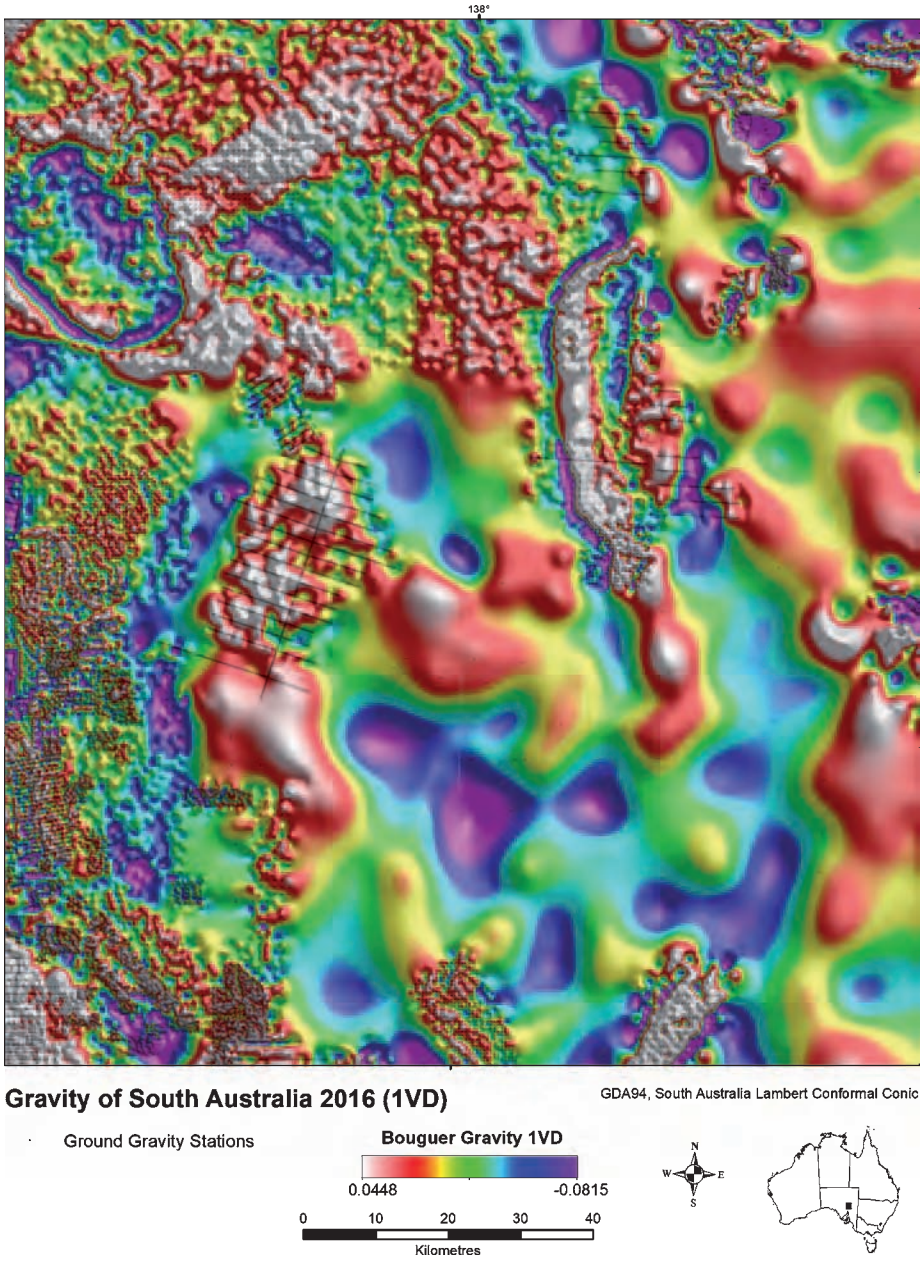

Figure 1. *Portion of the 2017 South Australian state wide gravity grid (1VD), illustrating the seamless result of the supervised variable density gridding process on gravity stations at a range of densities and configurations.*

Lithospheric Architecture Team

The Australian Lithospheric Architecture Magnetotelluric Program (AusLAMP) has covered about 95% of South Australia, with about 30 long-period MT sites remaining in the APY Lands. In 2017, the PaceCopper funded extension of the grid to the north-east of the state has improved our understanding of the north-eastern boundary of the Gawler craton and illuminated the poorly understood lithosphere beneath the Cooper Basin.

Outcomes in the form of 3D inversion resistivity models of the crust and mantle were presented at the Geological Survey of South Australia (GSSA) annual showcase event, Discovery Day, in December 2017, as well as at the international AGU conference in New Orleans, USA. Integration of the results with other geological data sets will be presented at the upcoming AEGC conference in Sydney, February 2018.

An outcome of the AusLAMP surveys is detailed in-fill magnetotelluric surveys using broadband equipment across areas of enhanced crustal conductivity. In 2017, the University of Adelaide conducted the Curnamona in-fill survey along a 2D EW profile funded by the GSSA PaceCopper program to map enhanced conductivity pathways into the upper crust associated with the Benadgerie Ridge.

The GSSA's own PaceCopper-funded Olympic Domain in-fill survey will begin in March 2018 covering an area spanning roughly 100 km x 100 km with over 330 broadband and audio-magnetotelluric stations. The aim of the survey is to map the upper and mid-crustal conductivity zones to the surface based on low-resolution conductive zones underneath the Stuart Shelf from AusLAMP surveys. The data will be augmented by 3 km

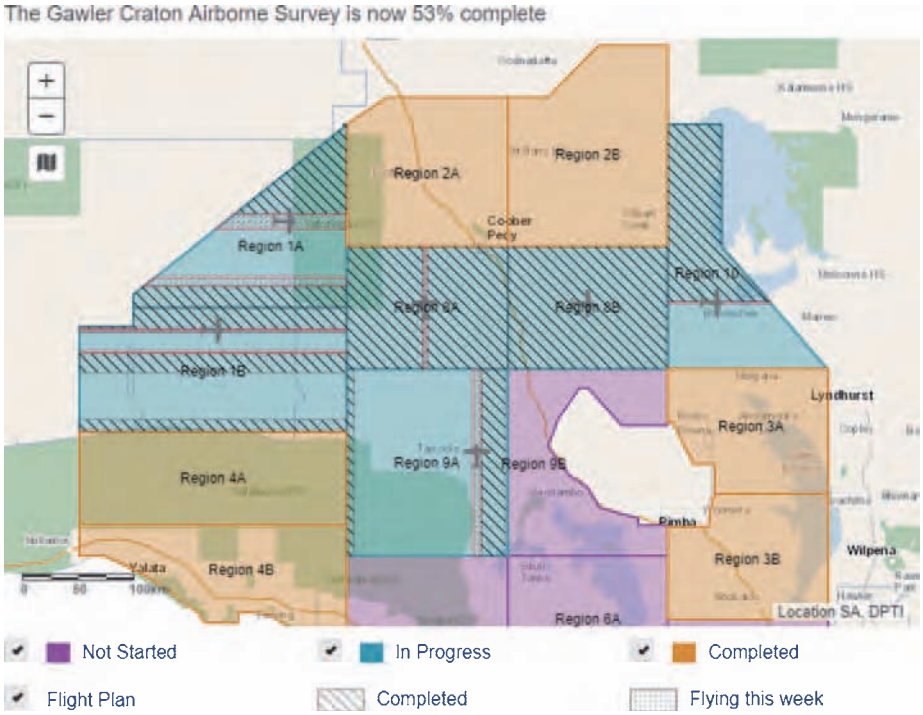

Figure 2. *The Gawler Craton Airborne Survey Community Information webpage. The web page delivers near-real-time information on survey aircraft activity and locality while also providing direct links to data downloads. Subscription to email updates is available, notifying subscribers of survey milestones and data releases. The webpage is located at http://www.minerals.statedevelopment.sa.gov.au/gcas.*

spaced airborne EM data collected in December 2017.

In 2018, the Lithospheric Architecture Team will convert the MT data acquisition programs into 3D resistivity models and seek integration to isotope geochemical data sets, potential field geophysical data and is collaborating on new insights gained from satellite gravity data.

Other news

In 2016 SARIG was redesigned so that users with tablet devices could use the system as well as desktop users. Geophysical surveys conducted in South Australia continue to be uploaded to SARIG and are available for free download. If users require assistance using SARIG please don't hesitate to contact Customer Services (Resources.customerservices@sa.gov.au).

The Geological Survey of South Australia will be moving offices in 2017. Currently located at 101 Grenfell Street, Adelaide, staff will be moving to 11 Waymouth Street, Adelaide, a short distance from the current office. The geophysical team is currently involved in transferring a large amount of data from older media (including ExaByte and Colorado tapes) to network storage.

Two AEM surveys flown by SkyTEM over the Fowler and Olympic Domains in South Australia are being QC'd by GA and should be available soon for public consumption via SARIG. The surveys were designed to map (at a reconnaissance scale):

- trends in regolith thickness and variability;
- trends in cover sequence thickness, character and variability;
- basement/bedrock paleo-topography;
- variations in bedrock conductivity;
- the continuity of key bedrock conductive units under cover; and
- the ground water resource potential of the region.

Stay tuned to *Preview* for more news on these surveys!

Laz Katona, Kate Robertson, Stephan Thiel and Philip Heath
Geological Survey of South Australia
Philip.Heath@sa.gov.au

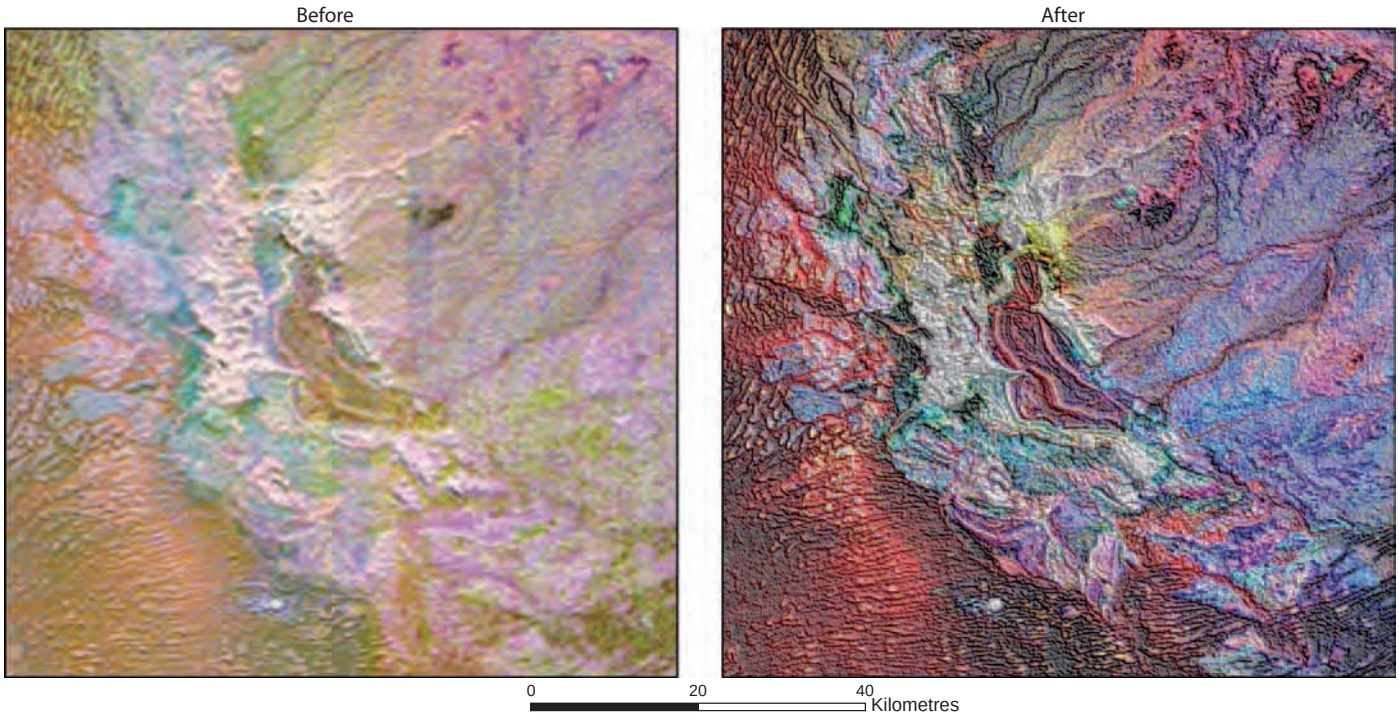

Figure 3. *Ternary radiometric image of the Peake and Dennison Ranges comparing the previous best available image (left) with the new image acquired by the Gawler Craton Airborne Survey (right). The clarity and detail of geological features and landforms in the image is unsurpassed.*

Geological Survey of Western Australia: regional and crustal-scale geophysical programs, 2018

Since 2009, the Government of Western Australia's Exploration Incentive Scheme (EIS) has enabled the Department of Mines, Industry Regulation and Safety's (DMIRS) Geological Survey of Western Australia (GSWA) division to undertake an extensive and accelerated program of regional and crustal-scale geophysical data acquisition projects throughout the State.

These projects are an integral component of GSWA's strategy to enhance Western Australia's precompetitive and public-use information-base with the ultimate aim of providing statewide 'surface-to-mantle' geoscience information at the best resolution affordable.

Figure 1 illustrates the range of existing datasets and planned geophysical programs that GSWA is undertaking with active assistance from its national counterpart, Geoscience Australia (GA), and leveraging support from a number of other national and state institutions.

These encompass:

- Complete State coverage with airborne magnetic and radiometric surveys at sub-500 m line spacing, with targeted areas at 100 m line spacing.
- An ongoing program to extend gravity coverage of the State with ground and airborne gravity surveys at 2.5 km spacing; with the objective of completing state coverage by 2020.
- Airborne electromagnetic surveys over targeted areas with additional surveys in the north of the State under consideration for joint funding as part of Geoscience Australia's 'Exploring for the Future' program.
- Crustal-scale reflection seismic transects across key geological regions. The Canning Basin is a currently active area of interest with a GSWA/GA jointly funded 900 km transect across the Kidson sub-basin to be completed in 2018.
- Crustal scale, long period magnetotelluric transects across major geological structures with more work under consideration as part of the Australian Lithospheric Architecture Magnetotelluric Project.
- Reprocessing of key regional vintage seismic lines in the Canning and Southern Carnarvon Basins is currently underway. Further reprocessing may be considered dependant on results of the current projects.
- Transects and networks of temporary broad-spectrum passive seismic stations for crustal and lithosphere scale interpretation, and which complement the reflection seismic transects. The current network is monitoring along the Canning Coastal line and there are plans to cover the Kidson sub-basin transect as well.

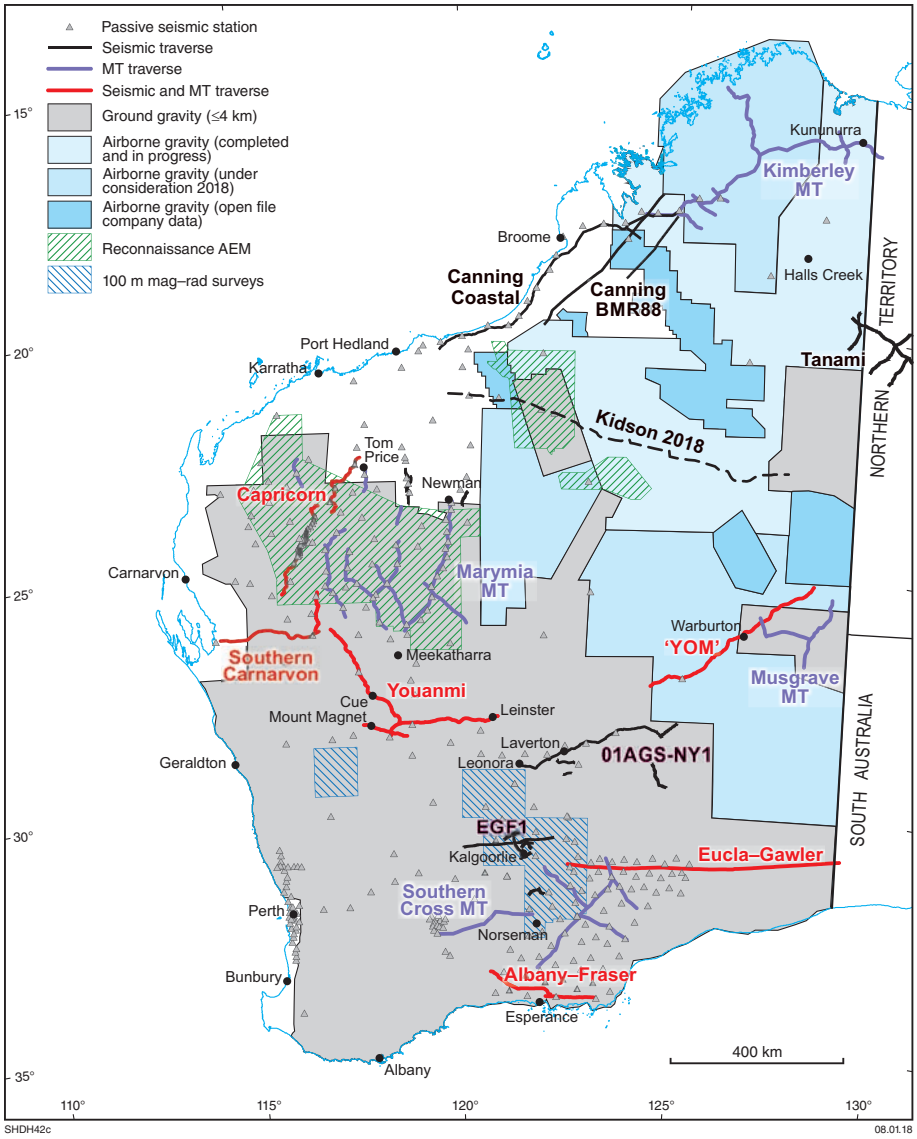

Figure 1. *Regional and crustal-scale geophysical programs in Western Australia, 2018.*

All raw data and processed statewide or individual survey images data are publicly available online through GSWA's or GA's various data delivery systems and the Australian Geoscience Information Network (AusGIN):

- GeoView.WA: www.dmp.wa.gov.au/geoview
- GADDS: www.ga.gov.au/gadds
- AusGIN: www.geoscience.gov.au/

Analyses and geological interpretations of these data by GSWA and its partners are available from the various project pages on the GSWA website at www.dmp.wa.gov.au/gswa.

For more information please email: geophysics@dmirs.wa.gov.au.

Overview of new and upcoming geophysics in the Northern Territory

Over the past 4 years the Northern Territory Geological Survey (NTGS) has acquired 4 km spaced ground gravity data over approximately 900 000 km^2 of the NT and two magnetic and radiometric surveys funded through the Northern Territory Government's $23.8 million *Creating Opportunities for Resource Exploration* (CORE) initiative (Dhu and Hallet, 2017). These surveys were acquired in collaboration with Geoscience Australia through a National Geoscience Agreement. The four-year CORE initiative was launched in 2014 and aimed at maximising opportunities for the exploration, discovery and development of new mineral and petroleum resources within the NT. Recently work has focussed on integrating and interpreting these new geophysical data with a range of products to be released in 2018.

Frogtech Geoscience has been contracted to update the SEEBASE® (Structurally Enhanced view of Economic BASEment) suite of products over the greater McArthur Basin (Figure 1). This project incorporates both the new potential field geophysics acquired through the CORE initiative and significant work undertaken by industry in the region including new drilling and seismic data. The final products including the SEEBASE® depth-to-basement grid (Figure 2) will be released in March 2018, supported by a workshop at NTGS's Annual Geoscience Exploration Seminar in Alice Springs (19–21 March; www.ages.nt.gov.au). The NTGS/Frogtech Geoscience greater McArthur Basin geological workshop will discuss key results from the SEEBASE® update and the definition of the Beetaloo Sub-basin.

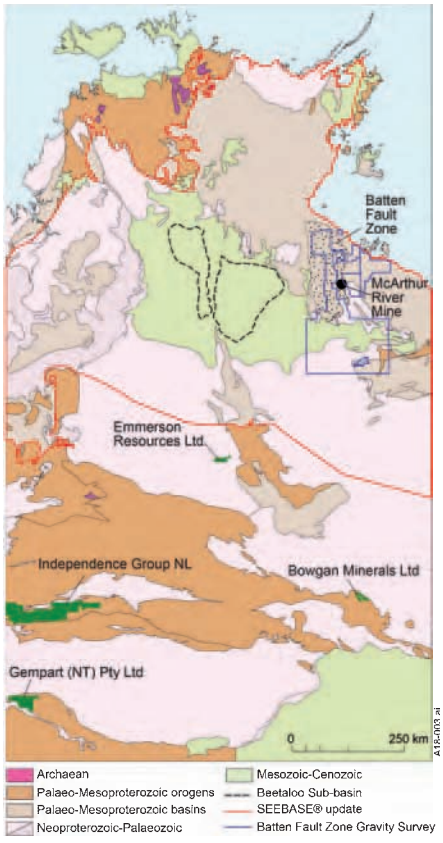

Figure 1. *Location of greater McArthur Basin and NTGS Geophysics and Drilling Collaboration projects.*

The NTGS is collaborating with CSIRO on geophysical acquisition, processing and interpretation projects in the Batten Fault Zone. The Batten Fault Zone is in north-eastern NT (Figure 1) and contains the world class McArthur River Pb-Zn-Ag mine, hosted within the HYC Pyritic Shale Member of the Barney Creek Formation. Over 40 publicly available, industry acquired AEM datasets have been assessed and reprocessed, where possible using EMFlow (Macnae et al., 1988), and for more recent data, using Geoscience Australia-Layered Earth Inversion (GA_LEI, Brodie and Fisher 2008). This work involved compiling adequate system characteristic descriptions and assessing suitability for inversion or transformation (Ley-Cooper et al., 2016) and then interpreting these data to determine their suitability for mapping the Barney Creek Formation (Munday et al., 2017). The reprocessed AEM datasets and associated system descriptions will be made publicly available in a new Digital Information Package (DIP): 'Reprocessing of historical AEM surveys in the Batten Fault Zone', and accompanied by an interpretation record.

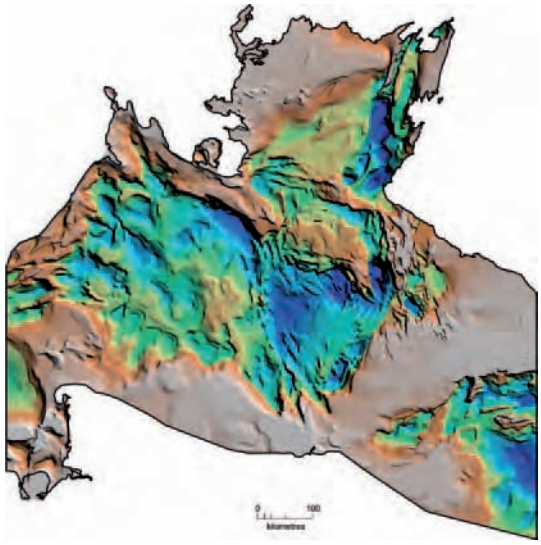

Figure 2. *SEEBASE® depth-to-basement grid in the greater McArthur Basin.*

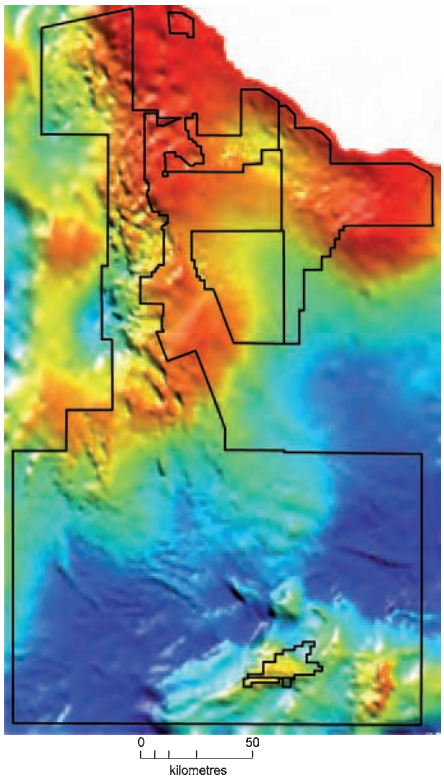

Figure 3. *New, higher resolution ground gravity data in the greater McArthur Basin.*

A new, higher resolution ground gravity survey has also been completed in the Batten Fault Zone. The Batten Fault Zone gravity survey acquired over 7000 new gravity readings, infilling the South McArthur gravity survey at 2 × 2 km spacing with selected traverses acquired at 500 m spacing (Figure 3). This data is now available and will feed into the geophysical and structural interpretation of the Batten Fault Zone to be released mid-2018.

The NTGS Geophysics and Drilling Collaborations (GDC) is also supporting a range of smaller scale geophysical surveys through co-funding of industry projects (www.dpir.nt.gov.au/mining-and-energy/geoscience-projects-and-initiatives/geophysics-and-drilling-collaborations). Round 10 of the GDC is currently underway

(Figure 1), with AEM (Independence Group NL and Gempart NT), 3D IP (Emmerson Resources) and ground gravity (Bowgan Minerals Ltd) surveys.

All data and products are available on request from NTGS (geoscience.info@nt.gov.au) and many are available for download at www.geoscience.nt.gov.au/gemis or through the STRIKE web mapping system (www.strike.nt.gov.au). Geophysical data and grids acquired through collaboration with Geoscience Australia are available for download via the Geophysical Archive Data Delivery System (GADDS).

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Geological Survey of Queensland: update on the Strategic Resources Exploration Program

Last year the Queensland Government's Strategic Resources Exploration Program was announced, with funding aimed at promoting discoveries in North West Queensland. Details of the 4-year program include:

- $3.6 million to drive exploration for gas in basins in the north-west including the Georgina, South Nicholson and Isa Superbasin
- $4.275 million on mineral geophysics projects
- $1.45 million on mineral geochemistry programs
- $3.6 million for a new Collaborative Exploration Initiative.

The Collaborative Exploration Initiative broadens on the scope of our Collaborative Drilling Initiative from the past. This means that there will be funding available not only for drilling, but for geophysical and geochemical programs in under-explored areas of the north-west that will provide a benefit to the regions understanding. Round 1 has closed and projects are underway, however it is anticipated that applications for future rounds will be opening later in 2018.

The first minerals geophysics project under the new program will be the acquisition of new 1 km grid spaced ground gravity data in the Lawn Hill area (Figure 1). The selected area is immediately north of the currently 2 km spaced gravity data available in the Mount Isa area. The data is expected to assist with resolving high density targets within structural trends in an area prospective for silver, lead and zinc and will supplement AEM data collected by the Geological Survey of Queensland (GSQ) last year.

Geophysical inversions of last year's Cloncurry Magnetotelluric (MT) data will be released shortly. Products available for download will include various conductivity depth slices, and sections as well as a 3D conductivity volume. The processed EDI files can also be obtained from QDEX Data.

The flying of the Cloncurry and Mary Kathleen airborne magnetic and radiometric surveys has been completed (Figure 1). Data for both surveys is currently undergoing QA/QC checking. These high resolution surveys (100 m and 50 m spacing) provide a seamless coverage over the area and show good improvement on the previous Mount Isa Mines Open Range survey acquired in the 1990s. Data for both surveys will be releases on QDEX Data once the final checks have been completed.

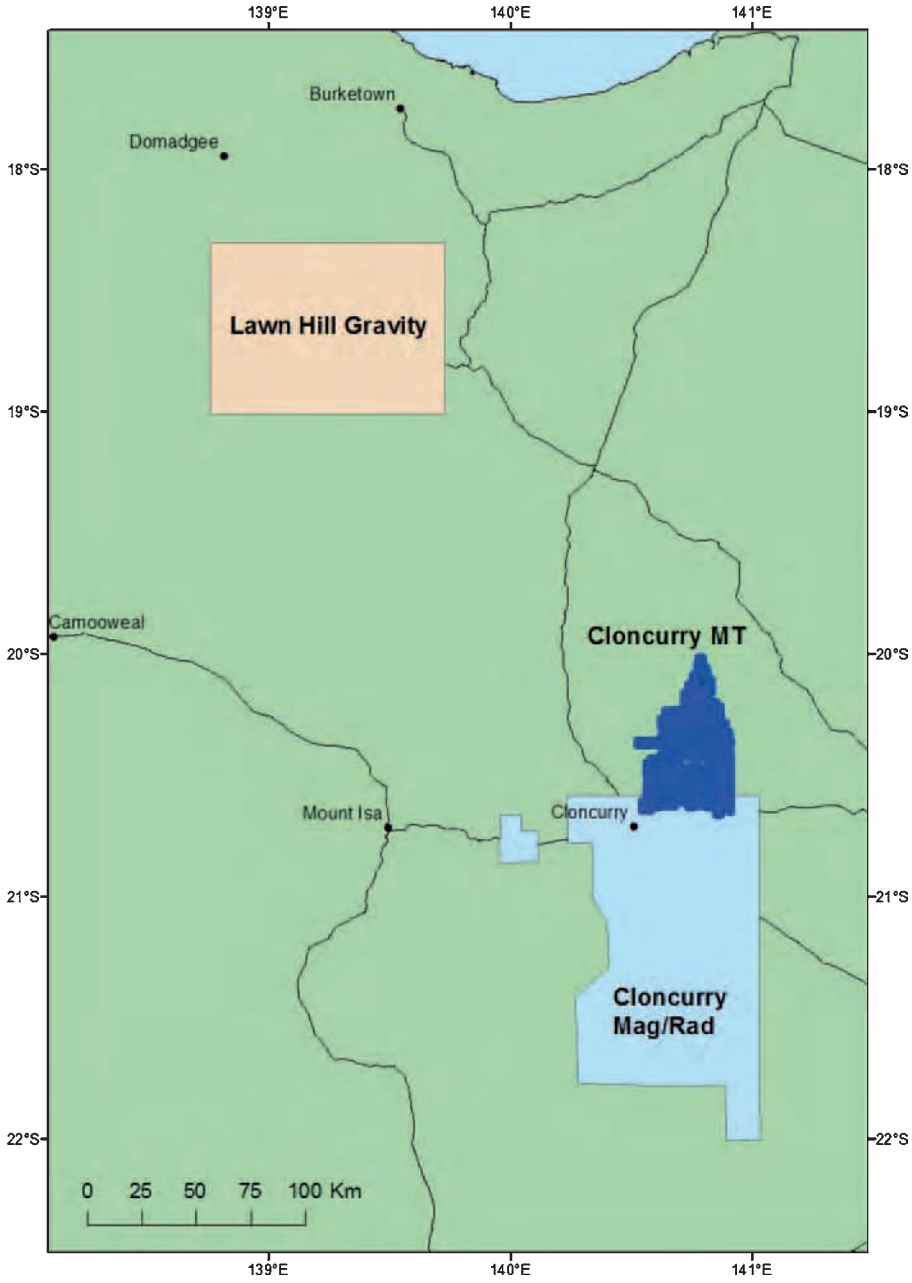

Figure 1. *Location of upcoming and newly released GSQ datasets.*

We look forward to seeing you all in Sydney for the AEGC2018, you can find us at the Australian Minerals booth.

Roger Cant, Matthew Greenwood and Janelle Simpson
Geological Survey of Queensland
Geophysics@dnrme.qld.gov.au

New products and data from the Geological Survey of New South Wales

The Geological Survey of New South Wales (GSNSW) collects, manages and distributes geological, geophysical, geochemical and geospatial data to inform government, resource industries and the community about the state's geology, and mineral and energy resources.

Important regional projects are supported by the New Frontiers Initiative, which is funded by industry through mineral and petroleum annual rental fees. New Frontiers aims to improve knowledge of under-explored areas within NSW, which includes acquisition of precompetitive geophysical data that provides essential support for geoscience mapping and mineral exploration.

Some GSNSW key achievements from the past year are outlined below, as well as major upcoming and ongoing projects.

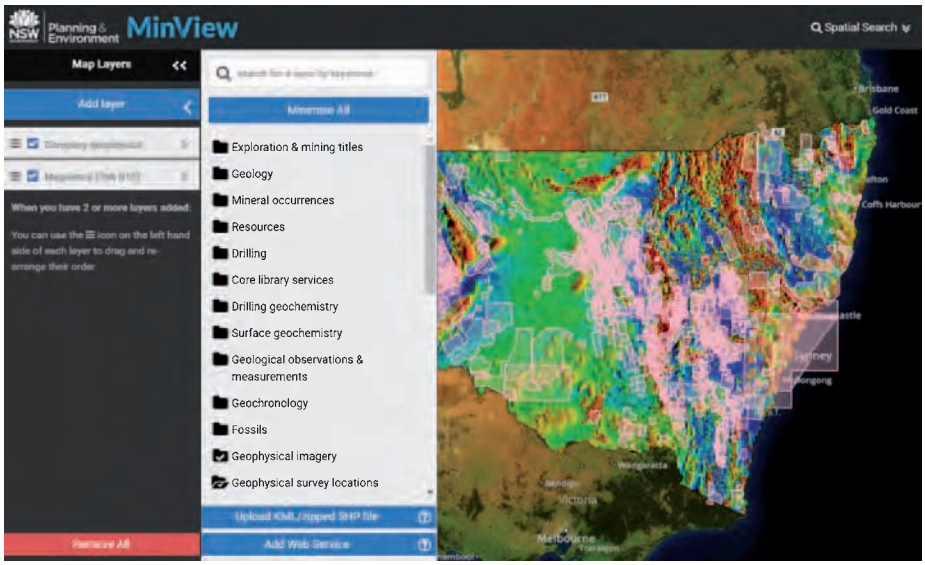

Figure 1. *Screenshot of MinView showing the data layer selection menu. The map window shows a statewide airborne magnetic image overlain by company airborne geophysical survey boundaries.*

New MinView released

MinView is a web mapping application which provides free access to view, search and download a comprehensive range of geological and geoscientific data for NSW. It also provides a range of supporting reference data by which to contextualise the geoscientific data including present and past exploration and mining titles, areas available or not available for exploration, and cadastral information. Data available from MinView includes geological maps, mineral occurrences, drillhole and sample locations, geological observations, geochronology, statewide geophysical imagery and geophysical survey areas.

MinView draws together a vast array of different data types and formats from the department's existing databases, with the intention of providing easy public access to all validated, non-confidential data from a single online map interface (Figure 1). You can interactively view, search and download our data or choose to build a custom map, which can be shared as a unique URL or annotated and then printed in hardcopy.

Access MinView at: https://www.resourcesandenergy.nsw.gov.au/miners-and-explorers/geoscience-information/services/online-services/minview

Contact: trisha.moriarty@planning.nsw.gov.au, (02) 4931 6598.

Coonabarabran geophysical data now available

In November 2017, GSNSW was pleased to announce the public release of the Coonabarabran Project data. Airborne magnetic, radioelement and digital elevation data was acquired around Coonabarabran and Gilgandra between May and July 2017. The project was undertaken in collaboration with Geoscience Australia and has improved the quality of geophysics coverage in this part of NSW by replacing low-

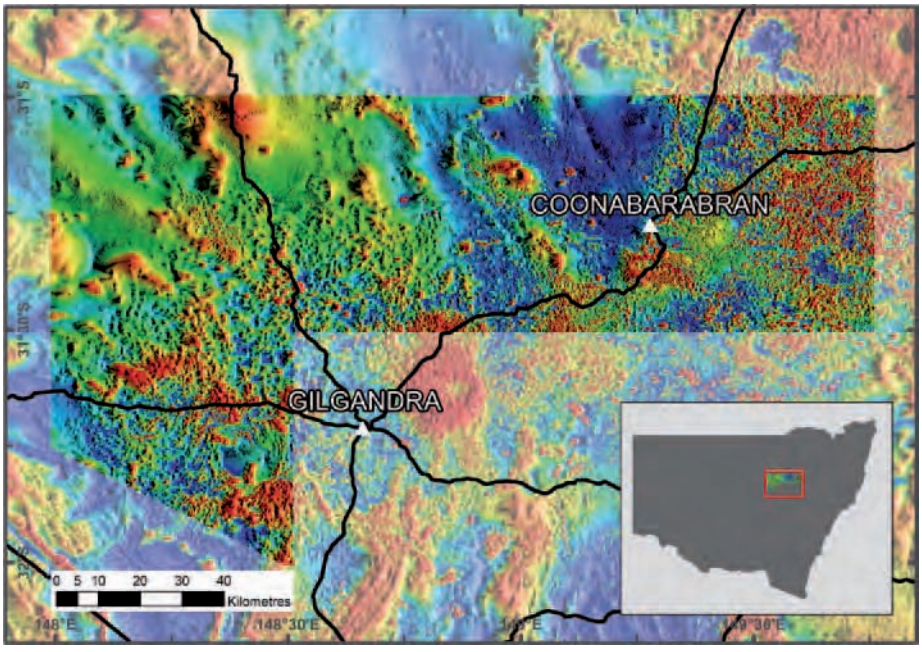

Figure 2. *Image of the new Coonabarabran Total Magnetic Intensity data overlaid on surrounding older magnetic data. Cooler (blue) colours indicate lower magnetic values and warmer colours represent higher magnetic intensity values.*

resolution data collected in the early 1980s (Figure 2). The data will be used to map geology, landforms and soils, and to inform land use assessments. The Office of Environment and Heritage and GSNSW have been using the Coonabarabran magnetic and radioelement data to map volcanic rocks and soils in the Warrumbungle National Park.

These data are available as georeferenced imagery, grids and ASEG GDF data. The new data is available on the NSW Government statewide geophysics data package, which is available for $110 plus postage. Alternatively, grids and located data can be downloaded for free via the GADDS website at http://www.geoscience.gov.au/.

Contact: astrid.carlton@planning.nsw.gov.au, (02) 4931 6732.

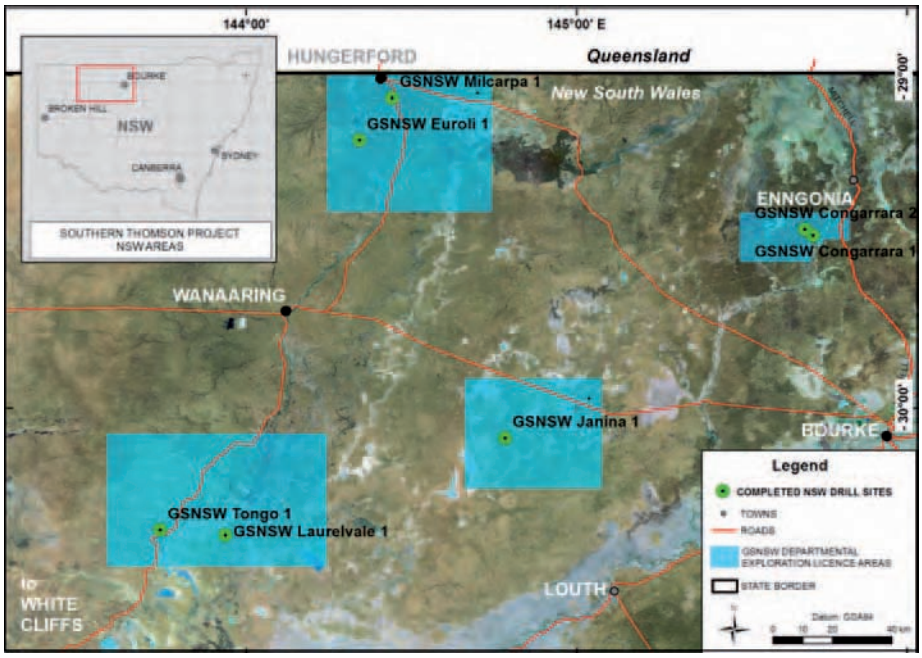

Figure 3. *Drill sites in the Bourke–Hungerford region.*

Southern Thomson Orogen Project: stratigraphic drilling

Stratigraphic drilling in the southern Thomson Orogen was completed in September 2017. Seven drillholes successfully sampled basement rocks of the Thomson Orogen, beneath the Eromanga Basin, in the Bourke–Hungerford area of remote northwest NSW (Figure 3).

The drilling program is part of a cross-border collaborative project between GSNSW, the Geological Survey of Queensland and Geoscience Australia. It is part of the national UNCOVER Initiative, which aims to reverse the decline in Australia's known mineral reserves by providing new information to government, explorers and the wider community about undercover regions.

Rocks of the southern Thomson Orogen in NSW are potentially prospective for copper, lead–zinc, gold and other metals, however mineral systems are masked by younger sedimentary rocks of the Eromanga Basin. The project initially acquired and analysed airborne and ground-based geophysical data and undertook surface geochemical sampling, field mapping and satellite image analysis to define areas to be tested by drilling within this vast (300 by 300 km) region.

The drilling program tested a variety of distinctive basement signatures in airborne magnetic and electromagnetic data (Table 1). Drilling methods involved a combination of rotary mud drilling through cover sequences and diamond drilling of underlying basement rocks, to provide around 50 m of representative basement core samples from each site. Wireline geophysical logs were run in the holes prior to casing. All cores are being comprehensively sampled for mineralogy, geochemistry and geochronology as well as being scanned by the Hylogger™.

A Southern Thomson Orogen Project workshop displaying drillcore and presenting results from the drilling will be run in at GSNSW's Londonderry core library as part of NSW Minerals Week on 9 May 2018.

Contact: chris.folkes@planning.nsw.gov.au, (02) 4931 6777.

Table 1. Summary of drilling results

Site ID (ref. Figure 1)	Total depth (m)	Basement lithology
GSNSW Milcarpa 1	290.9 m	Rhyodacite
GSNSW Euroli 1	153.7 m	Metasedimentary schist
GSNSW Tongo 1	312.8 m	Granodiorite
GSNSW Laurelvale 1	386.8 m	Siliciclastic turbidite
GSNSW Janina 1	222.2 m	Granite
GSNSW Congarrara 1	119.6 m	Mixed metasedimentary and altered intrusive, gneissic textures
GSNSW Congarrara 2	317.9 m	Muscovite–biotite granite

South East Lachlan Crustal Transect to commence in March

A new deep-crustal seismic survey is planned for southern NSW and north-eastern Victoria. The GSNSW and the Geological Survey of Victoria are collaborating with Geoscience Australia and AuScope Limited (part of the National Collaborative Research Infrastructure Strategy) on the South East Lachlan Crustal Transect. Two seismic reflection lines are designed to cross major geological boundaries and fault zones and will complete the east–west deep crustal seismic coverage across the Australian continent (Figure 4). Data will be acquired in Victoria between Benalla and Tubbut (~360 km) and in NSW between Delegate and Eden (~120 km).

The survey requires careful planning and execution to move the seismic survey equipment and acquisition team through the rugged terrain of the Australian Alps and the Snowy Mountains. Route planning, stakeholder briefings, land access and tendering are currently underway. Data acquisition is expected to commence in March 2018 and take about 70 days to complete, with initial results available 12 months later.

Contact: ned.stolz@planning.nsw.gov.au, (02) 4931 6554 or Cameron.Cairns@ecodev.vic.gov.au, (03) 9452 8972.

AusLAMP magnetotelluric acquisition underway in NSW

GSNSW is participating in the AusLAMP project to create a conductivity model of the deep Australian lithosphere. In 2016, GSNSW established a National Collaboration Framework Agreement with Geoscience Australia to acquire and model over 300 long-period magnetotelluric stations across NSW. To date 77 stations have been acquired in southern and far western NSW (see Figure 5). In 2018 acquisition is focussing on sites in central-western NSW with 10 magnetotelluric units currently deployed in the West Wyalong area. The survey will then move north and west to cover the prospective Tasmanides belt.

Contact: ned.stolz@planning.nsw.gov.au, (02) 4931 6554.

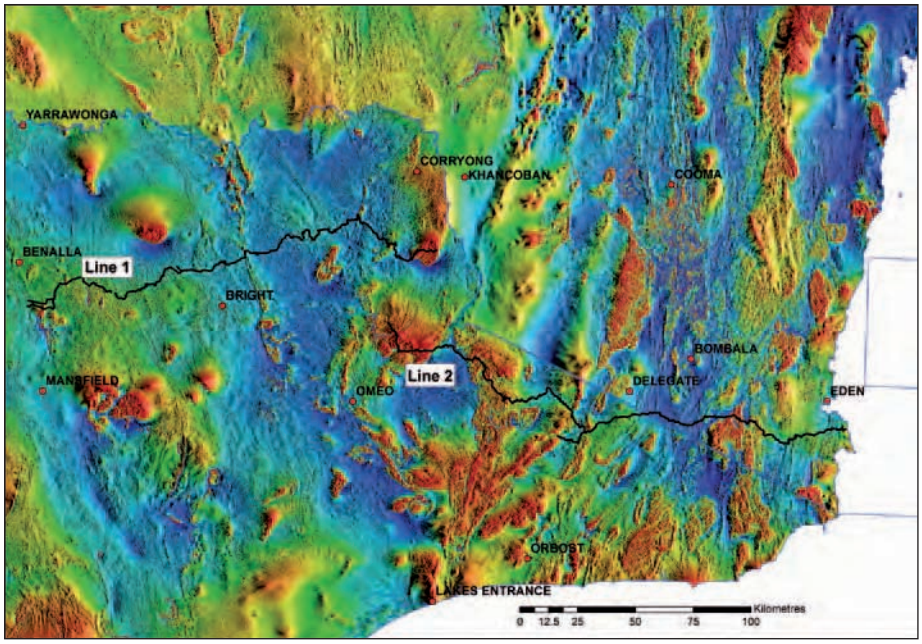

Figure 4. *Location of the proposed South East Lachlan Crustal Transect seismic survey (black lines) displayed over an airborne magnetic TMI image of eastern Victoria and southern NSW. The NSW–Victoria border is shown in blue and towns are labelled in black.*

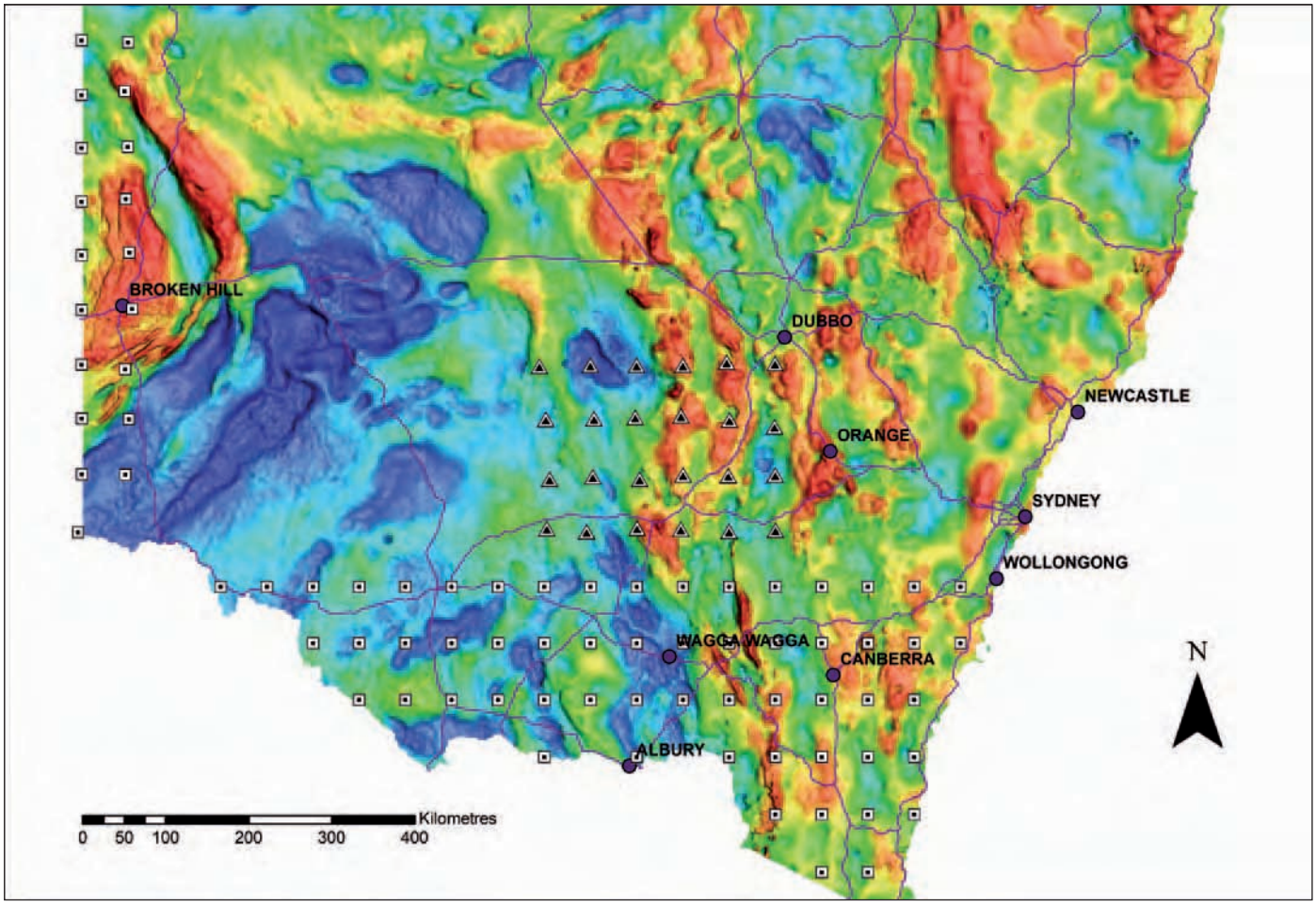

Figure 5. *Location of AusLAMP MT sites in NSW overlain on isostatically corrected Bouguer gravity image. Squares are sites from 2016–2017 and triangles are the sites being acquired in 2018.*

News from the Geological Survey of Victoria

Victorian Gas Program: airborne survey

The Geological Survey of Victoria (GSV) is planning to acquire airborne geophysical data (airborne gravity and/or gravity gradiometry) over the Otway Basin in 2018. The airborne gravity/gradiometry survey will be conducted over approximately 18 000 km^2 of the Otway geological basin, including State onshore and offshore areas and Commonwealth waters. It will extend from the western margin of the Otway Ranges in Victoria to the South Australian border (Figure 1).

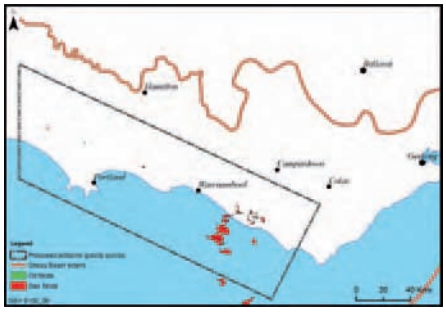

Figure 1. *Map showing the proposed area of the Otway Basin Gravity/Gradiometry Survey.*

The survey is part of the $42.5 million Victorian Gas Program, which will deliver a comprehensive program of geoscience and environmental research and related activities - including community engagement, resource planning and regulatory reform – in support of commercial exploration for further gas discoveries off the Victorian coast. The survey is one component of a precompetitive geoscience data package that will underpin petroleum acreage release in State waters in 2018.

All study results from the Victorian Gas Program will be made publicly available.

For more information go to the website:

www.earthresources.vic.gov.au/earth-resources/victorian-gas-program or email: vgp@ecodev.vic.gov.au.

Eastern Victorian Geoscience Initiative

The South East Lachlan Crustal Transect (SELCT) is a deep crustal seismic survey that is part of the GSV's Eastern Victorian Geoscience Initiative. The survey is due to begin near Benalla in early 2018. See the GSNSW update in this issue for more news on this exciting collaboration between GSV, GSNSW, Geoscience Australia and AuScope Limited.

Stavely Project

The Victorian Government has co-funded mineral exploration projects under its TARGET Minerals Exploration Initiative to further enhance the understanding of the geology and potential mineral deposits in western Victoria, and to encourage investment and new projects in regional Victoria.

The Government will soon be releasing thousands of square kilometres of ground for minerals exploration in the Stavely region (Figure 2), which has been identified as having potential for copper, other base metals and gold mineralisation, through a competitive, merit-based international tender.

Investors and explorers can access free pre-competitive and open-file reports, maps, interpretations, 3D models and data from the Earth Resources Online Store, Earth Resources Search Assistant and GeoVic – GSV's free web mapping application for searching and displaying geospatial databases and images provided by GSV. Geoscience data and reports generated by the Stavely Project are available through the project webpages at: www.earthresources.vic.gov.au/earth-resources/geology-of-victoria/gsv-projects/the-stavely-project and www.ga.gov.au/scientific-topics/minerals/unlocking-resource-potential/stavely-project.

Full text addresses for the resources mentioned above are:

http://earthresources.vic.gov.au/earth-resources/maps-reports-and-data/download-reports-maps-and-data
http://earthresources.vic.gov.au/earth-resources/maps-reports-and-data/search-tool
http://earthresources.vic.gov.au/earth-resources/maps-reports-and-data/geovic

Suzanne Haydon
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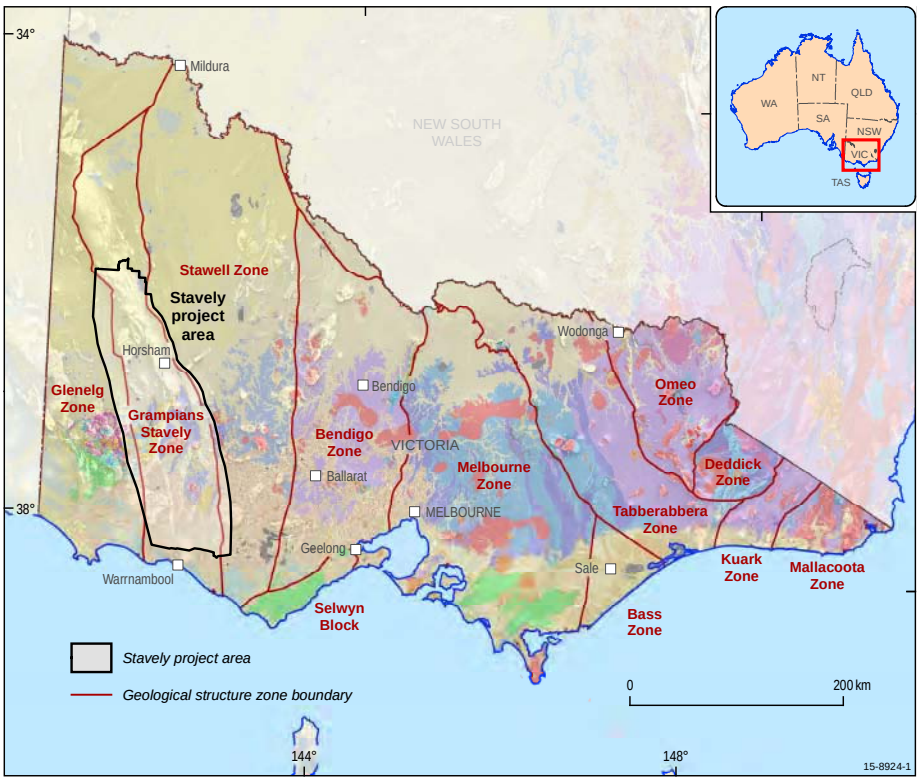

Figure 2. *Map showing the location of the Stavely Project area in Victoria with simplified geology and structural zones (modified from VandenBerg et al., 2000 , GSV Special Publication, by Geoscience Australia).*

Mineral Resources Tasmania: 3D geophysical modelling stimulates exploration

Mineral Resources Tasmania (MRT) continues to develop high resolution regional 3D models to stand alongside provision of traditional geophysical surveys, geological mapping and other value-added pre-competitive geoscientific data. This has directly stimulated and improved the focus of mineral exploration in Tasmania. In the instance described here, results from a previous study (Rosebery Region 3D model, reported in earlier issues of *Preview*) identified a significant negative gravity residual within the study area, a highly mineralised district in western Tasmania (Figure 1). This modelling outcome has led directly to new commercial greenfields drilling.

Geological setting

The area targeted for more detailed modelling, containing the gravity anomaly residual from the earlier regional study, is outlined in red on Figure 1. Structurally it is dominated by the N- to NNW-striking Huskisson Syncline, which at its core comprises Silurian-Devonian Eldon Group sediments overlaying the Gordon Limestone. Allochthonous fault bound slices of serpentinised ultramafic complexes are located to the west and east of the syncline with the Meredith Granite (which intruded the sequence in the Devonian) located north of the syncline.

Regionally the study area encompasses some of the most highly and diversely mineralised crust on the planet. The Rosebery polymetallic ore mineral system, which occurs within the Cambrian Mount Read Volcanic Belt – now in its ninth decade of continuous mining, is interpreted to be the product of volcanism following collision of a proto-Tasmanian micro-continent (represented by Neoproterozoic Crimson Creek Formation and older units) with an oceanic island arc (represented by serpentinised ultramafic units) around 520 Ma. In the late Devonian the region was intruded by granites. This led to additional metallogeny, including the world's largest underground tin deposit (Renison).

Tributary Creek gravity anomaly

In 2013, preliminary regional 3D modelling highlighted a significant negative gravity residual (Figure 2) near the southwestern Huskisson Syncline. The geometry of modelled low density Devonian granite was varied to account for this feature. This inversion process resulted in a substantial change to the previous granite model in the form of a spine underlying this region (Figure 3, white ellipse). Depth to this crest at its shallowest is estimated to be ~1000 m with the potential for granite possibly intruding ultramafics and/or Gordon Group carbonates. Either scenario has potential for generating mineralised systems.

Drill targeting

Following MRT reporting of this modelling, in 2017 Yunnan Tin began

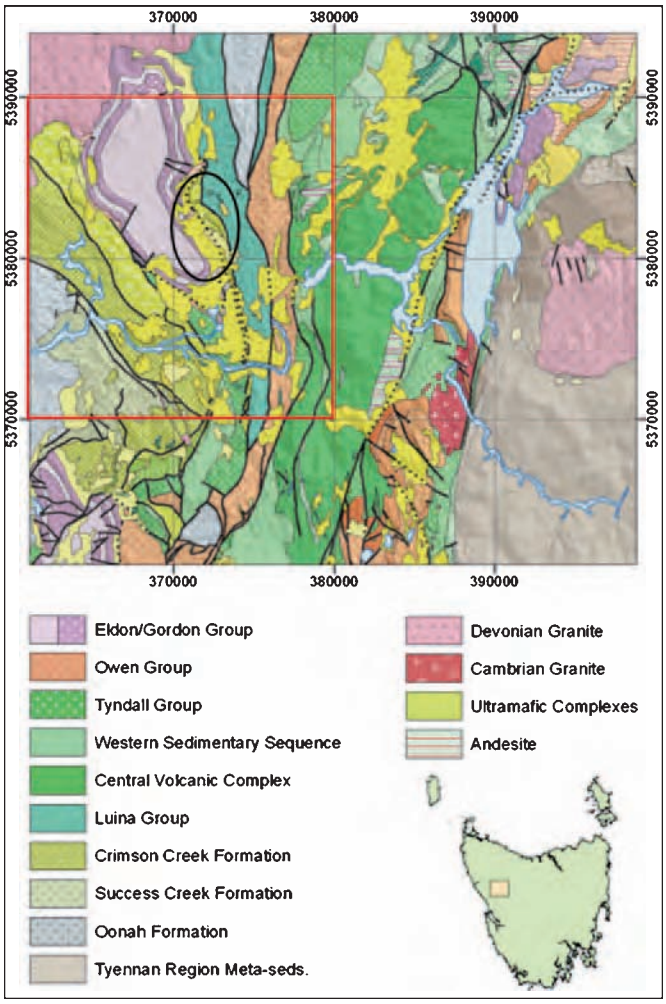

Figure 1. *Location and geology of the 3D model area.*

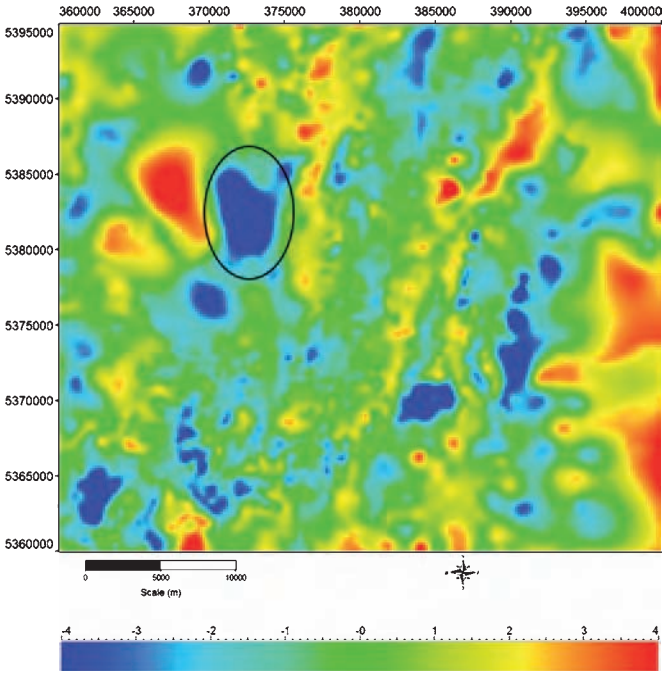

Figure 2. *Residual gravity following removal of 3D geological model response. The significant negative feature (black ellipse) is here referred to as the Tributary Creek gravity anomaly (TCGA). Colour ramp legend in mGals.*

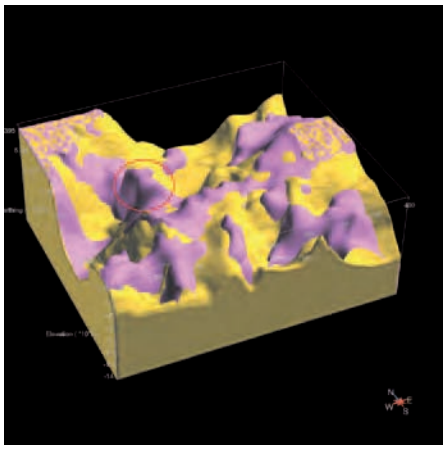

Figure 3. *Modelled granite surfaces with pink representing new and yellow old. Red ellipse highlights the TCGA.*

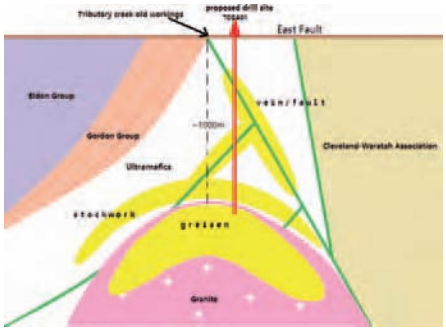

Figure 4. *Conceptual drill cross section of the TCGA with potential ore deposit types (image courtesy Joe Xie, Yunnan Tin).*

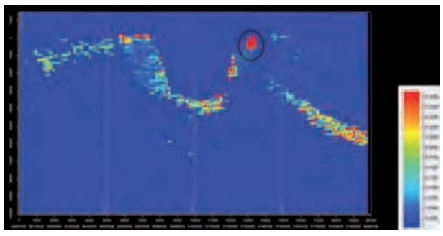

Figure 5. *Sectional view of the recovered magnetic susceptibility model, highly magnetic ultramafic units. Black ellipse represents the location of the TCGA and the volume targeted by diamond drill hole TCGA01. Colour ramp legend in SI units.*

an exploration campaign to investigate the anomaly. This commenced with detailed ground gravity (~100 m spacing) confirming the location and character of the TCGA. Figure 4 represents a schematic cross section of the TCGA locality illustrating concepts of potential mineral systems and deposition sites. Figure 5 is a sectional view of the 3D magnetic inversion result, indicating susceptibility variation within the modelled generally highly magnetic ultramafic units. Note the especially magnetised portion (red pixels), which is coincident with the TCGA gravity low. This volume was an additional target of Yunnan Tin's drilling.

Drilling results

Depth to granite was estimated at ~1000 m. Diamond drilling intercepted serpentinite (Figure 6) and several fault and shear zones, as predicted by the model. However, drilling was abandoned at 582 m due to the very high hydraulic load factor the drilling rod experienced in poor ground conditions associated with the faulting. Hand lens inspection of core identified the lithology as fairly uniform serpentinite with abundant calcite, talc, magnetite and asbestos. No visible mineralisation was observed. The hole was regularly traversed by shear zones, particularly the last ~170 m. Major structural zones were logged at 413–418 m, 497–499, 538–544.5 m and 568 m to EOH at 582 m.

Figure 6. *TCGA01 drill core (serpentinite). Image courtesy of Joe Xie and Yunnan Tin.*

Geochemical analyses of core

MRT staff conducted HyLogger and XRD analyses of TCGA01, using in-house facilities. The core contained significant asbestos and was sealed with PVA glue as a precautionary safety measure. A reconnaissance investigation showed that the PVA can confuse the automated mineral interpretation of TIR spectra. Nevertheless, HyLogger results showed that the core is primarily composed of lizardite plus carbonate. Downhole plots of carbonates (Figure 7) show that magnesite is the dominant species. Carbonates become slightly more common approaching the bottom of the hole. Calcite, dolomite and siderite were tentatively identified and occur near the bottom of the hole. Mg-rich hydrated carbonates occur in broken core and on joint/shear faces.

XRD analyses were undertaken to confirm the identity of the carbonates. Results confirm the presence of magnesite and dolomite towards the bottom of the hole within the major fault zone (Figure 8). These minerals frequently occur as alteration products resulting from low temperature hydrothermal and/or metasomatic effects. Other carbonates identified include sjogrenite, pyroaurite and brugnatellite, which are typical background products from the original (pre-granite intrusion) serpentinisation process. No siderite was identified.

Discussion

Drilling did not reach the target depth of 1000 m due to drilling difficulties associated with the fault zones intersected. Geochemical analyses of core identified several varieties of carbonates, though not the presence of sulphides. Magnesite and dolomite are low to mid temperature hydrothermal/metasomatic alteration products. Magnesite is evidence of fluid evolution to lower temperatures and higher CO_2 concentrations. Comparison and experimental results on the alteration/metasomatism of serpentinite indicates that a decrease in temperature from approximately 500 to <350°C, and an increase in CO_2 content from 0 to 3%, is required for magnetite dissolution. The fluid source for magnesite in hole TCGA01 is unknown. A possible mechanism for the formation of magnesite could be convection of meteoritic waters induced by a nearby magmatic source. Another possibility is low temperature hydrothermal fluids from a magmatic source encountering limestone, which would enhance CO_2 concentration and magnesite dissolution. The nearby Gordon Group limestone is a candidate CO_2 source and the shear zones within serpentinite could act as fluid conduits with magnesite crystallising out of solution as a result of decreasing fluid temperature.

Summary

Yunnan Tin's investigation of the TCGA shows how MRT's development of high precision regional 3D models is stimulating exploration. Drilling, unfortunately, did not reach depths of potential mineralisation sites due to technical issues, so this aspect of the model remains untested. However, it did confirm the 3D model ultramafic geometry. First petrophysical results from the new drill core are in line with

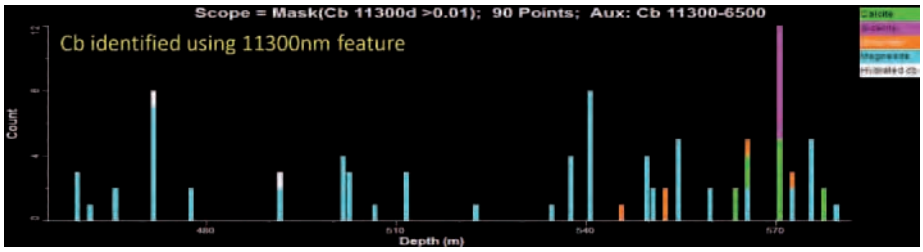

Figure 7. *Carbonate (Cb) abundances from HyLogger scanning of TCGA-01, showing magnesite (aqua) as generally dominant, with other species including dolomite (orange), calcite (green) and notably siderite (magenta) becoming more common approaching the bottom of the hole.*

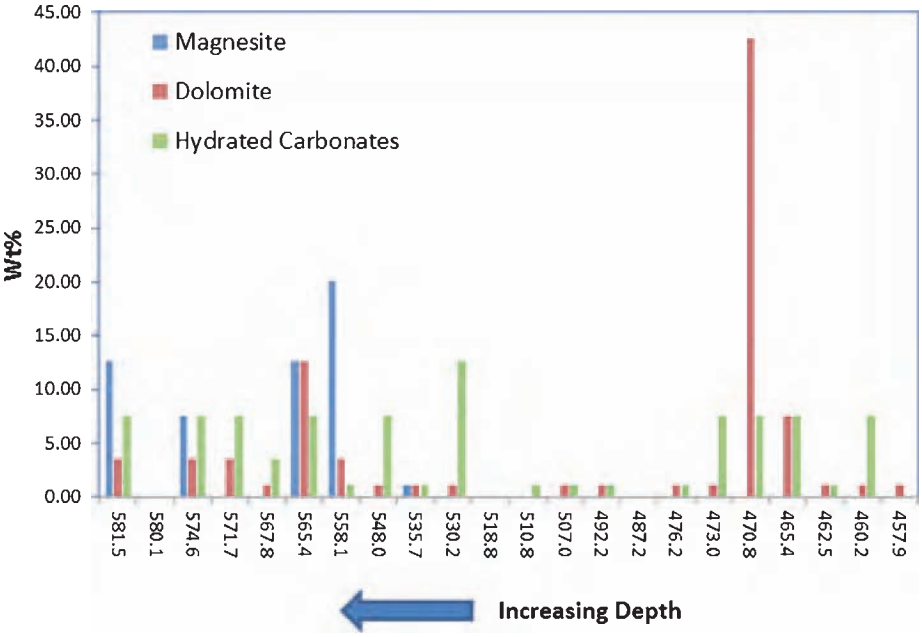

Figure 8. *XRD results confirming magnesite and dolomite as the dominant species becoming more common approaching the bottom of the hole.*

magnetic property expectations, however the implications of sample densities near the lower end of the modelled range for ultramafics (indicating total serpentinisation) are yet to be determined. Results from drilling suggests that the magnesite/dolomite found in shear/fault zones at the bottom of TCGA-01 could represent the distal part of a hydrothermal system arising from granite intrusion. Further exploration is required to understand the nature of this system.

Thanks to Joe Xie of Yunnan Tin and MRT staff including Ralph Bottrill, David Green, Richie Woolley and Lia Unwin.

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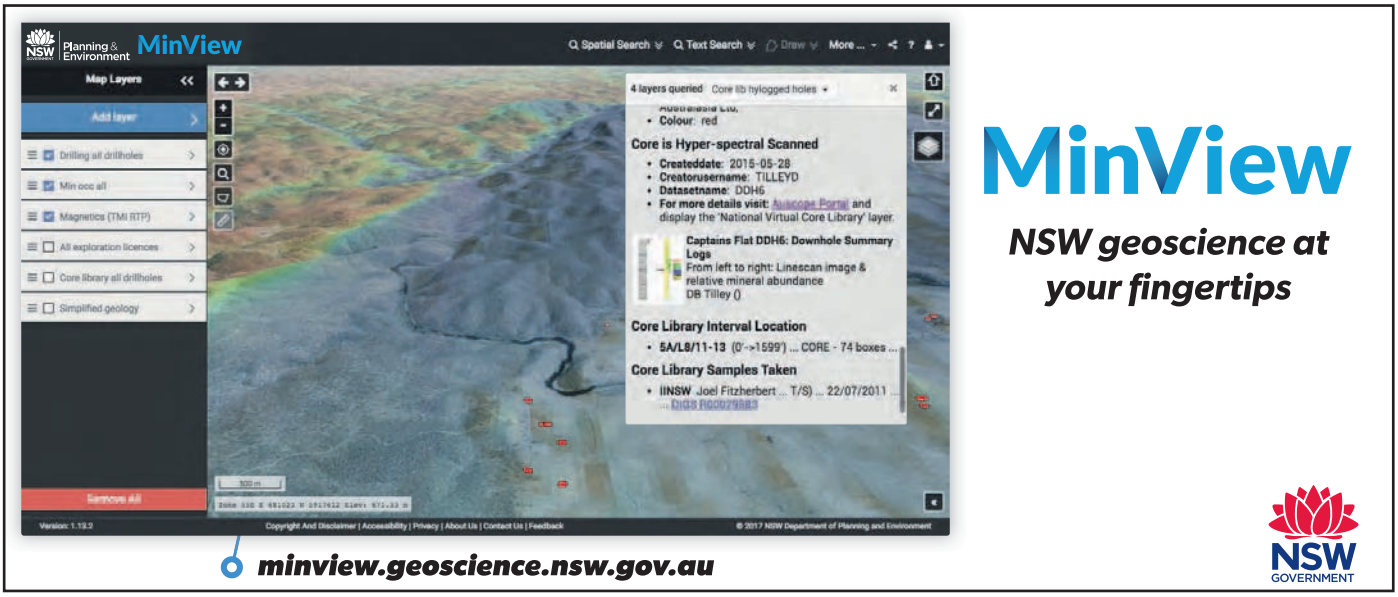

Update on geophysical survey progress from Geoscience Australia and the Geological Surveys of Western Australia, South Australia, Northern Territory, Queensland, New South Wales, Victoria and Tasmania (information current on 14 December 2017)

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
Andamooka	GSSA	GA	Sander Geophysics	23 Feb 2017	81 396	200 m 60 m E–W	14 560	6 Jun 2017	Final data QA/QC in progress	183: Aug 2016 p. 34	TBA
Barton	GSSA	GA	Thomson Aviation	22 Jan 2017	111 758	200 m 60 m E–W	20 560	11 May 2017	Final radiometric data QA/QC in progress	183: Aug 2016 p. 34	TBA
Fowler	GSSA	GA	Thomson Aviation	18 Feb 2017	95 009	200 m 60 m E–W	17 360	2 Jun 2017	Final radiometric data QA/QC in progress	183: Aug 2016 p. 34	TBA
Torrens	GSSA	GA	Sander Geophysics	4 Mar 2017	79 990	200 m 60 m E–W	14 800	15 Jun 2017	Final data QA/QC in progress	183: Aug 2016 p. 34	TBA
Coonabarabran	GSNSW	GA	UTS Geophysics	17 May 2017	50 827	250 m 60 m E–W	11 000	30 Jul 2017	Nov 2017	184: Oct 2016 p. 23	Nov 2017
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	National Collaborative Framework Agreement between GA and MRT is being updated. The survey has been deferred to occur between Oct 2017 and Mar 2018
Isa Region	GSQ	GA	GPX	3 Jul 2017	120 062	100 m 50 m E–W	11 000	5 Nov 2017	Raw edited data made available to GA on 7 Dec 2017	188: Jun 2017 p. 21	TBA
Tallaringa N (1A)	GSSA	GA	TBA	26 Oct 2017	97 762	200 m 60 m E–W	17 320	40.3%	TBA	190: Oct 2017 p. 26	TBA
Tallaringa S (1B)	GSSA	GA	TBA	26 Sep 2017	145 042	200 m 60 m E–W	26 010	41.5%	TBA	190: Oct 2017 p. 26	TBA
Coober Pedy (8A)	GSSA	GA	TBA	18 Sep 2017	90 627	200 m 60 m N–S	16 140	96.2%	TBA	190: Oct 2017 p. 26	TBA
Billa Kalina (8B)	GSSA	GA	TBA	10 Oct 2017	90 625	200 m 60 m N–S	16 140	94.2%	TBA	190: Oct 2017 p. 26	TBA
Childara (9A)	GSSA	GA	TBA	5 Nov 2017	135 021	200 m 60 m N–S	23 910	15.2%	TBA	190: Oct 2017 p. 26	TBA
Lake Eyre (10)	GSSA	GA	TBA	2 Oct 2017	91 800	200 m 60 m E–W	16 180	52.1%	TBA	190: Oct 2017 p. 26	TBA

TBA, to be advised.

Table 2. Gravity surveys

Survey name	Client	Project management	Contractor	Start survey	No. of stations	Station spacing (km)	Area (km^2)	End survey	Final data to GA	Locality diagram (*Preview*)	GADDS release
Tanami-Kimberley	GSWA	GA	Thomson Aviation	16 Jun 2017	49 825	2500 m line spacing	110 000	31 Oct 2017	Raw edited data made available to GA on 8 Dec 2017	The survey area covers the Billiluna (all), and parts of the Lucas, Cornish, Mount Bannerman, Mount Ramsay, Noonkanbah, Lansdowne, Lennard River, Derby, Charnley and Yampi 1:250 k standard map sheets	TBA
Kidson Sub-basin	GSWA	GA	CGG Aviation (Australia)	14 Jul 2017	72 933	2500 m line spacing	155 000	TBA	70.7%	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

TBA, to be advised.

Table 3. AEM surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Spacing AGL Dir	Area (km^2)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
East Kimberley	GA	GA	SkyTEM Australia	26 May 2017	13 723	Variable	N/A	24 Aug 2017	Nov 2017	TBA	TBA
AusAEM (Year 1)	GA	GA	CGG	TBA	59 349	20 km with areas of infill	TBA	TBA	32.9%	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	TBA	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	TBA	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	AusLAMP	150	50 km	Long period MT	The survey covers the area between Tennant Creek and Mount Isa

Reprocessed seismic data in the Tennant Creek region

The Tennant Creek crustal reflection seismic survey was co-funded by the Northern Territory Government through the Creating Opportunities for Resource Exploration (CORE) initiative and Emmerson Resources Limited. HiSeis Pty Ltd acquired the 60 km 2D seismic line (Line 101), proximal to the Tennant Creek town site and mining facilities, from 14 June to the 21 June 2015. Geoscience Australia, as part of the Exploring for the Future Program, provided specialised hard-rock seismic data processing to image deep crustal structures and sedimentary layers at the near surface.

The objective of the 2D survey was to define the regional scale structures contributing to the mineralisation in the area and target previously unidentified areas of prospectivity in the Tennant Creek Mineral Field, as well as demonstrate the value of seismic reflection for the minerals industry and to the geoscience community.

10 s stack and migrated data and a 20 s stack are provided as Tiff images and SEG-Y format. Depth conversions were performed on the migrated data and 30 km depth SEG-Y and 5 km depth Tiffs are included. Meta data including coordinates for all data sets, data processing streams and velocity files are included.

The data were released in December 2017 and are available as a single zip file (347 Mb file size) from the GA website at https://ecat.ga.gov.au/geonetwork/srv/eng/search by entering 115103 (the eCat ID number) into the search box.

Canberra observed

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2017: a better year for the resource sector

Resource stocks do well on the ASX

2017 was a better year for the resource sector than 2016, particularly in the Stock Market.

Figure 1 shows the All Ords Index for the ASX and the total value of the market capital of the resource companies listed in the top 200 companies in the ASX. The numbers have been adjusted to $A December 2017.

Before the Global Financial Crisis (GFC) in 2008, changes in these two parameters were strongly correlated, probably because of the dominance of the resource companies in the ASX before the GFC.

After the GFC the correlation is much weaker, with the resource values showing considerable volatility.

Without the income from dividends, the long-term investor with a wide portfolio of shares in 2005 would not have done well. Using CPI adjusted numbers, the All Ords Index only increased by 12% in this period – a growth of less than one percent per year. However, since the end of the GFC the All Ords Index rose steadily and in 2017 it rose by a very solid 6 percent.

If you held shares in resource companies you would have done much better, even if the ride was more unpredictable. The increase from 2005 to 2018 was about 44%, a very healthy 3.4% per year, and since the start of 2016 the resource companies have continued to prosper with an 80% increase over two years.

In 2017, apart from the small downward excursion in the first half of the year, the upward trend has continued. Some of the outstanding performers were the giants; BHP, which increased its value by 18% in 2017 from $81 billion to $95 billion, and Rio Tinto by 23% from $25 billion to $31 billion. Table 1 shows the result from some of the major companies.

Beach Energy and Whitehaven were two of the top performers with increases over the year of 66% and 71% respectively. The Whitehaven result is at odds with the expectation in some quarters the death of coal is imminent. King Coal is clearly alive and kicking and there was a 28% increase in the average price of thermal coal in 2017 from 2016. The only negative performer in table is Fortescue, which is unexpected because the average price of iron ore rose by 21 percent over the 2016 average.

Table 1. Changes in market capital of selected resources companies 2016–2017

Company	Value in $billion on 30 Dec 2016	Value in $billion on 29 Dec 2017	Percentage Change
BHP	80.48	94.97	18
Rio Tinto	25.41	31.26	23
Woodside	26.25	27.87	6
Fortescue	18.34	15.20	–17
Newcrest	15.53	17.51	13
Oil Search	10.927	11.87	9
Origin	11.56	16.56	43
Santos	8.17	11.35	39
Whitehaven	2.68	4.58	71
Beach	1.71	2.83	66

Prices for main commodities firm during 2017

During 2017 the prices for oil, iron ore, coal, gold and aluminium all firmed and, as indicated from the results in ASX, most companies are doing better than they did in 2016.

Figure 2 shows the results for aluminium and gold. Aluminium has done well with a price increase of 23% over the 2016 average price, but there has been

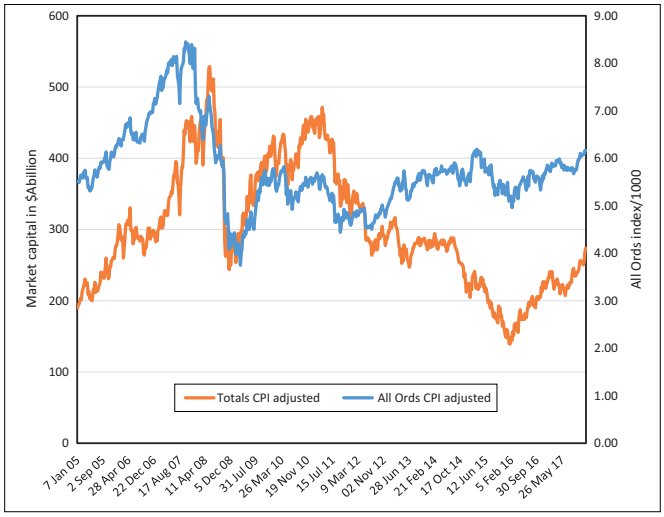

Figure 1. *Total market capital of resource companies for the top 200 in the ASX and the All Ordinaries Index for the period 2005–2017. The numbers have been adjusted to $A in December 2017.*

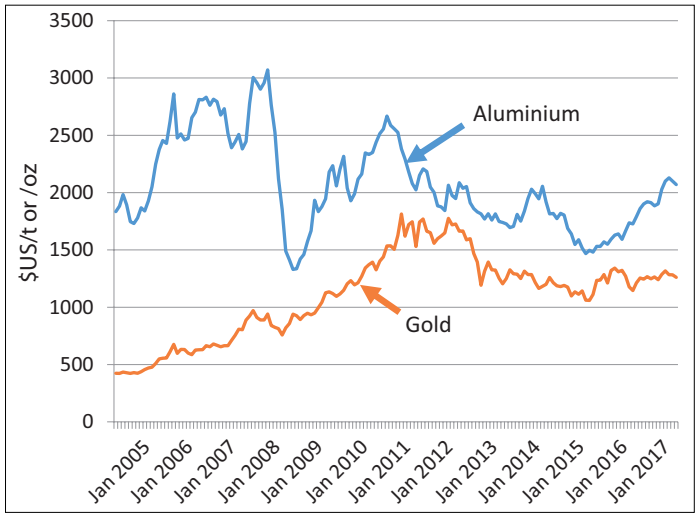

Figure 2. *Price of gold ($US/oz and aluminium ($US/t) from 2005–2017. Data taken from the London Metals Exchange (https://www.lme.com/metals). They have not been adjusted for any CPI increases.*

considerable volatility during the last 12 years. On the other hand, the gold price shows very little volatility during the same period. It seems to have been almost unaffected by the GFC. However, the increase in average price of only 1.3% would be very close to the annual rate of inflation. Gold would not have been a good investment in the past few years.

Figure 3 shows how the prices of coal, iron ore and oil have tracked from 2010 through 2017. As can be seen the price of each commodity bottomed in 2016 and since then they have all, except for gold, increased steadily by more than 20%.

The average numbers are shown in Table 2 and, if the trend in the first few days of 2018 continues, we can look forward to a good year ahead!

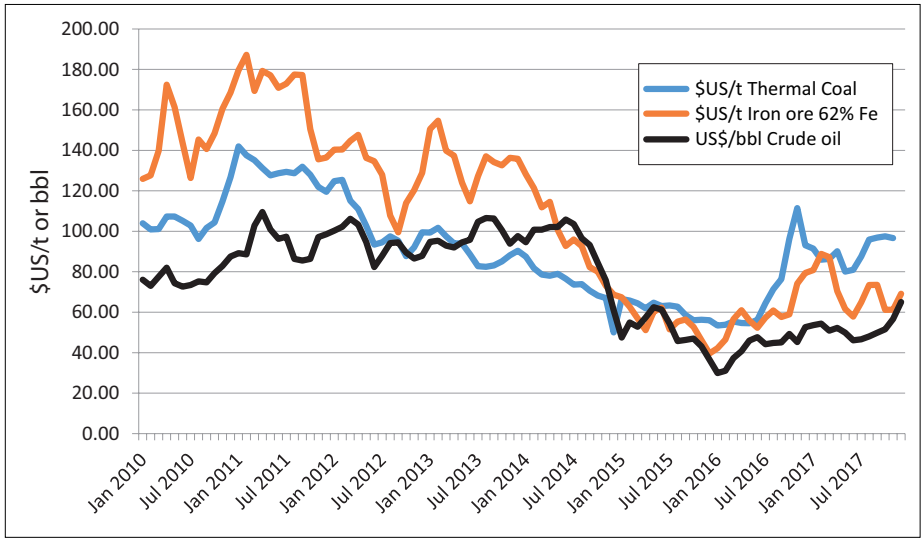

Figure 3. *Prices for thermal coal, iron ore and oil (West Texas Crude) for the period 2010 through 2017. Data taken from http://www.imf.org/external/np/res/commod/External_Data.xls, https://www.quandl.com/data/COM/FE_TJN-Iron-Ore-62-Fe-CFR-China-CME and http://www.economagic.com/em-cgi/data.exe/var/west-texas-crude-long. No adjustments have been made to correct for CPI increases.*

Table 2. Average prices for key commodities in 2016 and 2017

Commodity	2016	2017	% change	units
Aluminium (LME)	1604	1967	23	$US/tonne
Gold (LME)	1248	1264	1.3	$US/oz
Iron Ore 62% Fe China	58.6	70.8	21	$US/tonne
Oil (West Texas Crude)	42.8	52.1	22	US/bbl
Thermal Coal	70.1	89.9	28	$US/t

Coal's uncertain future analysed by the IEA

In 2016 the world consumed the equivalent of 13 billion tonnes of oil equivalent energy[1] (Figure 1). Although the annual increase in consumption in that year was, at 1%, well below the 10-year average of 1.8% and the third consecutive year at or below 1%, the global demand for energy continues to increase relentlessly. Oil, coal and natural gas continue to be the main source materials and, although coal still provides almost 30% of the energy consumed, it is now at the centre of a major national policy issue.

The challenge for coal, as the world's largest source of electricity, is that it is the largest source of energy-related man-made CO_2 and SO_2 emissions, and a major contributor to global warming and air pollution. At the same time coal's role is still central to providing energy in many developing countries, which are growing more rapidly than most OECD countries.

The International Energy Agency (IEA) found, in its Coal 2017 market and analysis report[2] released in December 2017, that: 'after a period of record growth for coal demand from 2000–12, our data and forecast show that the global demand for coal will have been stagnant over the decade 2013–22. Looking ahead, this stagnation masks important regional variations. As coal use continues to decline in many parts of the world these declines are offset by continued growth in India and Southeast Asia, as well as several other countries where today coal's role is small but is on the rise, such as Pakistan and Bangladesh'.

The report identifies eight highlights:

1. **Global coal demand declined 1.9% to 5 357 million tonnes of coal equivalent (Mtce) in 2016, in energy terms.** Although the decline since 2014 (4.2%) matches the largest percentage drop registered in IEA statistics (that of 1990–92), it is the largest drop in absolute terms. Coal's share in global primary energy supply declined to 27%, but it remains the second-largest source of energy after oil.
2. **Coal use declined in all sectors in 2016.** The drop in the power sector (0.5%) was driven by Europe and the United States and was partially offset by the People's Republic of China and India; the fall in the non-power sector (7%) was led by China. Metallurgical coal demand decreased by 0.5%.
3. **In China, coal demand declined for the third consecutive year in 2016.** The decline of 4.7% (–178 Mt) in

[1]BP Statistical Review of World Energy, June 2017.

[2]IEA (2017) *Market Report Series: Coal 2017*, IEA, Paris. http://dx.doi.org/10.1787/coal_mar-2017-en.

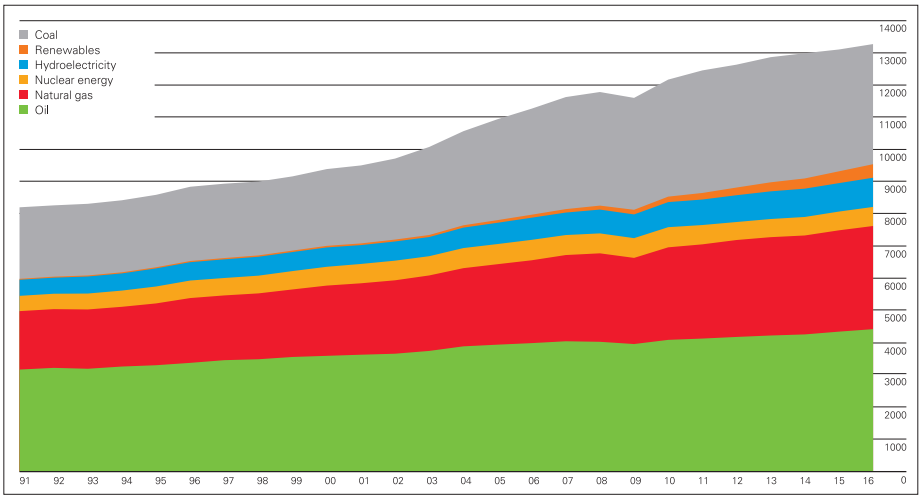

Figure 1. *World energy consumption (million tonnes oil equivalent) 1991–2016, from BP Statistical Review of World Energy June 2017, p. 10.*

physical volume (1.8% in energy terms) resulted in final consumption of 3 621 Mt, largely driven by reductions in the industrial and residential sectors. China remains key for the coal market, with 49% of global consumption and 46% of global production.

4. **India, the second-largest coal consumer in the world, had the largest demand growth in absolute terms in 2016 (+22 Mt, or 2.4%).** This is a significant slowdown compared with 6.8% annual growth recorded over the last decade. However, in Association of Southeast Asian Nations countries, coal demand increased by 6.2% in 2016, driven by coal-fired electricity generation.
5. **2016 was the first year in the United States in which coal was not the largest source of electricity.** The reduction of 121 terawatt hours (TWh) of coal generation was replaced mainly by an additional 71 TWh of renewable generation and 47 TWh of gas generation, driven by very low gas prices. Overall coal consumption declined by 54 Mt (–7.5%) in 2016, but the United States remained the third largest coal consumer in the world.
6. **The sharp decline in coal consumption of 8.1% (–56 Mt) in the European Union was led by a drop of 52% (–20 Mt) in the United Kingdom.** The UK carbon price floor that supports fuel switching from coal to natural gas in the electricity sector had already resulted in a sharp decline of 23% (–11 Mt) in 2015. Germany and Poland remain the last two large-scale consumers of coal in Europe, accounting for over half of EU coal consumption in 2016.
7. **Global production declined by 6% (–460 Mt) in 2016, the largest drop recorded in IEA statistics, also driven by China.** Amid declining demand, supply-side reforms in China resulted in an output reduction of 321 Mt (–9%). The closure of 290 million tonnes per annum of mining capacity and the reduction from 330 to 276 working days per year for Chinese miners led to supply cuts and the subsequent rise in global coal prices in 2016/17.
8. **India has become the second-largest coal producer in the world, surpassing the United States.** While production in the United States decreased by 17%, India's increased by 4% to 708 Mt in 2016, pushed by increasing energy demand and government policies.

Figure 2 summarises some of the main points in the report. It shows that global peak production of 4.00 billion tonnes appears to have been reached in 2013 and that Australian production probably peaked in 2015. However, if development of the Galilee Basin goes ahead that would significantly increase Australian production rates.

The IEA's global forecasts of coal production from now until 2022, as shown in Figure 2, are based on several assumptions. The first is that coal production in this period will be driven by GDP. The IMF expects this to grow at 3.7% per year over 2017–22 period (see p 68 of IEA Report). The second assumption is that fuel prices will remain at $US56 per barrel (Brent) throughout the five-year period. If I was a betting man I would have thought that the annual global GDP growth estimate is too high, and the price of oil is too low – but then, I can't forecast the future either!

As with all forecasts we will have to be patient and wait to see what happens.

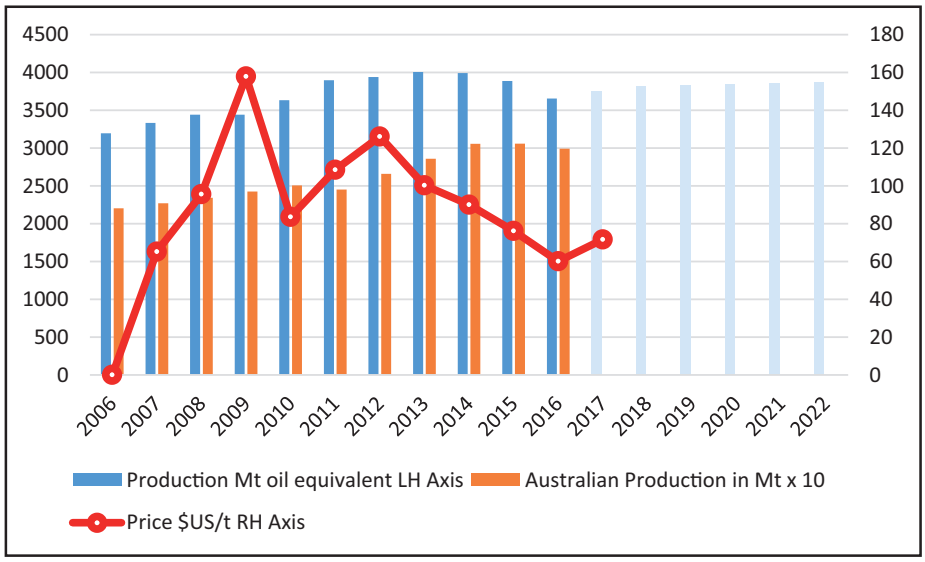

Figure 2. *Global and Australian coal production and price 2006–2016. The dark blue columns indicate the global coal production taken from BP and the IEA reports. The light blue columns indicate the IEA forecasts. The coal price is the Japan steam coal spot price from page 36 in the IEA report. A factor of 0.7 was used to conversion Mt coal to oil equivalent.*

Acreage release news for Offshore Petroleum Exploration

Proposed areas for the 2018 Offshore Petroleum Exploration acreage release

Following the nomination and short-listing process, 21 areas are proposed for inclusion in the 2018 acreage release (Table 1). These areas are shown on the map in Figure 1. They are in Commonwealth waters offshore Western Australia, Northern Territory, Tasmania and Victoria, and in the Territory of the Ashmore and Cartier Islands.

It is anticipated that the Minister for Resources and Northern Australia, Senator Matt Canavan, will announce the final 2018 acreage release at the annual Australian Petroleum Production and Exploration Association Conference in May 2018. Following the minister's announcement, full acreage release information including closing dates and geological write-ups of each area will be available at http://www.petroleum-acreage.gov.au/.

Table 1. Areas proposed for inclusion in the 2018 acreage release

State/Territory	Basin	Area
Northern Territory	Bonaparte	AC 18-1
Western Australia	Bonaparte	W 18-1-
Western Australia	Browse	W 18-2 & 3
Western Australia	Carnarvon	W 18-4, 5,6,7,8,9,10,11,12
South Australia	Bight	S 18-1
Victoria	Otway	V 18-1,2,3
Victoria	Gippsland	V 18-4,5,6,7

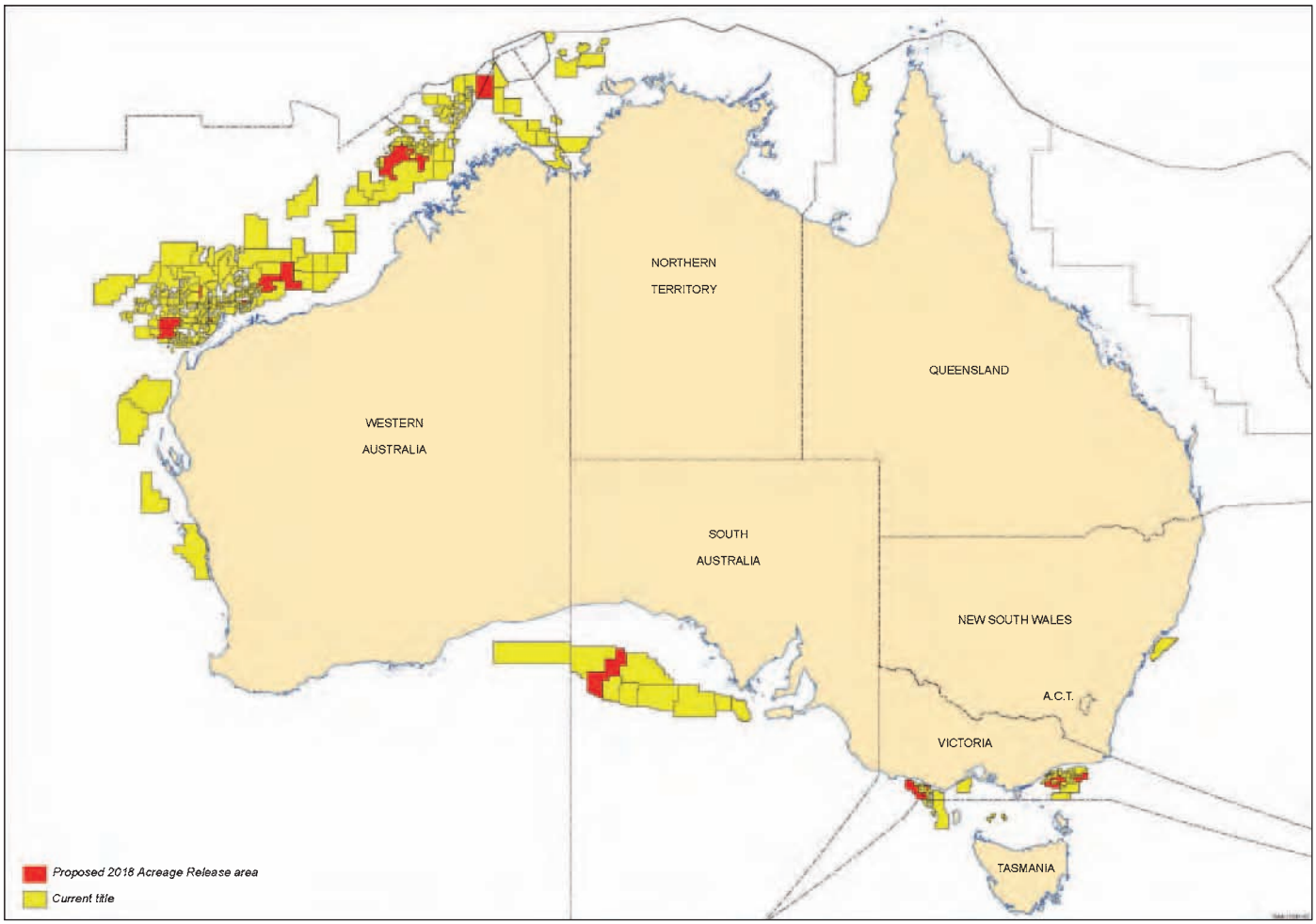

Figure 1. *2018 Offshore Petroleum Exploration acreage release – proposed areas coloured red, and existing leases coloured yellow.*

Outcomes of the 2016 Offshore Petroleum Exploration acreage release

The 2016 Offshore Petroleum Exploration acreage releases have been finalised with a total of eight exploration permits being granted. The indicative total exploration investment on these leases is expected to be A$359 million over the next six years, but this will depend on how many holes are drilled. All these holes, totalling $285 million, are included in the secondary work programs and my understanding is that if the companies don't find an attractive target they can walk away from the lease. The details are contained in Table 1.

In addition to the granting of the above leases, the Department of Industry advised that:

- Release area AC16-4 received one bid but has reverted to vacant acreage.
- Release area W16-2 is expected to be awarded, however there has been no formal offer.
- Release areas W16-5, W16-6, W16-9 and W16-24 were re-released as part of round one of the 2017 Acreage Release (bids closed 19 October 2017). Bids for that round are currently being assessed by the National Offshore Petroleum Titles Administrator.
- The following release areas have reverted to vacant acreage: AC16-1, AC16-2, W16-1, W16-3, W16-10, W16-11, W16-13, W16-15, W16-16, W16-19, W16-20, W16-21, W16-22 and W16-25.

Table 1. Details of exploration programs for areas granted exploration permits

Basin and Company	Guaranteed program	Secondary work program
Roebuck Basin, W16-8. 3D Oil Ltd. There were no other bids for this area.	$3.86 million comprising acquisition and processing of 510 km^2 of 3D seismic and geophysical and geological studies.	Further geophysical and geological studies and one exploration well, totalling $30.8 million.
Carnarvon ?deep water, W 16-17. Chevron Australia New Ventures Pty Ltd	$3 million, cash bid. No work program provided.	
Ashmore Platform of the Bonaparte Basin, AC16-3. Carnarvon Petroleum Pty Ltd. One other bid was received on this area.	$6.5 million comprising licensing of 682 km^2 of the Cygnus multi-client 3D PSDM seismic data and conducting a number of geological and geotechnical studies.	An exploration well and post-well studies, totalling $30.5 million.
Exmouth Plateau of the Northern Carnarvon Basin, W16-12. Joint venture between Chevron Australia New Ventures Pty Ltd and Woodside Energy Limited. There were no other bids for this area.	$14.25 million comprising acquisition and AVO processing of 2000 km^2 of PreSDM broadband 3D seismic data and reprocessing and geophysical and geological studies of 600 km^2 of the Monuments 3D seismic data set.	Further geological and geophysical studies and an exploration well, totalling $52.8 million.
Exmouth Plateau of the Northern Carnarvon Basin, W16-14. Joint venture between Chevron Australia New Ventures Pty Ltd and Woodside Energy Limited. There was one other bid for this area.	$14.5 million comprising acquisition, processing to PSDM and geological and geotechnical studies of 1900 km^2 of broadband 3D seismic data. Re-processing work of both the Foxhound Multi-client 3D seismic survey and the Monuments 3D survey.	Geological and geotechnical studies and an exploration well, totalling $52.8 million.
Exmouth Plateau of the Northern Carnarvon Basin, W16-18. Joint venture between Chevron Australia New Ventures Pty Ltd and Woodside Energy Limited, There were two other bids for this area.	$10.3 million including reprocessing work of 4700 km^2 of 3D seismic data, acquisition of an additional 900 km^2 of MC3D seismic data, with AVO processing and seismic inversion of 4000 km^2 across these data sets.	Further geological and geophysical studies and an exploration well, totalling $52.8 million.
Barrow Sub-Basin of Northern Carnarvon Basin, W16-23. Joint venture between Quadrant Northwest Pty Ltd and Santos Offshore Pty Ltd. There was one other bid for this area.	$1.45 million involving a targeted seismic processing and reprocessing of 3D seismic data from existing 3D surveys over the area.	Geological and geotechnical studies and an exploration well totalling $30.8 million.
Southern Browse Basin, W16-4. INPEX Browse E&P Pty Ltd. There were three other bids over this permit area.	$23.6 million including acquisition and processing of 7185 km of 2D seismic data and reprocessing of a further 2000 km of 2D seismic as well as AVO and seismic inversion analysis of the entire data set. It also involves the targeted conduct of these activities over 600 km^2 of 3D seismic data.	Geotechnical studies and an exploration well valued at $34.3 million.

Education matters

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The present is the key to the past

It was the father of geology James Hutton who coined this phrase in the 18th century, while working to replace the catastrophism dogma of the day with an understanding of geological processes. This month Heather Tompkins brings us an overview of a spectacular 'key', the *Joides Resolution* deep ocean drilling vessel.

Heather's article crossed my desk at the time I was working as a session convener for the European Geophysical Union conference (scheduled for Vienna, April 2018) where we plan to run a session devoted to cycles of climate change of the Holocene. Ocean deep drilling is one of the essential sources of data for such studies, whereby sediments with a high rate of deposition in ocean trenches are sampled and studied for age and proxy sea-surface temperature data using a range of isotopic and organic molecular structure criteria. Such data is then used to build a time series of temperature change over tens or hundreds of thousands of years. The results have potential importance beyond mere geological history, for an understanding of past climate cycles feeds into our current understanding of climate change and the relative contributions of natural and anthropogenic CO2 forcing factors. Such relationships and their causative factors will keep today's students busy at their desks, and at the benches of vessels such as *Joides Resolution*, for decades to come.

An inspiring hour on *Joides Resolution*

Heather Tompkins
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Joides Resolution came alongside Fremantle dockyard on Monday 27 November to resupply and participate in tours with local school children and members of the public. I was lucky enough to attend an hour-long tour on Monday afternoon.

Joides Resolution undergoes research as part of the Integrated Ocean Discovery Program (IODP), which is funded primarily by the United States, Japan, and a consortium of European countries. The vessel began working for the Ocean Drilling Program in 1985 and underwent various refits from 2006 and 2008. The ship is 143 m long and equipped to drill 4 km deep wells in water depths of up to 4 km.

Expedition 369 saw *Joides Resolution* complete studies of the Cretaceous climate and tectonics along the southern margin of Australia in the Bight and Mentelle Basins. The aim of the expedition was to improve the understanding of the Cretaceous hothouse, ocean anoxic events, paleoceanography, and the depositional history of the southern margin during the breakup of Gondwana. A total of 130 crew and scientists were on-board for the Australian expedition with Chief Scientists from Durham University, the Smithsonian Institute, and Texas A&M University.

During the tour we were taken through various workspaces on-board *Joides Resolution* and had the opportunity to speak with scientists from previous expeditions. The tour began near the base of the derrick on the catwalk, where core is carried in 10 m lengths from the drill string to core tables. We observed the various core bits, piston corers, and core catchers used during drilling and selected based on the properties of the substrate. The core is cut down to 1 m sections and stacked on racks inside the vessel to acclimatize before testing in the various lab spaces on-board. The first analysis completed on the core is semi-automated petrophysics including bulk density, magnetic susceptibility, p wave velocity, and natural gamma radiation. From here the core is split in half, one half for sampling and analysis and the other half is archived in one of three core repositories around the world. The core is logged using traditional core description methods by a team of sedimentologists and geologists. Subsequent on-board tests may include porosity, thermal conductivity, P wave velocity, density, scanning photography, colour spectra, magnetic susceptibility, paleomagnetism, and smear slides can be generated for microscope analysis. A world class, refurbished palaeontology lab is used to prepare samples for microscope and scanning electronic microscope (SEM) analysis including the classification of any forams, diatoms, dinoflagellates, or other microfossils within the core. A small section of each 10 m core length is also sent straight to the geochemistry lab to identify the presence of any hydrocarbon indicators. The lab is equipped with –80°C freezers to preserve samples and can complete additional tests such as interstitial pore fluid analysis,

Joides Resolution during expedition 369 in the Southern Ocean, captured from an altitude equal to that of the top of the derrick (63.4 m). Credit: Gabriel Tagliaro and IODP.

Top left: View of derrick from catwalk. Top right: Core tables on catwalk. Bottom left: Core logging and sampling laboratory. Bottom right: Drill and core bits.

gas chromatography, total carbon content, organic and inorganic chemistry analysis, thermal tests to determine porosity and permeability, and microbiology analysis.

The tour ended with a visit to the bridge and a quick discussion on the dynamic positioning capabilities of the vessel. Overall, the tour was very informative and a great opportunity to view a working research vessel. I'm confident that everyone ended the tour with a better appreciation for the information scientists can extract from beneath the ocean floor and how this can help unravel past climates and tectonic history. Walking away from the wharf, I couldn't help but feel an eagerness to submit an application to sail on a future expedition.

For further information check out http://joidesresolution.org/.

Environmental geophysics

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Welcome readers to this issue's column on geophysics applied to the environment. We have a slightly unusual piece for you this month – something that came across my desk that was just too intriguing not to present. Antonio Menghini, a geophysicist working with the Aarhusgeo group in Italy has been converting EM data into music, possibly initially to see if the data could be interpreted this way, but then as a tool to help explain geology and geophysics to a wider audience. Ultimately the sounds that he and his group of musicians are producing, based on the raw data, are mesmerising - at least to me.

As I read about this concept I found a few more websites that included examples of EMusic by Antonio and his group: (1) sounds from the First Break story referenced below: https://soundcloud.com/eagepublications/sets/what-is-the-sound-of-the-earth-first-steps-into-emusic; (2) some of the presentation (in Italian mostly) of the Viterbo concert described here: https://www.youtube.com/watch?v=sjnoDX-M0Fg; and (3) sounds from a dinner party at the Russian Minex Conference in 2016: https://www.youtube.com/watch?v=UeUD5sDUXNo.

I thank Antonio for his interesting work, and encourage you all to check it out.

Here is Antonio's story:

Jammin' with the Earth

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'Travertines sound like a diminished E chord, while diatomites like a B13 one': these observations come from our experiment with EM data called EMusic, a scientific-musical project born in Italy a couple of years ago. The idea is simple, to transform the raw data collected using a Transient ElectroMagnetic (TEM) system into musical notes (Menghini and Pontani 2016, Menghini 2016). It's only a question of numbers, the trick is to distribute the wide dynamic range of the TEM data to a smaller range of audible frequencies. It follows that we can actually extract musical 'information' that reflects the effective geological setting and that any site has its own soundtrack - that is a 'soundscape,' the audio component of a landscape.

The power of the project is essentially didactic, as it allows us to explain in a funny way, and to a wide audience, complicated phenomena like the EM propagation into the Earth. At the same time, by looking at (listening to?) the data in a different way perhaps we can enhance our understanding of the underlying geological and natural heritage. For this reason, our group is starting a project with a number of Italian schools to expand EMusic - as EMusic can be the gateway to talking about and understanding local geology, paleogeography, geophysics, natural risks, earthquakes, landslides, music, improvisation and musical composition - all in one!

Let me show you a practical example, coming from the EM concert we gave the last summer in the ancient Roman theatre of Ferento, close to Viterbo, Central Italy (Figure 1). During this concert my role as the 'master of ceremonies' was to introduce the tracks, preparing the audience for what they were going to hear – combining information about the geological background of each layer, the geophysical response and how these combined to produce the music. We collected data near the concert location – a site that is notable both archaeologically as well as geologically - and the first composition, called 'Descensus', is based on the direct sonification of the transient collected over the archaeological site (Figure 2). The audience was able to experience a journey into the Earth by riding the eddy currents produced by the changing EM field. It is not only a journey in geological space, but also in time, as we are exploring by means of music, older and older geological formations.

The progressive decrease of the signal translates into playing lower and lower tones. In order to make audible the single pitches in real time, we applied a time expansion factor of 1 million (hence 1 second of music corresponds to 1 microsecond of geophysical data). This first composition allowed me to explain how the TEM method works, going into the technical details of the instrumentation in a simple way. I explained how a geophysicist can model the subsurface by comparing the decay rate of the transient with the interval between pitches (tight intervals for conductive layers and wide ones for the resistive units). The 1D model of the data shown in Figure 3 shows, in a simple way, how the resistivity of each individual formation influences the propagation of the signal: the pitches are grouped closer in the less resistive diatomites and clays, while they are more separated in the resistive travertine/volcanic units and in the sand/conglomerate units.

During the second composition 'Ascensus' the musicians began to interplay with the pitches provided by the Earth: we

Figure 1. *EMusic concert, summer 2017 in the Ancient Roman Theatre of Ferento, near Viterbo in Central Italy.*

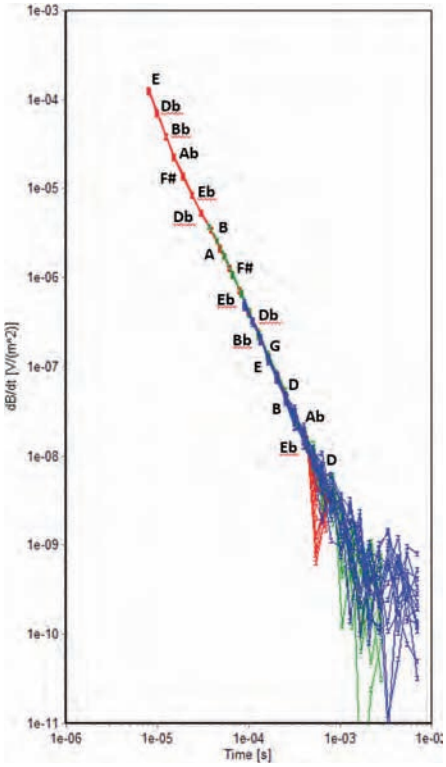


Figure 2. *Raw TEM data from the Ferento site, with notes assigned.*

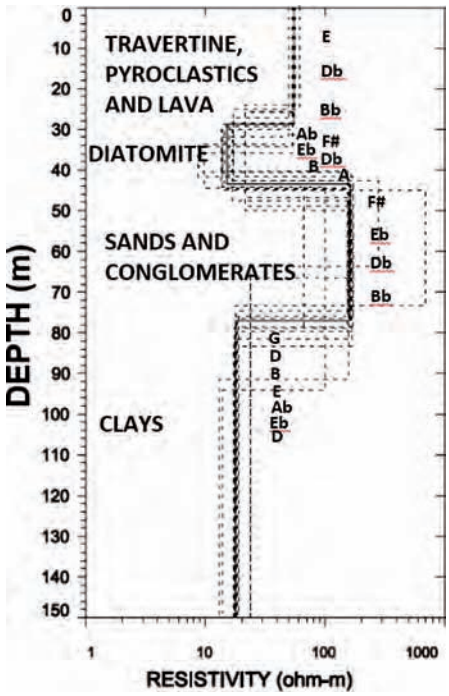


Figure 3. *1D inversion of TEM data, with musical notes assigned – used as the basis for the various musical compositions presented during the EMusic concert in Ferento.*

reversed the first track so that people listened to the return from the maximum exploration depth (in this case about 100 m) to the surface. The saxophonist and the guitarist were able to improvise over the EMusic base, by using the same pitches, in a sort of natural jam session, where the Earth is the band leader.

Then, we analysed each geological formation, by exploring the musical mood provided by the 'raw data's' relative pitch at each layer. For the first interpretive track 'Voltumna' I explained to the audience about the deposition of a shallow travertine layer by the thermal waters that were first used by the ancient Romans (a beautiful spa was excavated in the area, Figure 4). Interestingly the local travertine is the same material that was used to build the theatre where the performance was held (Figure 5). But the thickness of the travertines at the survey location is so thin that the travertine signal does not last long and the pitches quickly reach the underlying volcanic rocks. This area was the site of recent, intense volcanic activity (between 150 000 and 300 000 years ago), in fact the most recent eruption of the Vulsini Volcano

(the Montefiascone apparatus) that our signal flows through. This gave me the opportunity to talk about pyroclastics and lavas and about volcanism in general. A funny musical comment: the three pitches extracted from the travertine-volcanics formation, happened to have formed a diminished chord. In music diminished chords are said to generate a dramatic/mysterious mood, suggesting a sense of irresolution and restlessness. Of course, it was a little lucky that it turned out this way, but we can nevertheless enjoy a nice agreement between the geological scenario and the musical footprint.

The next track 'Elephas Antiquus' was really appreciated by the children attending the concert, because I talked about the presence in this area (about 300 000 years ago) of African fauna, including ancient elephants, hippos and lions, as seen in the rich fossil deposits found in this layer. The Paleontological Museum of the University La Sapienza in Rome holds a beautiful specimen of *Elephas Antiquus* that was found close to Ferento (Figure 6). During this period the area was characterised by the presence of lagoons and swamps, where many of these animals were trapped in the (dangerous) fine clays. This composition allowed us to talk also about climatic changes. It's really curious to verify that the pitches extracted from the diatomaceous clay sound like a B13 chord, suggesting a more relaxing atmosphere, resembling the quiet waters of the lagoons: once again we get a fortuitous coincidence between the palaeogeographic scenario and the musical flavour.

From 45 to 75 m depth we crossed sands and conglomerates that were deposited close to the coastline of an ancient ocean, about 1 million years ago. Hence the Ferento area was submerged, with some coastal islands from that period visible as present-day hills. The track 'Onde' was inspired by this environment, characterized by high energy and waves.

The last composition 'Abissi' reflects the sound feature of the grey-blue clays, deposited in the deep sea during the Pliocene. During this period the area was characterised by cold temperatures, as testified to by the presence of *Arctica Islandica* fossils (a type of cold water clam). Our musical trip stops here, only because there was no more data. If we had more late-time TEM data (e.g. by using a larger transmitter loop and/or lower base-frequencies), we could have

Figure 4. *Roman era spa, taking advantage of local hot springs that deposited the travertines, directly overlying older volcanics.*

Figure 5. *The concert venue – built out of the local travertines.*

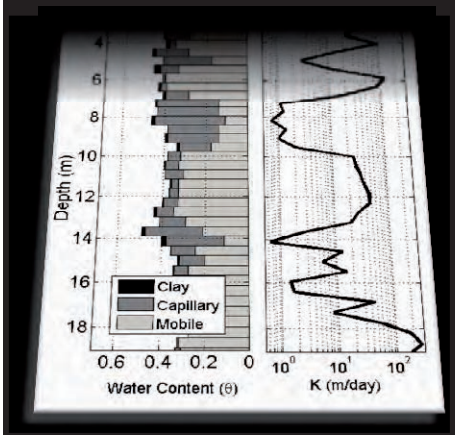
Figure 6. *Elephas Antiquus fossils found in the area, showing that African animals once inhabited this part of Italy.*

explored deeper and had more geology to interpret musically.

The musicians involved with this project were Stefano Pontani (electric guitar, loops and electronics) and Marco Guidolotti (saxophones). You can hear an excerpt of the full program here: https://www.youtube.com/watch?v=IaQLhoEQi84&feature=youtu.be, while the whole concert is available via a number of major on-line music sources like Apple's Itunes and Spotify; search for 'Live at Ferento'. If you are going to attend the next EGU (the European Geosciences Union) Assembly in Vienna in April 2018, don't miss our EM concert, called 'Sounds from the Geology of Italy', during which we'll play EMusic from four wonderful Italian sites (Venice Lagoon, Selinunte Temple, Phlegrean Fields and Castelluccio Plain). For more info about EMusic: www.emusic.world.

Antonio Menghini took a Master's degree in geological sciences at University of Rome 'La Sapienza', in 1989. He has worked as freelance geologist and geophysicist for many years. He is currently working in Aarhus Geophysics, a company specialising in the processing of Airborne EM data for mining, groundwater and geotechnical applications. He is Associate Editor of the *Journal of Environmental and Engineering Geophysics* (EEGS official review) and author of several international publications. He was Professor of Applied Geophysics at the University 'Gabriele D'Annunzio' of Chieti (Italy), during the 2008–2009 academic year. He is the inventor of EMusic and scientific director of the EMusic project.

Hydrogeologic Properties Measured with NMR



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Minerals geophysics

Terry Harvey
Associate Editor for Minerals geophysics
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When is enough, enough?

When investigating blind targets (e.g. under younger cover) or larger areas of interest (e.g. a magnetic complex) one of the harder decisions in mineral exploration geophysics is deciding when to stop collecting data and start drilling. We're all familiar with exploration case histories where perseverance finally triumphed. Equally, there are lots of examples where the exploration effort far exceeded what the target warranted. Do you drill sooner to save money and risk missing the real target, or do you continue to add detail where an early drill-hole could have told you not to bother?

Site your drill-holes on insufficient data and you run the risk of testing the wrong part of the target, or missing it altogether. Discouragement from poorly sited drill-holes could result in exploration being prematurely abandoned – a potential discovery jeopardised.

Collect too much data and you've wasted time and resources that could have been better directed to investigating other targets. Results from drilling earlier in the program may have shown the geological environment to be unpromising or the mineralisation to be uneconomic. All exploration effort after that could have been better expended on other more worthy targets.

Here are a couple of Australian examples where extra exploration resulted in a better understanding of the targeted mineralisation.

Systematic IP-resistivity on 500 m spaced lines passed either side of a small zone of mineralisation that previous drilling had shown to be of inadequate size and grade. The IP patterns on the two lines were quite similar, inviting extrapolation across the 500 m gap. However, linear extrapolation gave an IP anomaly trend which by-passed the known mineralisation (see Figure 1). Were these IP anomalies highlighting a new untested zone of mineralisation, or was the trend arcuate, passing through the area of previous drilling? Additional information was needed. A gradient array IP-resistivity survey was commissioned to map the area between the two lines. This showed that the original IP anomalies were not part of the same linear trend, but were from two separate sources, possibly arranged in an *en echelon* pattern (see Figure 2). Previous drilling had already tested one of the features. The second feature could be considered as yet untested, but was probably similar. Subsequent drill-testing confirmed this, obviating the need for additional drilling.

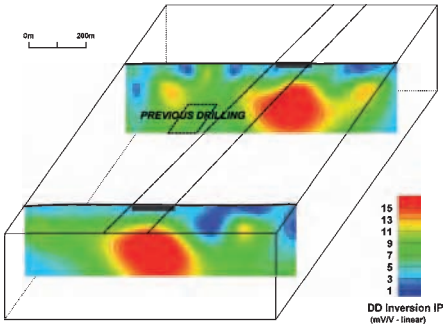

Figure 1. *Linear extrapolation between 500 m spaced IP data giving an IP anomaly trend which by-passes known mineralisation.*

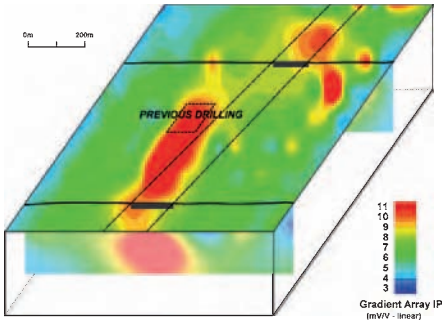

Figure 2. *A gradient array IP-resistivity survey mapping the area between the two lines shown in Figure 1 and demonstrating that the original IP anomalies were not part of the same linear trend, but were from two separate sources.*

In the second example results from a semi-regional scale aeromagnetic survey over an area of surficial cover showed that drill-hole DH1 appeared to have tested the source of a discrete magnetic anomaly (see Figure 3). DH1 drill-hole results, however, were disappointing and the magnetite concentrations intersected were inadequate to account for the magnetic anomaly. Had mineralisation been missed? A later much more detailed aeromagnetic survey revealed that the original discrete magnetic anomaly actually comprised two separate features, with drill-hole DH1 passing between the two sources (see Figure 4). Subsequent drill-testing (DH2) encountered significant magnetite, adequately explaining the source material for these magnetic features, adding to the understanding of the geology in the target area.

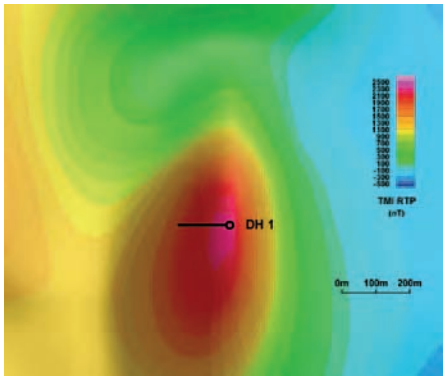

Figure 3. *A semi-regional scale aeromagnetic survey over an area of surficial cover showing that drill-hole DH1 appears to have tested the source of a discrete magnetic anomaly.*

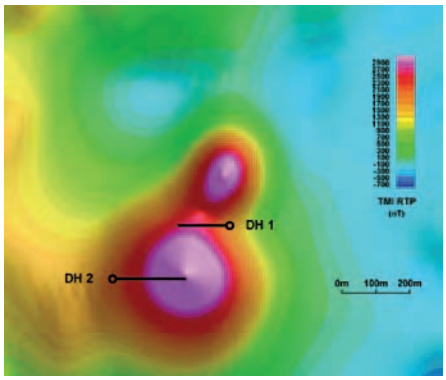

Figure 4. *A more detailed aeromagnetic survey of the area shown in Figure 3 revealing that the original discrete magnetic anomaly actually comprised two separate features, with drill-hole DH1 passing between the two sources.*

Collecting too much data thus wasting time and resources is typically realised

only in hindsight. An early see-what's-down-there hole drilled purely to find out whether the geological environment and/or mineralisation style is worth persevering with may have merit. In this case, management would have to know that the drill-hole wasn't the definitive test of the target, merely one step in the exploration process.

How you decide when enough is enough is hard to quantify and I really don't know the answer. I suspect it won't be formulaic, and will be on a case by case basis, reacting to new information as it comes in. This re-affirms the need for interpretation, experience, and imagination – all qualities that go to make a good explorationist. What do you think?

Editor's note: If Terry's column has caught your attention, you might also be interested in the talk being given by Andy Green on Wednesday in the Exploration Strategy session at the AEGC Conference. The presentation is entitled 'Budget allocation and the stopping problem in mineral exploration' and the abstract appears in the Conference Handbook section of this issue of *Preview*.

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Seismic window

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Acquisition footprint or anisotropy

Figure 1 is a seismic amplitude map at the top of a reservoir unit. There is obvious striping, but what is the cause? Such striping is commonly referred to as an acquisition footprint, which may be partly true, but the underlying cause of this phenomenon is velocity varying with azimuth or azimuthal anisotropy. Acquisition footprint is characteristically strongest on the shallowest horizons and diminishes with depth, so if this is a footprint it should be observed on the shallower horizon of Figure 2, but it is not.

I first encountered this striping when searching for oil prospects in the Exmouth Sub-basin 15 years ago. At the time Mark Stanley (then at BHP) was processing a large 3D survey and was investigating the cause of the striping, which was particularly strong

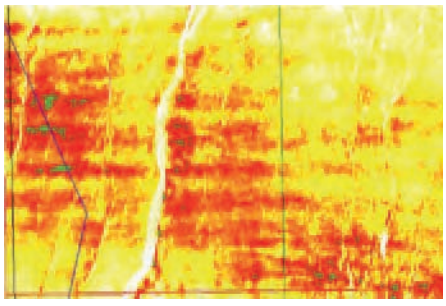


Figure 1. *Map of seismic amplitude at a relatively deep hoizon corresponding to the top of a reservoir. This map has obvious E–W striping which is often refered to as acquisition footprint, but this is incorrect even though the striping is parallel to the acquisition direction.*

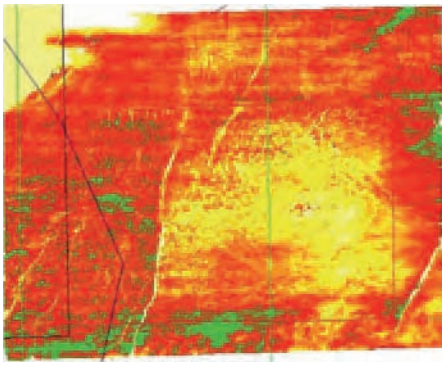


Figure 2. *This is a map of seismic amplitude at a shallow horizon and it has far less striping than the deeper horizon of Figure 1 suggesting it is not caused by acquisition geometry.*

on the reservoir reflector. Something at depth was affecting the data and it was eventually found to be azimuthal anisotropy of velocity in sandstones of the Barrow Group. Independently it had become standard procedure to acquire a cross dipole sonic log in exploration wells. This tool was able to measure shear wave velocities, which were useful for modelling AVO responses and in cross dipole mode could measure the variation of shear velocity with azimuth. These logs found a velocity variation related to the local stress direction, commonly up to 10–15%, that was only observed in the Barrow Group section in the area.

How does a varying velocity cause striping in amplitude and travel time maps? Mark came up with the following explanation, or at least a similar one. Figure 3 shows a schematic seismic acquisition spread and an ellipse representing the horizontal velocity. Because of the different angles relative to the fast velocity direction, the velocity from source to near and far receivers varies across the spread. I have attempted to illustrate this with ellipses where the long axis indicates the fast velocity direction, and the short axis is the slow direction. When travelling west velocities in the northern half of the spread are slower than the southern half, and when travelling east the northern half of the spread is fast compared to the southern half. The central traces are recorded in the average velocity direction. By plotting the relative times on a schematic pre-stack gather (Figure 4) the cause of the striping starts to become more obvious.

Points A1–A4 plot off the average velocity trend with A1 delayed relative

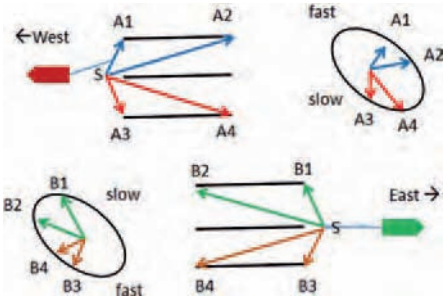


Figure 3. *Acquisition schematic showing raypath directions relative to the fast velocity direction. In this area there is strong azimuthally varying velocity anisotropy (represented by the ellipse with long axis in the fast velocity direction). When travelling E to W (top row) the near traces A1 and A3 travel in the slow velocity direction, far trace A2 travels in the average velocity direction and trace A4 is close to the fast velocity direction. Similarly when travelling west ray paths B1 and B2 are aligned with the fast direction (bottom).*

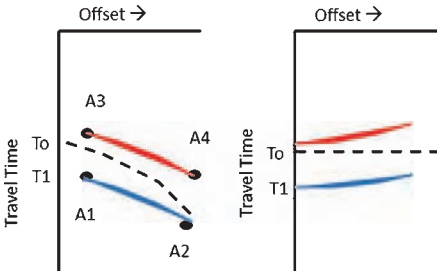


Figure 4. *Stylised uncorrected (left) and corrected (right) gathers. There is a time delay on traces recorded along the slow direction (e.g. A1) and if move-out correction uses the average velocity the reflections from outer traces will be overcorrected leading to diminished amplitude when stacked. When towed in the opposite direction there is a similar result.*

to A3 and A4 early relative to A2. These time differences result in an apparent slower velocity when compared to the average velocity. It is also apparent that if the reflectors are corrected with the average velocity they will be over corrected, and stacking these non-flat gathers will result in a reduced amplitude as well as a time delay relative to the correctly flattened traces.

In a typical racetrack acquisition pattern (Figure 5*a*) adjacent swaths have a time difference if recorded in the same direction and a saw tooth pattern is seen on cross lines (Figure 5*b*).

The result is striping of both amplitude and time maps in the sail line direction.

The amplitude and relative time of a reflection on a cross line XY across the sail lines (Figure 5) shows amplitude

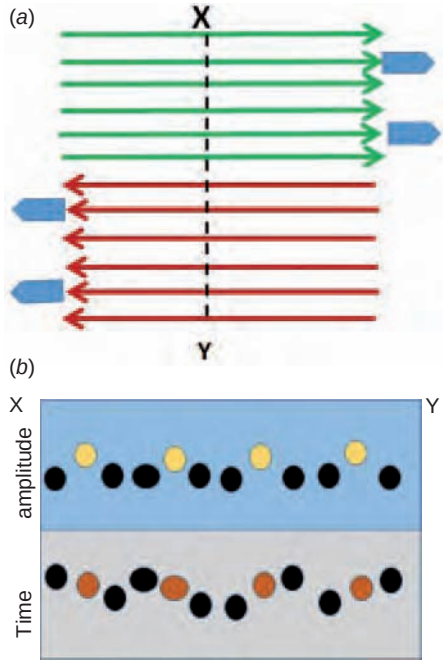


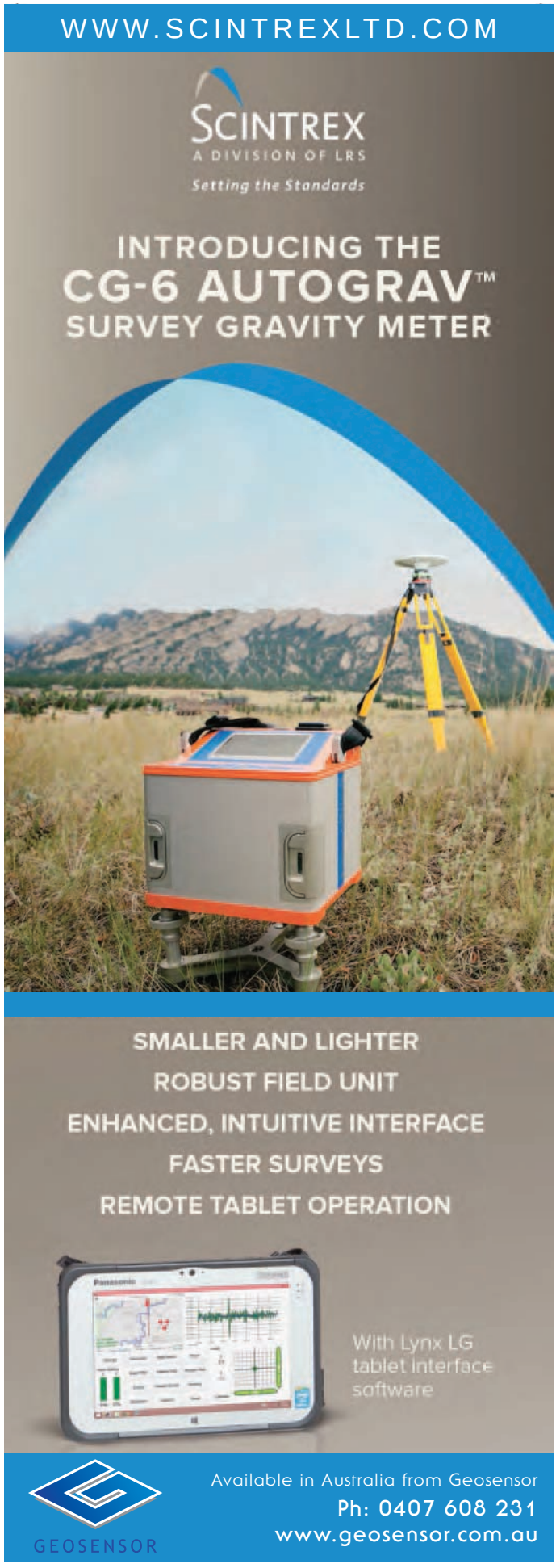
Figure 5. *Acquisition spread with two swathes recorded in each direction (a). The centre traces of each swath aligns with the average velocity direction and have true amplitude and relative time while the outer traces have relatively early or late time depending on the direction of recording and reduced amplitude because non-aligned traces are stacked. Amplitude and time along a crossline XY (b) shows the variations (centre traces coloured).*

variations resulting from mis-stacking and time variations because of the azimuthally varying velocity. Both cause the observed stripes.

Azimuthally varying velocity results in time and amplitude striping and while it is caused by the acquisition direction relative to the fast velocity direction it is not really an acquisition footprint.

This survey had possibly the worst sail line direction relative to the fast velocity direction. By recording parallel to the fast velocity azimuth the effects of anisotropy can be minimised.

Fortunately processing algorithms have been developed to take these velocity variations into account and the effects can be effectively reduced.



Webwaves

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A guide to the ASEG Website for non-ASEG Members

The *Webwaves* column is written mainly by the ASEG's Webmaster and it is designed to inform readers of web-related developments as they relate to the ASEG. Recent columns have focussed on data security, how the site, aseg.org.au, is used and by whom, and other columns have addressed agility and site additions. The ASEG's website is overseen by a committee of four who work with the site's developers (SpringDigital) to maintain and improve the site. The current site is the ninth version since 1999, and uses images contributed by Members in a photo competition. This edition of *Webwaves* highlights general aspects of the website that may be of interest to non-ASEG Members.

Some areas of the website, such as those related to the technical journal, *Exploration Geophysics*, purchasing Special Publications and the Society's annual wine offer are restricted to ASEG Members. However, much of the site, like *Preview*, is freely available to the general public in order 'to promote the science of geophysics, and specifically exploration geophysics, throughout Australia'. Of course, websites can be navigated using many devices from many locations throughout the world. Figure 1 shows site visits by country since the website's launch at the ASEG's 25th International Conference and Exhibition in Adelaide in 2016. Naturally, site visits are dominated by Australia, but there are significant levels of access from other English-speaking countries. It is also apparent that the site has been accessed from much of the world, partially reflecting the ASEG's second largest Branch: International Members. In Australia, most access is from Perth, then Melbourne, Sydney and Brisbane. Two international cities (Lagos and Santiago) appear in the top 10 cities.

much of the ASEG website, like Preview, is freely available to the general public

Mostly the site is used to access information about the current conference as well as the ASEG's Technical Journal; *Exploration Geophysics*. The ASEG's History Committee is active and their work documenting the evolution of the Society since its founding in 1970 includes documenting the ASEG's formation (https://www.aseg.org.au/about-aseg/aseg-formation) and the history of geophysical education in Australia (https://www.aseg.org.au/about-aseg/exploration-geophysics-education). Other reasons to access the site are to renew[1] membership (https://www.aseg.org.au/members/overview), catch up on news and events and a number of ASEG initiatives. Some of these initiatives are the maintenance of a contractor database, maintenance of a repository of equipment manuals, course material and videos. The remainder of this column focuses on these initiatives.

The ASEG's Contractor Database is designed to help find geophysical contractors throughout the world. An initial list, which was compiled by Pat Kineen and Ken Witherly, has been extended and is updated on request. Currently in the final stages of a major redesign, it should help the geophysical community identify contractors by method and location. The contractor database can be accessed at https://www.aseg.org.au/employment/contractor-database.

Although geophysical instrumentation is in a constant state of development and refinement, much use is made of historical data. Often reports contain high-quality data that can be digitised and incorporated in modern interpretations. However, without metadata such as transmitter and receiver parameters, it is not possible to model such data without resorting to trial and error. Manuals for equipment used to collect historical data can be of critical importance to using these data and saving reacquisition costs. Equipment manuals are available at https://www.aseg.org.au/equipment-

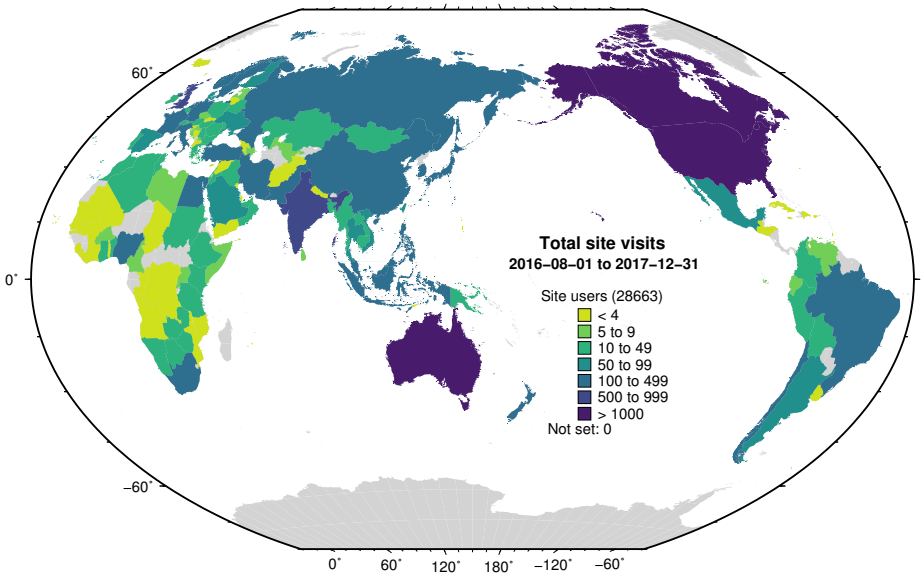

Figure 1. *Cumulative site access by country between August 2016 and December 2017. Nearly every country in the world is represented. Site access is dominated by Australia, the USA and Canada, and there is significant access from other countries in areas of active geophysical exploration such as Africa, South America and South East Asia.*

[1]Or join!

manuals-brochures. Somewhat related to historical data is the online equipment museum (https://www.aseg.org.au/equipment-museum), which provides photos and brief descriptions of a number of historical instruments.

Workshops are an integral component of ASEG conferences providing up-to-date information on geophysical exploration. Post-conference, this material is often lost even though it may be of interest to the general community. The same is true for ASEG-sponsored seminars. Therefore, with the permission of workshop and seminar convenors, the ASEG has begun to make material presented at conference workshops and seminars available to the general public who were unable to attend these sessions. Currently, presentations from nine workshops and seminars are available at https://www.aseg.org.au/workshop-proceedings.

The final, more recent initiative concerns videos. Currently the site provides access to five videos. Three of these are from a session at the 2015 ASEG conference, while a fourth was excerpted from an ASEG-sponsored workshop. The final video was taken at a branch technical night and webcast live internationally. Because this allows Members who were not able to attend the technical night access to material, the ASEG hopes to expand the number of such videos in 2018. ASEG Videos can be accessed at https://www.aseg.org.au/aseg-videos.

This column has attempted to provide an overview of the ASEG through its website, and the publicly available sections. We look forward to new visitors, and hope that they see enough value to join the ASEG (https://www.aseg.org.au/members/overview).

NSW GOVERNMENT

Senior Geoscientist – Geophysics & Data Stewardship

- Role Type: 3 year term
- Location: Maitland

The Geological Survey of NSW is a division of Department of Planning & Environment and a custodian of a large collection of geophysical data from across the state. These data include airborne magnetics, radiometrics and ground gravity data acquired by governments since the 1970s, as well as open-file airborne, ground and downhole data submitted by private companies. The Senior Geoscientist – Geophysics and Data Stewardship is a member of a small team responsible for acquisition, processing, modelling, interpretation, compilation and archiving of these data. The geophysical data contribute to the Geological Survey's mission to improve the geological understanding of the state and provide geoscience information for explorers and decision-makers. The role requires expert knowledge of magnetic and gravity data, a focus on data quality and fitness-for-purpose, and strong data compilation and cataloguing skills.

The preferred candidate will be a geoscience professional with broad experience in geophysical data acquisition and processing, familiarity with modelling and inversion software, and proficiency in compiling data, harvesting metadata and maintaining databases. You will have a sound knowledge of potential field geophysics as well as understanding the geological significance of geophysical features. The role requires an ability to work collaboratively with strong teamwork and communication skills. An understanding of electromagnetic and electrical geophysics would be advantageous.

If you have the capability to achieve success in this role and are interested in creating a more prosperous NSW we would love to hear from you!

BLZ132825

Applications Close: Sunday 25 February 2018

Applications must be lodged electronically. Please go to iworkfor.nsw.gov.au and search Job Reference Number 00005R38.

I work FOR NSW

CONFERENCE HANDBOOK

Australian Society of Exploration Geophysicists

PESA Petroleum Exploration Society of Australia

AUSTRALIAN INSTITUTE OF GEOSCIENTISTS

AUSTRALIA MINERALS

REALISE THE OPPORTUNITY

Australia Minerals is a collaboration of Australia's federal, state and Northern Territory government geoscience agencies working together to offer ground-breaking information, unrivalled expertise and a record of innovation to support mineral explorers and investors to realise investment opportunities.

With a long history of successful mineral exploration and mining, Australia is one of the world's biggest minerals exploration markets. Even so, Australia is one of the world's biggest untapped exploration markets with huge remaining brownfields and greenfields discovery potential. With readily accessible geoscience expertise and research support, Australia Minerals enables investors to tap into Australia's diverse geological potential in a range of commodities to achieve one of the highest exploration returns.

Australia's business, policy and investment processes, proven record of environmental, social, financial, legal and political stability, and its proximity to Asia's fast-growing markets, make it the smart, secure choice for exploration investment.

Australia Minerals offers:

- Assistance to help guide you through the exploration and investment process
- Breadth and depth of data to help you realise opportunities
- Intellect, innovation and technology to apply to opportunities
- Business, policy and investor relations
- Access to effective and efficient sustainable exploration policies, processes and technologies.

www.australiaminerals.gov.au

GA PP-1483 | eCat 115701

Welcome to the first Australasian Exploration Geoscience Conference

The Australian Society of Exploration Geophysicists, the Australian Institute of Geoscientists and the Petroleum Exploration Society of Australia, have again joined to run the pre-eminent geoscience conference held in Australia.

Your joint Chairs, Mark Lackie and Max Williamson, wish to extend the warmest of welcomes to you, your partner and your colleagues attending this Conference at the brand new world-class International Conference Centre in Darling Harbour in Sydney.

This is the first running of the Australasian Exploration Geoscience Conference and it incorporates the **26th ASEG Conference and Exhibition** and the **PESA Basin Symposia**. Our conference theme 'Exploration • Innovation • Integration' reflects that if you explore, be it for energy, mineral or groundwater resources, you need be innovative and importantly integrate all aspects of technology, science and history to succeed.

Peter Botten, the Managing Director of Oil Search will be giving the plenary address. We have 15 keynote speakers covering a variety of topics from groundwater, to industrial and strategic minerals, to airborne EM and IP, to multi-component seismic applications and to looking at footprints of ore deposits.

We have eight concurrent streams, three covering the Energy stream, three covering the Mineral Geoscience stream and two covering the Near Surface and Groundwater stream. In the Energy stream we cover a diverse range of topics from Basin Symposia (Western Australia, Central Australia and Eastern Australia), through to Non-Conventional, PNG and New Technologies in seismics. The Mineral Geoscience theme covers such topics as geophysics and geology case histories, airborne geophysics, magnetics and EM theory and Industrial and Strategic. The Near Surface and Groundwater theme has such topics as innovation, case studies and what is new in groundwater investigations.

We will have over 80 posters on display for the three days of the conference in the foyer. Poster presenters will have a dedicated poster session after lunch, giving delegates ample opportunity to discuss the science with the author.

Complementing the oral presentations and posters is the workshop program. We are offering 12 workshops, either before the technical sessions on the Sunday, or after on the Thursday.

At the time of writing we have over 60 exhibitors and we encourage you to visit them all.

Finally, thank you to all the sponsors who have come on board. Without you this conference simply could not happen. At the time of writing our sponsors are: **Australia Minerals** (Platinum sponsor), **CSIRO** (Sapphire Sponsor), **Oil Search, RioTinto** (Gold Sponsors), **Geoscience Australia** (Opal Sponsor**), Bridgeport, Geosoft, Horizon Oil, Kinetic**, **Velseis** (Silver), **GBG Australia**, **Taylor & Francis** (Morning Tea Sponsors), **First Quantum Minerals Ltd** (Best Papers awards Sponsor) and **Wireline Services Group** (Lanyard Sponsor).

On behalf of the whole Conference Organising Committee, we welcome you all to the first Australasian Exploration Geoscience Conference.

Max Williamson
(Joint Chair)

Mark Lackie
(Joint Chair)

AUSTRALIA MINERALS

REALISE THE OPPORTUNITY

Australia Minerals is a collaboration of Australia's federal, state and Northern Territory government geoscience agencies working together to offer ground-breaking information, unrivalled expertise and a record of innovation that supports mineral explorers to realise investment opportunities.

Australia is one of the world's biggest minerals exploration markets with huge remaining brownfields and greenfields discovery potential. With readily accessible geoscience expertise and research support, *Australia Minerals* enables investors to tap into Australia's diverse geological potential in a range of commodities to achieve one of the highest exploration returns.

Australia's business, policy and investment processes, proven record of environmental, social, financial, legal and political stability, and its proximity to Asia's fast-growing markets, make it the smart, secure choice for exploration investment.

Australia Minerals offers:

- Assistance to help guide you through the mineral investment process
- Breadth and depth of data to help you realise opportunities
- Intellect, innovation and technology to apply to opportunities
- Business, policy and investor relations to realise opportunities
- Access to effective and efficient sustainable exploration policies, processes and technologies.

Reputation

Australia has a solid reputation for success in minerals exploration and mining. Australia supports investors to realise exploration and mining opportunities, and is pro-actively making it easier to explore, do business and invest.

- Australia has world-class geoscience information systems to provide (for free) pre-competitive data to define and target minerals
- World's best geoscience and innovation for exploring under cover, with remaining unrealised potential in giant ore camps
- World leading business assistance and investment advice so you can find opportunities that meet your needs and
- Local and federal governments that work together to streamline processes, gain efficiencies and facilitate exploration in Australia.

Sustainability

Australia is committed to efficient and effective, environmentally sound, socially responsible, and economically viable practices for the benefit of communities and investors, and the reputation of the global exploration and mining sector:

- Australia's Leading Practice Sustainable Development Program for the Mining Industry has contributed directly to better exploration, mining, environmental and land practices globally
- Australia is a pioneer in the development and application of non-disruptive, remote sensing exploration technologies such as TEMPEST and FALCON to assess mineral potential prior to drilling
- Australia is delivering a 'one-stop shop' for environmental approvals to simplify the approvals process for businesses and lead to swifter decisions, whilst maintaining high environmental standards and
- Reforms such as the Council of Australian Governments' Land Access for Resources Working Group are improving exploration approvals and access certainty in relation to competing land uses, native title and aboriginal heritage.

GA PP-1484 | eCat 115681

AUSTRALIA MINERALS
REALISE THE OPPORTUNITY

Promotional events

Prospectors and Developers Association of Canada Convention

The Prospectors and Developers Association of Canada Convention (PDAC) is held in the first full week of March each year at the Metro Toronto Convention Centre in Toronto, Canada.

PDAC is the world's leading convention for people, companies and organisations in, or connected with, mineral exploration. *Australia Minerals* attends this event to promote Australia's exploration and investment potential to the 24 000 attendees.

China-Australia Resources Investment Forum

Australia Minerals proudly hosts a China-Australia Resources Investment Forum each year in Beijing, China.

Australia Minerals hosts this forum to promote Australia's exploration and investment potential in this key investment market. This event aims to attract increased investment in mineral exploration in Australia by engaging international government agencies and mining/exploration companies.

The seminar includes multiple presentations on Australian minerals/energy commodities and the Australian investment and policy environment. Spoken presentations are simultaneously translated into Chinese or English and PowerPoint presentations are displayed in both Chinese and English. A panel discussion session involving a moderator, an expert panel and the audience follows each presentation. A display area with tables and posters allows attendees to engage with participating government agencies and companies.

China Mining Congress and Expo

Australia Minerals participates in the China Mining Congress and Expo held each September at the Meijiang Convention and Exhibition Centre in Tianjin, China.

China Mining is one of the world's largest mineral investment, cooperation and trading platforms. More than 10 000 delegates attended in 2017, including more than 1100 international visitors. *Australia Minerals* attends this event to promote Australia's exploration and investment potential at this significant convention in a key investment market.

In addition to a large booth, *Australia Minerals* presents a Mining in Australia session during the convention.

If you are in Tianjin at this time please come and visit the *Australia Minerals* booth for more information about pre-competitive geoscience activities and exploration and investment opportunities from every state and territory.

Japan-Australia Mineral Investment Seminar

Australia Minerals hosts a Japan-Australia Mineral Investment Seminar at the Australian Embassy in Tokyo, Japan each year.

Australia Minerals promotes Australia's exploration and investment potential in this significant market in an effort to attract increased investment in mineral exploration in Australia by engaging international government agencies and mining/exploration companies.

The half-day seminar includes a series of presentations on Australian minerals/energy commodities and the Australian investment and policy environment. Spoken presentations are simultaneously translated into Japanese or English with PowerPoint presentations displayed in English. A display area is set up in the foyer to allow attendees to engage with participating government agencies and companies and a networking event is held immediately after the seminar.

Australia-Korea Mineral Investment Seminar

Australia Minerals hosts a Korea-Australia Mineral Investment Seminar in Seoul, South Korea in alternate years.

The *Australia Minerals* team promotes Australia's exploration and investment potential in this important investment market to attract increased investment in mineral exploration in Australia by engaging Korean government agencies and mining/exploration companies.

The half-day seminar includes a series of presentations on Australian minerals/energy commodities and the Australian investment and policy environment. Spoken presentations are simultaneously translated into Korean or English with PowerPoint presentations displayed in English. Time is also allocated for attendees to engage with participating government agencies and companies.

Engagement with the Indian International Mining and Investment Industry

Each year *Australia Minerals* attends a mining and investment convention in India or hosts a series of seminars. In November 2017, *Australia Minerals* participated in a promotional tour organised by Austrade India. The team conducted seminars and meetings in Kolkata, Hyderabad, Mumbai and New Delhi.

India is a key developing trading partner for Australia's mining industry, as a source of investment into Australia, and as a market for export of METs capability.

Science in the Surveys

Science in the Surveys is hosted every two years by one of Australia's state or territory geological surveys. The event aims to highlight the outstanding science being conducted by Australia's geological surveys, CSIRO, UNCOVER and the DET CRC.

Attendees have the opportunity to directly engage with senior government geoscientists and learn how their teams are working to improve understanding of Australia's geology, its mineral potential, and the exploration opportunities it presents. Industry professionals, researchers, government, sector stakeholders and geoscience students are invited to attend.

Australasian Exploration Geoscience Conference

Australia Minerals are Platinum Sponsors of the Australasian Exploration Geoscience Conference to be held from 18–21 February at the International Conference Centre Sydney, in Sydney, Australia.

The conference focusses on exploration geoscience with a technical program based on three overarching themes: Energy, Mineral Geoscience, and Near Surface and Groundwater. *Australia Minerals* will host a large booth at the conference, address the Opening Ceremony and give a keynote presentation.

Contact us

For more details please visit the Australia Minerals website:
www.australiaminerals.gov.au

If you would like some more information about Australia Minerals or are interested in one of the promotional events please email:
mineral.promotions@ga.gov.au

GA PP-1484 | eCat 115681

AEGC Sapphire sponsor

www.csiro.au

We have the resources to make new discoveries

We're focussed on developing better techniques for resource exploration, delivering innovations in data acquisition & driving integration of geoscience data

- We deliver industry solutions, services and research, partnering with grass-roots explorers to global miners and oil producers
- Our minerals program delivers cost effective exploration through advances in detection technologies, understanding of mineral systems, resource characterisation, data integration and analysis
- Our Energy Program is pioneering low-emission technologies that create value for all Australians and provides the knowledge which will help guide Australia towards a smart, secure energy future
- Our Deep Earth Imaging Future Science Platform is developing expertise to unlock the resource potential of this vast and relatively under-explored continent

Contact: opportunity.minerals@csiro.au

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Oil Search
COMMITTED TO PNG

The Oil Search story

Key facts

- Listed on **ASX** (share code: OSH), **POMSox** (OSH) and **US ADR** (OISHY).
- Market capitalisation of approximately **A$11 billion.**
- Produced **30.24 million barrels** of oil equivalent (mmboe) in 2016.
- Paid **A$452 million in royalties** and **A$109 million in oil development levies** to the PNG Government from 1991 – 2016.
- Discovered **Muruk field, PNG** in late 2016.
- Acquired interests in **Alaska** in November 2017 - assets include **500 million barrel** undeveloped oil field
- Committed **US$56 million** to the Oil Search Foundation in 2016 to be used over five years to deliver sustainable development for PNG communities.

Who we are

Oil Search was established in Papua New Guinea (PNG) in 1929, where it operates all of the country's producing oil fields, holds an extensive appraisal and exploration portfolio and has a 29% interest in the PNG LNG Project, operated by ExxonMobil PNG Limited. The Company also holds interests in a number of major undeveloped gas fields, including Elk-Antelope in PRL 15, operated by Total SA, and P'nyang in PRL 3, operated by ExxonMobil. These fields contain sufficient gas resource to underpin >8MTPA of new LNG train capacity. The Muruk gas discovery located on-trend with Hides and P'nyang provides longer term production optionality and the potential to underpin a third expansion train, depending on appraisal success. Recently Oil Search acquired world-class oil interests in the prolific Alaska North Slope, USA, which complement its PNG portfolio, which is primarily gas.

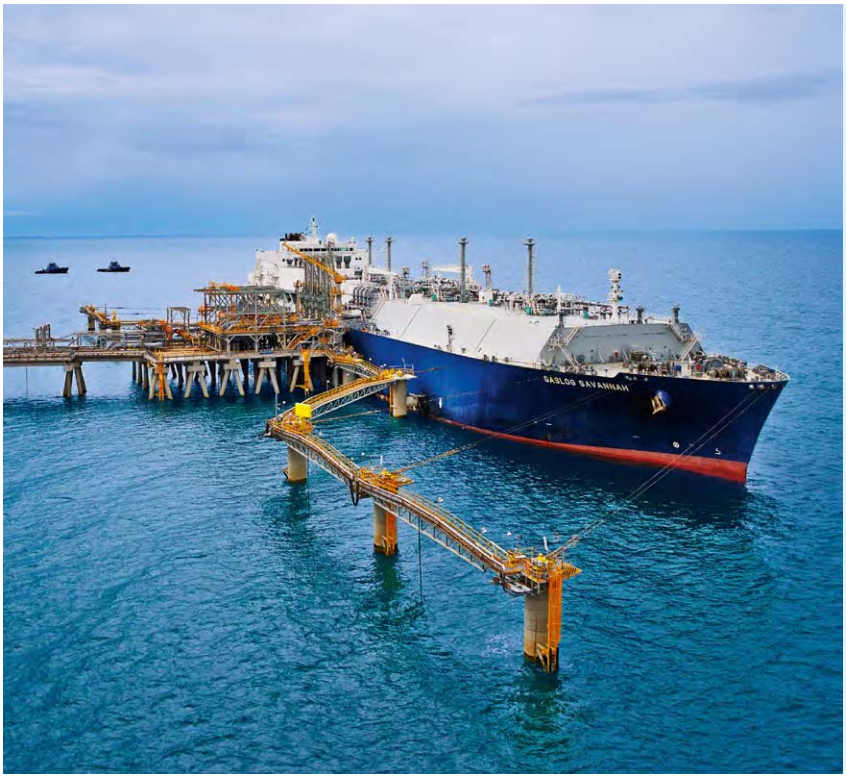
In 2016, Oil Search delivered strong performance, both operationally and financially. Total net production of 30.24 mmboe exceeded guidance and was 3% higher than 2015. The Company is on track to deliver 2017 production in the upper end of its 29.0 - 30.5 mmboe guidance range.

Oil Search's production assets have low operating costs and sustaining capital requirements and generate positive cash flows even at low oil prices. In addition, the Company has a strong balance sheet and sufficient liquidity to fund its globally-competitive growth projects in PNG and Alaska, which have the potential to deliver sector-leading returns to shareholders.

Oil Search's vision

Oil Search's vision is to generate top quartile returns for shareholders through excellence in socially responsible oil and gas exploration and production.

Oil Search believes that, given its growth opportunities, it can continue to deliver superior TSR performance over the next five to seven years.



PNG LNG Project

The world-class PNG LNG Project, in which Oil Search holds a 29% interest, came on-stream in 2014. It has transformed Oil Search into a regionally significant exporter of high quality LNG with a long-term predictable revenue stream.

Operated by ExxonMobil PNG Limited, the PNG LNG Project is a two train development with a nameplate capacity of 6.9 MTPA. Since coming onstream, the Project has consistently performed above expectations, with production in 2016 averaging 7.9 MTPA and 2017 third quarter production averaging 8.6 MTPA approximately 25% above nameplate capacity.

Currently 6.6 MTPA of the Project's output is sold under long-term offtake agreements with premium buyers from Japan, Taiwan and China. An additional 1.3 MTPA of short-medium term duration LNG volumes is being marketed by ExxonMobil on behalf of the PNG LNG Project participants.

Balance sheet strength

Oil Search continues to maintain a strong balance sheet.

At the end of the 2017 third quarter, the Company had total liquidity of US$2 billion comprising cash of US$1.2 billion and US$850 million of undrawn corporate credit facilities.

Oil Search

COMMITTED TO PNG

Pursuing growth opportunities

Oil Search has a range of growth opportunities which have potential returns well in excess of its cost of capital and which could significantly increase the Company's production by early in the next decade.

Activities continue on the expansion of the PNG LNG Project and on the proposed Papua LNG Project development, both assessed to be in the lowest quartile of costs for proposed LNG developments in our region.

Oil Search believes that cooperation between these two potential developments is essential to maximise value and avoid high-cost infrastructure duplication in PNG. There are a wide range of development activities which, if pursued in a coordinated and cooperative manner, could generate material value, with benefits not just from lower capital and operating costs but also from ongoing operational synergies. ExxonMobil and Total, the Company's joint venture partners, have confirmed their intent to pursue an integrated development and key issues, including project definition, financing and marketing arrangements, are being actively progressed.

PNG is a world-class gas province with an estimated 7 billion barrels of oil equivalent yet-to-find, of which 90% is gas. Oil Search has an active exploration programme planned focused in the Highlands, onshore and offshore Gulf and in the deepwater Gulf.

In November 2017, Oil Search announced the acquisition of oil interests in the Alaska North Slope in the United States. This new venture in the Alaska North Slope is part of Oil Search's strategic objective to develop options for material growth in a prolific, well established oil province. It complements our existing high quality gas assets in PNG and balances our gas dominated portfolio. These assets provide us with a unique opportunity to participate in a world class, high returning, proven oil province, acquired at a compelling price, that can add significant value to our Company.

Oil Search

COMMITTED TO PNG

Power of partnership

Oil Search is a key player in PNG's oil and gas industry.

Our joint venture partners are among the strongest and most successful oil and gas operators in the world. Combined with our in-country expertise and PNG's world class assets, we are well placed to continue to develop further LNG trains and grow PNG's presence in the global LNG market.

Our partnerships with communities and governments are vital to developing the resources of PNG in a responsible, equitable manner and in ensuring a stable operating environment.

More than 83% of our employees in PNG are Papua New Guineans. Developing our local PNG talent and increasing the percentage of women in leadership roles are two of our key goals. We are committed to ensuring a safe and inclusive workplace and rewarding our employees as partners in our success.

Making PNG lives better - Oil Search Foundation

- As a key player in PNG's oil and gas industry, Oil Search believes that proactive participation in the development of the country by the corporate sector is not only needed, but an obligation. Being committed to sustainable development is an important part of maintaining our social license to operate.
- Oil Search Foundation is one of the more visible ways we are able to make this important contribution.
- The Foundation's operations are underpinned by strong governance, measurable performance, risk management and ongoing capacity development of our workforce.
- The Foundation delivers services for Project Impact Areas (PIAs) in Hela, Southern Highlands and Gulf Provinces in the areas of Health, Women's Protection and Empowerment, and Leadership and Education.
- The Foundation also works with other donors on innovative ways to deliver best practice grant management solutions to support other parts of PNG.
- The Foundation concentrates on building partner capacity to deliver services by supporting and engaging with stakeholders at all levels to build the systems that underpin effective service delivery.
- Oil Search's continued financial commitment confirms the importance of the Foundation's work to the sustainable development of PNG, and it highlights the success of its programmes in changing and improving the lives of Papua New Guineans.

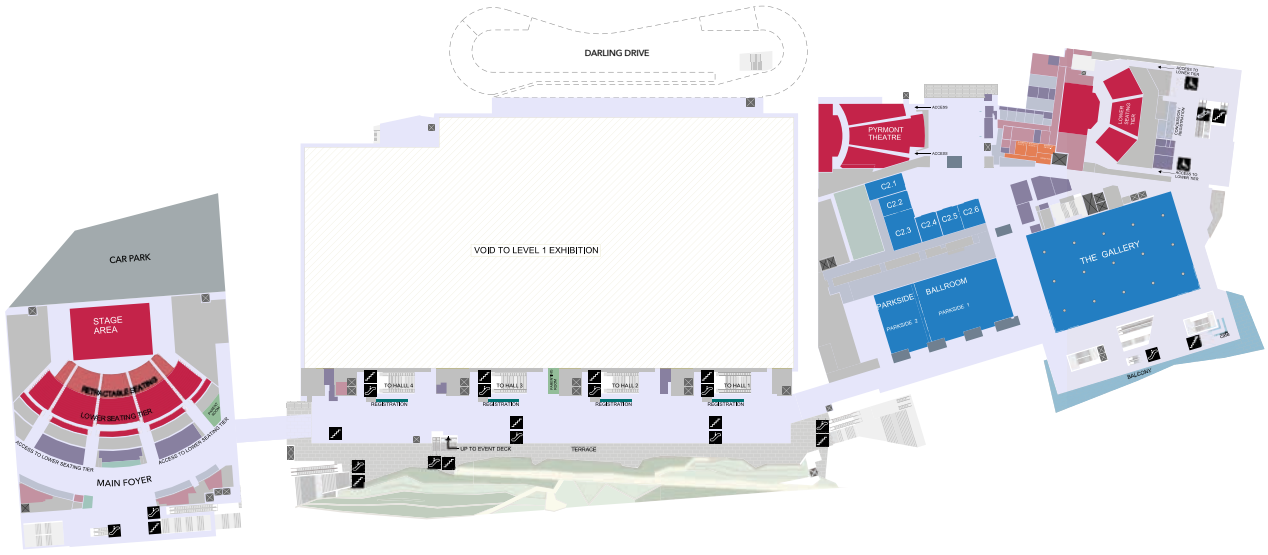
Oil Search Foundation

- Oil Search is the founder and principal donor to Oil Search Foundation.
- The Foundation is a not-for-profit development partner dedicated to improving the lives of Papua New Guineans by working closely and in alignment with PNG's own development priorities.
- **In 2016 Oil Search committed US$56 million to the Foundation to be used over five years.**
- The Foundation partners with the PNG Government and other donors.
- The Foundation supports the National Development agenda as an active and effective development partner, always working through PNG government systems.

For more information:

Visit: www.oilsearch.com
Email: investor.relations@oilsearch.com

LEVEL TWO FLOOR PLAN

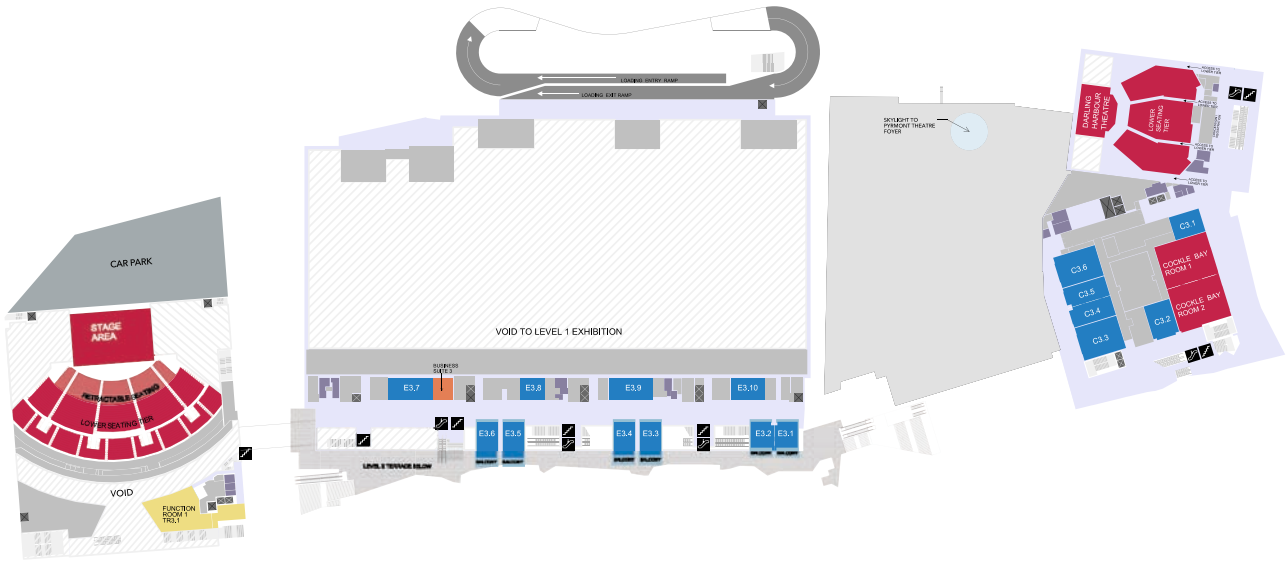


PLENARY · CIRCULATION · KIOSK · BUSINESS SUITE 2 · STAIRS · PUBLIC LIFT
MEETING · REGISTRATION · TOILETS · THEATRE GREEN ROOMS/ AMENITIES · ESCALATOR · GOODS LIFT

29/03/2017, DRAWING SUBJECT TO CHANGE

0 10m 30m 50m

LEVEL THREE FLOOR PLAN



PLENARY · FUNCTION AREA · CIRCULATION · TOILETS · STAIRS · PUBLIC LIFT
MEETING · BUSINESS SUITE · BALCONY · ESCALATOR · GOODS LIFT

29/03/2017, DRAWING SUBJECT TO CHANGE

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General information

Venue

International Convention Centre (ICC) Sydney

14 Darling Drive, Darling Harbour, Sydney, NSW, Australia

App

Download the *free* AEGC2018 app. Download from the App or Google Store – search '*World Leading Conferences*' OR go to this link on your device: wlc.eventapp.com.au

Catering

All morning tea, lunch and afternoon tea breaks will be provided in the exhibition area. For break times please refer to the program.

Dietary requirements

If you have advised the Conference Secretariat of special dietary requirements, please speak to a member of the catering staff during the lunch break, or at any of the functions that you may be attending. Catering staff will have a full list of those with special dietary requirements.

Chairpersons and speakers

Please ensure you are available in your presentation room at least **15 minutes** prior to the start of the session. Speakers, please ensure you have loaded your presentation with the audio visual technicians in the Speaker Preparation Room.

Speaker preparation room

All speakers and presenters are asked to check in to the Speaker Preparation Room at least two (2) hours prior or the day before their presentation. The Speaker Preparation Room will be located on Level 2 in **Business Suite 2.3** and will be open from midday on Sunday 18 February.

Dress code

The conference dress code is smart casual.

Exhibition

The Conference Exhibition will be located in The Gallery on level 2 at the ICC and will be open at the following times:

Monday 19 February 7:30 am – 6:40 pm
Tuesday 20 February 7:30 am – 6:40 pm
Wednesday 21 February 7:30 am – 3:30 pm

Name badges and lanyards sponsored by

For security purposes, delegates are requested to wear their name badge at all times during the conference, as it is your official pass and must be worn to obtain entry into program sessions and social functions. If you misplace your name badge, please go to the registration desk to arrange a replacement.

Mobile phones

Delegates are asked to switch their mobile phones to silent when in sessions.

Pre and post conference workshops

Pre conference workshops will be held on Saturday 17 February and Sunday 18 February and post conference workshops will be held on Thursday 22 February at the ICC Sydney, unless stated otherwise. You must be pre-registered to attend these workshops. Please see staff at the registration desk for more information.

Pocket program

Each delegate will receive a pocket program upon registration.

Program

Every endeavour has been made to produce an accurate program. If you are presenting at the conference, please confirm your presentation times as contained within this program. The organisers reserve the right to change the conference program at any time without notice.

Program changes

Program changes will be sent via app notifications. Delegates are advised to download the app for the latest program information.

Conference handbook

The Conference handbook, which has been published as part of a special issue of *Preview*, is available free of charge to all Conference delegates. It can be collected from the registration desk or from the ASEG booth.

Posters

Posters are located in the **Pyrmont Theatre foyer** and are on display for the duration of the conference. Poster sessions will be held after the lunch breaks to allow delegates to ask questions of the poster presenters, who will be standing by their posters at specified times. The poster session times are as follows:

Poster Session 1 Monday 19 February 1320–1345
Poster Session 2 Tuesday 20 February 1320–1345
Poster Session 3 Wednesday 21 February 1320–1345

Registration desk

The registration desk is located on Level 2 at the ICC Sydney. The registration desk will be open from midday on Sunday 18 February.

Recording and photography

Unauthorised audio taping, video recording, digital taping or any other form of recording is strictly prohibited in the conference sessions. Discrete and polite still photography is permitted. Speakers who do not wish to have photographs taken of their PowerPoint slides must state this at the start of their presentation.

Smoking

Smoking is not permitted in the ICC Sydney.

SECTION 1
CONFERENCE PROGRAM

Australian Society of Exploration Geophysicists

PESA Petroleum Exploration Society of Australia

AUSTRALIAN INSTITUTE OF GEOSCIENTISTS

The power of PARTNERSHIP

Oil Search, working closely with its joint venture partners, operates all of PNG's currently producing oil fields, as well as the Hides Gas-to-Electricity Project.

The Company has a 29% interest in the PNG LNG Project, operated by ExxonMobil PNG Limited. The Project is performing well above nameplate capacity, delivering incremental value to stakeholders and demonstrating that the co-venture partners and PNG are capable of delivering a world-class LNG development.

Oil Search recently acquired world-class oil interests in the prolific Alaska North Slope, USA, complementing its PNG portfolio, which is primarily gas.

Oil Search has an unrivalled understanding of how to operate successfully and safely in PNG. By promoting a cooperative agenda with key stakeholders, we are well positioned to deliver the next wave of growth opportunities. We believe there is sufficient gas, in the NW Highlands in the P'nyang gas field and in the Elk-Antelope gas fields in the onshore Gulf Province, to support more than 8 MTPA of additional LNG capacity, unlocking significant value for PNG. With exploration and appraisal success, such as the Muruk gas discovery, a third expansion train is possible.

We are committed to ensuring our impact in Papua New Guinea goes well beyond our position as the country's largest non-government employer and investor. By working closely with joint venture partners, regulators, the PNG Government, landowners and communities, we have built mutually beneficial partnerships that deliver real, long-term benefits to PNG.

As a Papua New Guinean company, Oil Search is a PNG specialist and a partner of choice.

That's what sets us apart.

That's what makes us Oil Search.

Oil Search

www.oilsearch.com

Program at a glance

<table>
<tr><th>Saturday
17 February</th><th colspan="3">Sunday 18 February</th><th>Monday
19 February</th><th>Tuesday
20 February</th><th>Wednesday
21 February</th><th>Thursday
22 February</th></tr>
<tr><td rowspan="14">Pre Conference workshops</td><td rowspan="14">0700–1800
Blue Mountains field trip</td><td colspan="2" rowspan="3">Pre Conference workshops</td><td>0820–0940
Opening ceremony</td><td></td><td></td><td rowspan="14">Post Conference workshops</td></tr>
<tr><td>Plenary 1</td><td>Session 4</td><td>Session 8</td></tr>
<tr><td colspan="3">1010–1040 Morning tea (Exhibition | The Gallery)</td></tr>
<tr><td rowspan="11">Pre Conference workshops</td><td rowspan="11">1200–1900
Registration
opens</td><td>Session 1</td><td>Session 5</td><td>Session 9</td></tr>
<tr><td colspan="3">1220–1320 Lunch (Exhibition | The Gallery)</td></tr>
<tr><td colspan="3">1320–1345 Poster sessions
Pyrmont Theatre Foyer</td></tr>
<tr><td>Session 2</td><td>Society plenaries</td><td>Session 10</td></tr>
<tr><td colspan="3">1500–1530 Afternoon tea (Exhibition | The Gallery)</td></tr>
<tr><td rowspan="2">Session 3</td><td>Session 6</td><td>Closing ceremony</td></tr>
<tr><td>Session 7</td><td rowspan="3">1630–1800
Closing drinks</td></tr>
<tr><td>1710–1840
Drinks
(Exhibition | The Gallery)</td><td>1710–1840
Drinks
(Exhibition | The Gallery)</td></tr>
<tr><td colspan="3" rowspan="3">1800–1930
Welcome reception
(Exhibition)
The Gallery @ ICC</td><td rowspan="3">1800
Rocks geology, history and pub tour</td><td>1800
Student trivia night
Pyrmont Bridge Hotel</td><td rowspan="3">1800
Rocks geology, history and pub tour</td><td rowspan="3"></td></tr>
<tr><td>1930–2330
Conference dinner
Parkside Ballroom @ ICC
MC: Tom Gleeson</td></tr>
</table>

Rio Tinto

Discover
the job, the challenge
Exploration in Rio Tinto

Rio Tinto is a leading international business involved in each stage of metal and mineral production. The Group combines Rio Tinto plc, which is listed on the London Stock Exchange, and Rio Tinto Limited, which is listed on the Australian Securities Exchange.

Within Rio Tinto, the Exploration group is tasked with providing growth opportunities to the company by discovering or acquiring new mineral resources. It has been delivering value for more than 50 years.

Exploration involves the identification, prioritization and testing of geological, geochemical and geophysical targets. The exploration process ends when a discovery is handed over to studies team in G & I for detailed evaluation.

Our objective is to safely discover “Tier 1” deposits. This is a deposit that contributes disproportionately to global production of a commodity due to its size and character.

Rio Tinto’s exploration strategy brings us sustained success in a highly competitive environment. We have maintained our commitment to exploration over the years and the consistency of expenditure and activity has produced extraordinary results.

We have an exceptional set of assets and growth opportunities, both in advanced projects and early stage prospects. Our multi-commodity exploration portfolio is composed of the best opportunities and is rigorously prioritised globally.

We set ourselves apart from the rest of the mining industry by having a clear focus on finding and mining only the best resources. These resources must be profitable in all parts of the price cycle and deliver long-term economic value to Rio Tinto, the communities we work with and the countries we operate in.

Drill Rig at Hidden Treasure project

Micro-analytical facility, Bundoora, Melbourne

Pioneering in Exploration

Rio Tinto Growth & Innovation operates a dedicated micro-analytical facility in Bundoora, Melbourne for RTX utilising Laser Ablation Microprobe (LAM) and Mineral Liberation Analyser (MLA) technology linked in a unique configuration. We have developed the world's first automated Kimberlitic Indicator Mineral (KIMs) analytical facility as well as having in-house U-Pb geochronology capability.

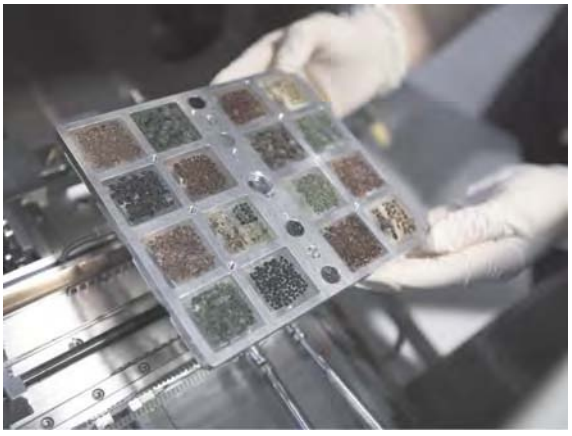
Using this equipment RTX have also developed innovative new exploration techniques using Resistate Indicator Minerals (RIMs).

The MLA generates large volumes of quantified mineralogy and high quality mineral chemistry at very low cost (in excess of 1 million major element analyses a year).

The LAM can analyse up to 500 trace element analyses a day on target mineral grains.

These datasets are interpreted by a dedicated team who combine mineralogy expertise with data analytics and research outcomes from industry collaborative projects to support exploration programs globally.

Mineral Liberation Analyser:
Quantitative mineralogy and major element chemistry



KIMs facility Bundoora

Laser Ablation Microprobe (LAM):
Trace Element Mineral Chemistry

RioTinto

Our commitment

Rio Tinto Exploration is an integral part of the sustainable development equation for Rio Tinto.

Our strategy of investing in large, long-life mines and businesses means that we operate on extended time horizons. Some of our projects last 40 years or more from mineral discovery through to closure, representing large-scale, long-term investments.

These long-term commitments provide opportunities for us to plan and implement projects in such a way that they deliver sustainable contributions to social wellbeing, environmental stewardship and economic prosperity.

The Exploration group's core objective of finding Tier 1 resources is the starting point for the wider Rio Tinto Group's efforts in sustainable development. These discoveries can become the catalyst for local economic diversification, skills development in the local workforce and improvements to infrastructure.

Each of the countries and regions in which we explore has different cultures, peoples, laws and expectations. Our exploration teams are often the first contact we have with communities who may be our neighbours for generations. We respect the diversity and concerns of local communities and engage in a manner that is open, personal and tailored to the specifics of each region, village or individual stakeholder.

On a day-to-day basis our Exploration group contributes to local communities by employing local people and introducing improvements in local health and safety practices.

We actively encourage community engagement, striving to establish trust at an early stage so that we can bring about mutual benefits through the development of high-quality mineral resources.

There is no room in Rio Tinto Exploration for anything but the most value-creating opportunities, the most constructive, collaborative and adaptable behaviours; and a personal commitment to sustainable development from

Communities engagement at an Exploration project

Demonstration of muster point at Exploration project

RioTinto

For 140 years, we've been discovering safer, more effective and more sustainable ways to find, mine, and process the minerals and metals essential for everyday life.

Our purpose is to be a company that is admired and respected for delivering superior value, as the industry's most trusted partner. Our operations give us the opportunity to create mutual benefit with the communities, regions and countries in which we work.

Using the latest in technology and innovation, Rio Tinto Exploration is focused on smarter ways to find the mines of tomorrow.

We are currently seeking high quality opportunities to add to our growing exploration

Exploring 8 different commodities across 15 countries.

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RioTinto

Sunday 18 February 2018								
1800–1930	Welcome Reception, The Gallery at the ICC (Exhibition)							
Monday 19 February 2018								
0730–0830	Registration							
0830–0940	Conference Welcome and Opening, Pyrmont Theatre Foyer							
0940–1010	Plenary Speaker 1 **Peter Botten**, Managing Director, Oil Search, Pyrmont Theatre							
1010–1040	**Morning tea** *(Exhibition | The Gallery)* Sponsored by GBG Australia							
	SESSION 1							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
	Coal	**West Australian Basins Symposium**	**East Australian Basins Symposium**	**Geology Case History**	**IP From EM Surveys**	**Inversion Modelling Methods**	**Regional Tectonic**	**Geotechnical and Environmental**
Room	**E3.10**	**C2.2 / C2.3**	**C2.1**	**Pyrmont Theatre**	**C2.5 / C2.6**	**E3.2**	**C2.4**	**E3.1**
	Chair: Max Williamson	**Chair: Phillip Cooney**	**Chair: Malcolm Bocking**	**Chair: Phillip Hellman**	**Chair: Steve Collins**	**Chair: David Pratt**	**Chair: Graham Heinson**	**Chair: Simon Williams**
1040–1105	Keynote Presentation Coal in NSW **Kevin Ruming**	Keynote Presentation High impact data creates high impact opportunities **Peter Baillie**	Tectonics and geodynamics of the eastern Tethys and northern Gondwana since the Jurassic **Sabin Zahirovic**		Modelling IP effects in airborne time domain electromagnetics **Dave Marchant**	Cooperative inversion: A review **Brett Harris**	Palaeomagnetic test of oroclinal rotation in the Dundas Trough, Tasmania **Robert Musgrave**	Tracking the Diprotodon – microtremor passive seismic profiling as a tool for location of megafauna bone beds **Michael Asten**
1105–1130			Predicting and detecting carbonate cemented zones within Latrobe Group reservoirs of the Gippsland Basin **Mark Bunch**		A thorough synthetic study on IP effects in AEM data from different systems **Andrea Viezzoli**	Application of geologically conditioned petrophysical constraints in joint inversion: A case study **Jeremie Giraud**	Mapping metasomatised mantle by integrating magnetotelluric, passive seismic and geochemical datasets – SE Australia **Karol Czamota**	An integrated analysis of geophysical data for landslide risk assessment **Koya Suto**
1130–1155	Discovery through the ages – a journey of coal resource discovery in Queenslands Bowen Basin from the 1960's and the 2000's **Darren Walker**	Mapping northern Australia's present day stress field: The Canning Basin **Adam Bailey**	Impact of sequence stratigraphy on static and dynamic reservoir models: Examples from the Precipice–Evergreen succession, Surat Basin, Queensland **Andrew La Croix**	Lithogeochemistry of pegmatites at Broken Hill: An exploration vector to mineralisation **Glenn Coianiz**	Keynote Presentation Airborne EM and IP below 10 Hz **Jim Macnae**	Constraining an inversion to follow curving trends in an image **Andrew King**	Geoscience Australia's contribution to AusArray – Passive seismic imaging of Australia **Alexei Gorbatov**	The application of VSP in the Pilbara **Ashley Grant**
1155–1220	The use of FWI in coal exploration **Mehdi Asgharzadeh**	Regional Jurassic sediment depositional architecture, Browse Basin: Implications for petroleum systems **Nadege Rollet**	Organic geochemistry and petroleum potential of Permian outcrop and core samples from the southern Sydney Basin **Simon George**	Ore and gangue minerals of the Hera Au-Pb-Zn-Ag deposit, Cobar Basin, NSW **Angela Lay**		Exploring inversion solution space: A case study over a Cu-Ag deposit in the Kalahari copper belt **Robert Ellis**	Coordinating and delivering a 1.8 million line kilometre magnetic and radiometric survey – a state government perspective **Laszlo Katona**	Application of the passive seismic Horizontal-to-Vertical Spectral Ratio (HVSR) technique for embankment integrity monitoring **Regis Neroni**
1220–1320	**Lunch** *(Exhibition | The Gallery)*							
1320–1345	**Poster Session** *(Pyrmont Theatre Foyer)*							

	SESSION 2							
	A	B	C	D	E	F	G	H
	Coal	**West Australian Basins Symposium**	**East Australian Basins Symposium**	**Geology Case History**	**EM & Deep Radar**	**Exploration**	**Regional Tectonic**	**Geotechnical and Environmental**
Room	**E3.10**	**C2.2 / C2.3**	**C2.1**	**Pyrmont Theatre**	**C2.5 / C2.6**	**E3.2**	**C2.4**	**E3.1**
	Chair: Kevin Ruming	**Chair: Tom Bernecker**	**Chair: Barry Smith**	**Chair: Doug Menzies**	**Chair: Keith Leslie**	**Chair: Regis Neroni**	**Chair: Robert Musgrave**	**Chair: Andrew Spyrou**
1345–1410	Seismic diffraction imaging for improved coal structure detection in complex geological environments **Binzhong Zhou**	Evolution of 'Tres Hombres' – a large mid-crustal dome structure within the northern Beagle Sub-basin Western Australia: An integrated geophysical investigation **Gerry O'Halloran**	Targeting core sampling with machine learning: Case study from the Springbok Sandstone, Surat Basin **Oliver Gaede**	Keynote Presentation **Richard Hillis**	2.5D vs 1D AEM forward and inversion methods at a survey scale: A case study **Desmond Fitzgerald**		Evolving 3D lithospheric resistivity models across southern Australia derived from AusLAMP MT **Kate Robertson**	How to build your own simple, low-cost, seismic system **Tim Dean**
1410–1435	Integration of downhole geophysical and lithological data from coal exploration drillholes **Brett Larkin**	Controls on Mesozoic rift-related uplift and syn-extensional sedimentation in the Exmouth Plateau **Hayley Rohead-O'Brien**	The influence of reverse-reactivated normal faults on porosity and permeability in sandstones: a case study at Castle Cove, Otway Basin **Natalie Debenham**		Otze – airborne EM inversion on unstructured model grids **Carsten Scholl**	Understanding geology and structure: An essential part of mineral resource estimation **Bert De Waele**	Imprints of tectonic processes imaged with magnetotellurics and seismic reflection **Tom Wise**	Feasibility study of near-surface dispersion imaging using passive seismic data **M. Javad Khoshnavz**
1435–1500	Quantifying gas content in coals using borehole magnetic resonance **Tim Hopper**	Shelf-margin architecture and shoreline processes at the shelf-edge: Controls on sediment partitioning and prediction of deep-water deposition style **Victorien Paumard**	High frequency refraction/reflection full-waveform inversion case study from North West Shelf offshore Australia **Xiang Li**	Pathfinder exploration techniques targeting porphyry and epithermal alteration systems in the Temora copper-gold belt **Bruce Hooper**	Realistic expectations for deep ground penetrating radar performance **Jan Francke**	Building 3D model of rock quality designation assisted by co-operative inversion of seismic and borehole data **Duy Thong Kieu**	Identifying lithospheric boundaries and their importance for mineral discovery **Stephan Thiel**	Refraction Microtremor method for delineation of layers and lenses, and assessing liquefaction potential within an alluvial setting – Morobe Province, Papua New Guinea **Aaron Tomkins**
1500–1530	**Afternoon tea** *(Exhibition | The Gallery)*							
	SESSION 3							
	A	B	C	D	E	F	G	H
	Coal	**West Australian Basins Symposium**	**East Australian Basins Symposium**	**Geology Case History**	**Airborne Gravity**	**Electrical Methods**	**Regional Gawler Isa Halls Creek**	**Groundwater**
Room	**E3.10**	**C2.2 / C2.3**	**C2.1**	**Pyrmont Theatre**	**C2.5 / C2.6**	**E3.2**	**C2.4**	**E3.1**
	Chair: Kevin Ruming	**Chair: Tom Bernecker**	**Chair: Barry Smith**	**Chair: Glenn Coianiz**	**Chair: Clive Foss**	**Chair: Jim Macnae**	**Chair: Jim Austin**	**Chair: Aaron Tomkins**
1530–1555	Cooper Basin deep coal – the new unconventional paradigm: Deepest producing coals in Australia **Bronwyn Camac**	Influence of Permian and Carboniferous extensional history on the northern Carnarvon basin and its influence on Mesozoic extension **Amy I'Anson**	Petroleum plays of the Bowen and Surat basins **Alison Troup**	Cargo Porphyry Cu-Au deposit – where is the high grade core? **David Timms**	Validating the Gedex HD-AGG™ airborne gravity gradiometer **David Hatch**	Laboratory confirmation of non-linear electrical effects in mineralised rocks **Alan Oertel**	A hidden Palaeoproterozoic ocean-continent transition in the northern Gawler Craton **Tom Wise**	Using microgravity to characterise water storage and usage at Kings Park, Perth, WA **Alan Aitken**

1555–1620	Predicting structural permeability in the deep coal play, Tirrawarra-Gooranie fields, Cooper Basin **Cameron Bowker**	Interpretation of a Permian conjugate basin margin preserved on the outer northwest shelf of Australia **Christopher Paschke**	Borehole gravity in horizontal wells **Andrew Black**	Implicit modelling of the Las Bambas deposits, Peru **Anthony Reed**	Airborne gravimetry takes off in the Western Australia 'Generation 2' reconnaissance gravity mapping project **David Howard**	Field trials of the Biassed Heterodyne method of exploration for sulphide minerals **Steve Collins**	Thermochronological history of the northern Olympic Domain of the Gawler Craton; correlations between cooling ages and mineralising systems **James Hall**	Microgravity surveys on the Nullarbor **Philip Heath**
1620–1645	Towards understanding phosphorus distribution in coal: A case study from the Bowen Basin **Brooke Davis**	New insights into early Triassic rifting in the NW shelf help explain regional structural styles and associated deposition model **Malcolm MacNeill**	The stratigraphic significance of paralic deposits in the Precipice–Evergreen succession, Surat Basin, Queensland **Andrew La Croix**	What is down plunge of the Dobroyde Hill high-sulphidation epithermal deposit, near Junee, NSW? **Glen Diemar**	Gravity gradiometer design comparison by three different methods **James Brewster**	Getting a better control of IP acquisitions with GDD's new IP post-processing software **Circe Malo-Lalande**	Tectonic framework of the southern Mount Isa Province **Janelle Simpson**	Uncertainty analysis of faulting and folding on near surface aquifers **Titus Murray**
1645–1710	Evidence for glacial and polar impacts in the Permian coal measures of the Sydney basin **Malcolm Bocking**	Modelling reservoir deliverability within the northern Beagle Sub-basin, Western Australia **Christopher Hurren**	Next generation reservoir engineering **Klaus Regenauer-Lieb**	The discovery of the Edna Beryl Deposit – A journey with a destination! **Rob Bills**	An overview of tensors, gradient and invariant products in imaging and qualitative interpretation **Matthew Zengerer**	The effective use of forward modelling and petrophysical analyses in the application of induced polarisation surveys to explore for disseminated sulphide systems in the Paterson province, Western Australia **Nikhil Prakash**	Magma evolution in the Halls Creek Orogen; insight from geodynamic numerical modelling and geochemical analysis **Fariba Kohanpour**	

Tuesday 20 February 2018								
0700	**From Faxes to FaceTime: Building intergenerational relationships through networking and mentoring *(C3.4 @ ICC Sydney)***							
	SESSION 4							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
	PNG and NZ	**West Australian Basins Symposium**	**Non Conventional**	**Geophysics Technology**	**Strategic and Industrial**	**Magnetotellurics**	**Regional Mapping**	**Groundwater Case Studies**
Room	**C2.1**	**C2.2 / C2.3**	**E3.10**	**E3.2**	**C2.4**	**Pyrmont Theatre**	**C2.1 / C2.2**	**E3.1**
	Chair: Scott Keenan	**Chair: Marita Bradshaw**	**Chair: Malcolm Bocking**	**Chair: Alan Oertel**	**Chair: Steve Collins**	**Chair: Kim Frankcombe**	**Chair: Ian Roach**	**Chair: David Allen**
0830–0855	Keynote Presentation Innovative exploration in Papua New Guinea; past, present and future **Kevin Hill**	Onshore inventory – targeting new basins (Officer, Perth, Canning Basins) **Lidena Carr**	Integrated Seismic (IS) for shale gas exploration and management **Shastri Nimmagadda**	Mathematical properties and physical meaning of the gravity gradient tensor eigenvalues **Carlos Cevallos**	Keynote Presentation Strategic and industrial minerals leading the next production revolution **Richard Flook**	Particularities of 5-component magnetotelluric soundings application for mineral exploration **Igor Ingerov**	Keynote Presentation National mineral exploration strategy: A vision for unlocking Australia's hidden mineral wealth **Richard Blewett** **Sponsored by** AUSTRALIA MINERALS REALISE THE OPPORTUNITY	Characterizing the Spiritwood Valley Aquifer, North Dakota, using helicopter time-domain EM **Jean Legault**
0855–0920		Linear trends of paleo-pockmarks and fluid flow pipes in the Jurassic and Triassic sediments of offshore northwest Australia **Tayallen Velayatham**	Using multiazimuth seismic data for anisotropy estimation in an unconventional reservoir **Surabhi Mishra**	Application of frequency domain induction EM soundings with controlled source (FDEMS method) for precise tracing of boundaries in geoelectrical sections **Igor Ingerov**		Sferic signals for lightning sourced electromagnetic surveys **Lachlan Hennessy**		Reinterpretation of wireline log data in the eastern Galilee Basin, Queensland: stratigraphic and hydrogeologic implications **James Hansen**

0920–0945	4D characterisation of PNG's Petroleum Systems **John Warburton**	The effect of flexural isostasy on delta architecture: Implications for the Mungaroo Formation **Sara Morón-polanco**	A new computational model to predict breakdown pressures in cased and perforated wells in unconventional reservoirs **Mohammed Asad Pirzada**	Application of passive seismic in determining overburden thickness: North West Zambia **Nikhil Prakash**	The Pilgangoora Lithium-Tantalum Deposit – Geological overview and evolution of discovery **John Holmes**	Keynote Presentation What is new in magnetotellurics? **Graham Heinson**	An integrated approach to mapping crustal geology and structures in the NE Capricorn Orogen, Western Australia: Implications for uranium exploration **Ashley Laurence Uren**	Keynote Presentation **Katarina David**
0945–1010	Structural and reservoir development of the western Papuan Basin gas and condensate fields **Michelle Spooner**	Mesozoic to Cenozoic depositional environments & fluid migration within the Caswell Sub-basin: Key insights from new interpretation & modelling of the Schild phase 2 3D **Jarrad Grahame**	An optimised hydraulic fracturing treatment on challenging Rizq Field **Muhammad Asad Pirzada**	Scintillators for PGNAA in mineral exploration **Anton Kepic**	Evaluating Rare Earth Deposits **Phil Hellman**		Archean controls on basin development and mineralisation in the southern Capricorn Orogen **Sandra Occhipinti**	
1010–1040	**Morning tea** *(Exhibition | The Gallery)*						**Sponsored by** Taylor & Francis Taylor & Francis Group	
	SESSION 5							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
	PNG and NZ	**West Australian Basins Symposium**	**Non Conventional**	**General Geology**	**Strategic and Industrial**	**EM Inversion Modelling**	**Regional Mapping & Thomson Orogen**	**Groundwater Case Studies**
Room	**C2.1**	**C2.2 / C2.3**	**E3.10**	**Pyrmont Theatre**	**C2.4**	**E3.2**	**C2.1 / C2.2**	**E3.1**
	Chair: Scott Keenan	**Chair: Marita Bradshaw**	**Chair: Malcolm Bocking**	**Chair: Bruce Hooper**	**Chair: Richard Flook**	**Chair: Dave Annetts**	**Chair: Dave Robson**	**Chair: Trent Bowman**
1040–1105	Plio-pleistocene river drainage evolution in New Guinea **Gilles Brocard**	Canning Basin – petroleum systems analysis **Andrew Murray**	New method for monitoring steam injection for Enhanced Oil Recovery (EOR) and for finding sources of geothermal heat **Gordon Stove**	Keynote Presentation Geophysical detection of the hydrothermal alteration footprints of ore deposits **John McGaughey**	Industrial minerals – evaluation and profitability **David Turvey**	Trans-dimensional Monte Carlo inversion of short period magnetotelluric data for cover thickness estimation **Wenping Jiang**	AusAEM; acquisition of AEM at an unprecedented scale **Alan Ley-Cooper**	Rate of success for a groundwater drilling program planned from AEM, Gascoyne River, WA **Aaron Davis**
1105–1130	Geophysical and geological characterisation of dredge locations from RV Southern Surveyor voyage ss2012_v06 (ECOSATI): Hotspot activity in northern Zealandia **Maria Seton**	The Ungani oil field, Canning Basin – evaluation of a dolomite reservoir **David Long**	A new system for efficiently acquiring vertical seismic profile surveys **Tim Dean**		Mineral deposits in the Ontario Cobalt Belt **Ian Pringle**	Comparative analysis and joint inversion of MT and ZTEM Data **Wolfgang Soyer**	Application of AEM for cover thickness mapping in the southern Thomson Orogen **Ian Roach**	Geophysical investigation to support characterisation of structurally controlled groundwater flow into an open pit mine **Michael Carroll**
1130–1155	Compressional evolution of the PNG margin from an orogenic transect from Juha to the Sepik **Kevin Hill**	Depositional, diagenetic and mineralogical controls on porosity development in the Ungani Field, Canning Basin **June Then**	What we know, what we don't know, and things we do not know we don't know about hydraulic fracturing in high stress environments **Raymond Johnson**	Creating a new frontier in detection and data integration for exploration through cover **Robert Hough**	The Sinclair Zone Caesium Deposit, Pioneer Dome, WA **David Crook**	1, 2.5 and/or 3D inversion of airborne EM data – options in the search for sediment–hosted base metal mineralisation in the Mcarthur Basin, Northern Territory **Timothy Munday**	Estimating cover thickness in the southern Thomson Orogen – a comparison of applied geophysics estimates with borehole results **James Goodwin**	Uncovering the Musgrave Province in South Australia using airborne EM **Camilla Soerensen**

1155–1220	Tectonic and geodynamic evolution of the northern Australian margin and New Guinea **Joanna Tobin**	Laurel gas play, Canning Basin – recent stratigraphic learnings **Simon Sturrock**	The role of diagnostic fracture injection testing to improve reservoir evaluation and stress characterisation in compressive stress regimes **Raymond Johnson**	Episodic mineralising fluid injection through chemical shear zones **Thomas Poulet**		Spatially and conductivity log constrained AEM inversion **Alan Ley-Cooper**	Increasing prospectivity in a covered terrain – the southern Thomson Orogen, northwestern NSW **Rosemary Hegarty**	A multidisciplinary study of groundwater conditions in sedimentary strata at Thirlmere Lakes (NSW) **Katarina David**
1220–1320	**Lunch** *(Exhibition | The Gallery)*							
1320–1345	**Poster Session** *(Pyrmont Theatre Foyer)*							
1345–1410	**SOCIETY PLENARIES**							
	SESSION 6							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
	PNG and NZ	**International**	**Non Conventional**	**Geochemistry**	**Industrial – Sands**	**EM Inversion Modelling**	**Regional Cobar**	**Innovation**
Room	**C2.1**	**C2.2 / C2.3**	**E3.10**	**Pyrmont Theatre**	**C2.4**	**E3.2**	**C2.1 / C2.2**	**E3.1**
	Chair: Kevin Hill	**Chair: Mark Taylor**	**Chair: Bruce McKay**	**Chair: David Cohen**	**Chair: David Turvey**	**Chair: Mike Asten**	**Chair: Ian Neuss**	**Chair: Simon Williams**
1410–1435	A method for assessing earth model uncertainty in the Taranaki Basin, New Zealand **Edward Lewis**	On the geothermal potential of the Heyuan Fault, South China **Lisa Tannock**	The use of coring-induced petal fractures in coal to supplement and ground truth the interpretation of image logs **David Titheridge**	Keynote Presentation 21st century exploration geochemistry – the good, the bad and the ugly **Ryan Noble**	Frac sand supply and demand Australia **Murray Lines**	Large scale 3D airborne electromagnetic inversion – Recent technical Improvements **Mike McMillan**	Metamorphism and skarn mineralisation in the Cobar Basin: Implications for exploration **Joel Fitzherbert**	Source Assisted Marine Refraction Microtremor (ReMi) for marine material strength assessments – New Ireland Province, Papua New Guinea **Trent Bowman**
1435–1500	Modelling and visualising distributed lithospheric deformation of Australia and Zealandia using GPlates2.0 **Dietmar Müller**	The discovery and development of oil rim fields in the Beibu Gulf, China **Andrew Fernie**	Automatic fracture identification using X-ray images **Ankita Singh**		High-grade silica sands in the Eastern Murray Basin NSW **Graham Lee**	3D time-domain airborne EM inversion with finite-volume method **Xiuyan Ren**	Cobar deposits – structural control **Vladimir David**	Bootstrapping reliable noise measure in time-gated nuclear magnetic resonance data **Brian McPherson**
1500–1530	**Afternoon tea** *(Exhibition | The Gallery)*							
	SESSION 7							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
	PNG and NZ	**International**	**Non Conventional**	**Geochemistry**	**Brine Deposits**	**New Airborne EM Techniques**	**Regional Mapping Methods**	**Innovation**
Room	**C2.1**	**C2.2 / C2.3**	**E3.10**	**Pyrmont Theatre**	**C2.4**	**E3.2**	**C2.1 / C2.2**	**E3.1**
	Chair: Kevin Hill	**Chair: Mark Taylor**	**Chair: Bruce McKay**	**Chair: Neal Rutherford**	**Chair: Murray Lines**	**Chair: Tim Munday**	**Chair: Vladimir David**	**Chair: Andrew Spyrou**
1530–1555	Investigation of possible shallow gas accumulations associated with pockmarks on the Otago slope southeast of New Zealand **Jasper Hoffmann**	Shelf-margin architecture and shoreline processes at the shelf-edge: Controls on sediment partitioning and prediction of deep-water deposition style **Victorien Paumard**	Fraccing onshore Australia **Maxwell Williamson**	A new blasthole xrf probe for mining grade control **Phil Hawke**	Lithium: fundamental supply/demand, the lithium brines of South America and exploration/ development methodologies **Steve Promnitz**		Characterising the subsurface architecture and stratigraphy of the McArthur Group through integrated airborne EM and gravity inversion **Teagan Blaikie**	Low noise, multichannel surface NMR receiver system with wireless connections to receiver coils **Jakob Juul Larsen**
1555–1620	Characterisation of focused gas hydrate accumulations from the Pegasus Basin, New Zealand, using high-resolution and conventional seismic data **Andrew Gorman**	Sedimentary characteristics and lithological trap identification of distant braided river delta deposits: A case study on the Upper Cretaceous Yogou Formation of Termit Basin, Niger **Zhao Ning**	Impact of artificially matured organic matter on the dielectric and elastic properties of compacted shales **Matthieu Cauchefert**	Cassiterite and rutile as indicator minerals for exploring the VMS system **Walid Salama**	Evaluating brine deposits using borehole magnetic resonance **Tom Neville**	Sub-Audio Magnetics (SAM) – Ground-based and HeliSAM FLEM trials at the Forrestania EM test range **Malcolm Cattach**	Self organising maps – a case study of Broken Hill **Tasman Gillfeather-Clark**	ECloud – Magnetotelluric Webapp **Andrew Pethick**

1620–1645	Comparing shale gouge ratio and juxtaposition analysis using stochastic trap analysis: Examples from Gippsland, Taranaki, Otway and Southern North Sea Basins **Titus Murray**	Airborne gravity gradiometer survey over the Pelarang Anticline onshore Kutai Basin Indonesia **Asbjorn Norlund Christensen**	The stratigraphic architecture, distribution and hydrocarbon potential of the organic rich Kyalla and Velkerri shales of the Upper Roper Group (McArthur Basin) **Mattilda Sheridan**	Can geophysics and geochemistry combine to detect mineralisation under transported cover? **David Cohen**		CGG'S new Helitem-C AEM systems **Adam Smiarowski**	The utility of machine learning in identification of key geophysical and geochemical datasets: a case study in lithological mapping in the Central African Copper Belt **Stephen Kuhn**	Groundwater assessment in a coal measures sequence using borehole magnetic resonance **Benjamin Birt**
1645–1710	New regional data and advances in understanding of the stratigraphy, tectonics, structure and prospectivity of the Gulf of Papua (Papua New Guinea) **Dariusz Jablonski**	The effect of deep burial and folding on sandstone reservoirs in Giant Gas Fields, South America **Gregory Smith**	Geomechanical prestack depth migration of the Kraken 3D (Browse Basin, Australia) **Jarrod Dunne**	Field analysis of low ppb gold using pXRF and new detectORE technology **Melvyn Lintern**		Passive EM processing of megatem and helitem data **Daniel Sattel**	Terrain correction correction Tasmania – results and implications **Mark Duffett**	Geologically-constrained interpretation of airborne electromagnetic data for definition of prospective groundwater resources, Albany Hinterland, Western Australia **James Reid**

Wednesday 21 February 2018								
	SESSION 8							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
	New Technology Seismic	**New Technology CO2**	**Central Australian Basins Symposium**	**History**	**Geophysical Case History**	**Hardrock Seismic**	**Groundwater**	**Groundwater**
Room	**C2.2 / C2.3**	**E3.10**	**C2.1**	**Pyrmont Theatre**	**C2.5 / C2.6**	**C2.4**	**E3.2**	**E3.1**
	Chair: Phillip Cooney	**Chair: Max Williamson**	**Chair: Amandeep Kaur**	**Chair: Steve Collins**	**Chair: Robert White**	**Chair: Andrew King**	**Chair: Simon Williams**	**Chair: David Allen**
0830–0855	Broadband least-squares wave-equation migration **Andrew Long**	Rock-physics based time-lapse inversion in Delivery 4D: Synthetic feasibility study for CO2CRC Otway Project **Anton Egorov**	Evolving exploration methods in the hydrocarbon play within the Patchawarra Formation on the Western Flank, Cooper Basin **Johann Soares**	Keynote Presentation Ocean and atmosphere chemistry drive cycles of basin-hosted ore deposits through time **Ross Large**	Constrained 3D modelling and geochemical analyses of the Horseshoe Range BIF: tools for evaluating magnetic signatures under cover **Ben Patterson**	Potential of full waveform inversion of vertical seismic profile data in hard rock environment **Stanislav Glubokovskikh**	Impact of airborne electromagnetic (AEM) surveys in groundwater management in the Lower Platte South natural resources district, Nebraska, USA **Jared Abraham**	
0855–0920	Methods for reducing unwanted noise (and increasing signal) in passive seismic surveys **Tim Dean**	Application of time-lapse full waveform inversion of vertical seismic profile data for the identification of changes introduced by CO_2 sequestration **Anton Egorov**	Stromatolite construction, biofacies and biomarkers in the Lower Cambrian Hawker Group, Arrowie Basin, South Australia **Bronwyn Teece**		Comparing responses from different AEM systems and derived models at the Sunnyside Nickel Project, Botswana **Andrea Viezzoli**	The rise of 3D seismic in hardrock mineral exploration **Frank Bilki**	Aquifer delineation using the tempest AEM system **Adam Smiarowski**	The 'exploring for the future' groundwater program: a multi-physics, inter-disciplinary systems approach for de-risking investment in agriculture in northern Australia **Narelle Neumann**

0920–0945	Quantitative Interpretation: Use of seismic inversion data to directly estimate hydrocarbon reserves and resources **James Shadlow**	3D vertical seismic profiling acquired using fibre-optic sensing DAS – results from the CO2CRC Otway project **Julia Correa**	Reservoir modelling, structural history and volumetrics of the Jerboa Area, Eyre Sub-Basin **Jordan McGlew**	Quest for the Holy Grail; BHP's Geophysical Research Program 1985–2005 **Ken Witherley**	What is ZTEM seeing over this tropical porphyry? **Chris Wijns**	Fast-tracking gold exploration below 300m – 3D seismic case history from Darlot gold mine **Greg Turner**	Resolving changes to freshwater lens systems in a 'sea of salinity' using multi-date airborne EM **Timothy Munday**	An integrated hydrogeophysical approach to exploring for groundwater resources in southern Northern Territory **Christian Seiler**
0945–1010	Solid substitution: Theory versus experiment **Stanislav Glubokovskikh**	Geochemistry of storing CO_2 and NO_x in the deep Precipice Sandstone **Julie Pearce**	Tertiary deep-water coral supports cold seeps in the Ceduna Sub-Basin **Laurent Langhi**	Ten years in the wild: The P223 experiment **David Annetts**	Airborne geophysics over the Dolly Varden VMS and low sulphidation epithermal silver deposits, northwestern BC, Canada **Jean Legault**	Distributed acoustic sensing for mineral exploration: Case study **Andrej Bona**	Stretching AEM near-surface resolution limits related to low- and very high resistivity contrasts **Andi Pfaffhuber**	Using AEM and GMR methods for non-invasive, rapid reconnaissance mapping and characterisation of groundwater systems in the Kimberley region, northern Australia **KokPiang Tan**
1010–1040	**Morning tea** *(Exhibition | The Gallery)*							
	SESSION 9							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
	New Technology Seismic	**New Technology CO_2**	**Central Australian Basins Symposium**	**Exploration Strategy**	**Geophysical Case History**	**Petrophysics**	**Groundwater**	**Groundwater**
Room	**C2.2 / C2.3**	**E3.10**	**C2.1**	**Pyrmont Theatre**	**C2.5 / C2.6**	**C2.4**	**E3.2**	**E3.1**
	Chair: Phillip Cooney	**Chair: Peter Gunn**	**Chair: Amandeep Kaur**	**Chair: Ken Witherly**	**Chair: Keith Leslie**	**Chair: Phil Schmidt**	**Chair: David Allen**	**Chair: Andrew Spyrou**
1040–1105	Keynote Presentation Multi-component seismic: Applications and new developments **Natasha Hendrick**	Feasibility of Seismic monitoring of CCS in Perth Basin **Stanislav Glubokovskikh**	Regional migration and trapping frameworks in the frontier Ceduna Sub-Basin: New insights from stratigraphic forward modelling and 'triangle juxtaposition' diagrams **Laurent Langhi**	Keynote Presentation **Mike McWilliams** **Sponsored by** CSIRO	Imaging high quality conductors at Golden Grove **Neil Hughes**	The use of petrophysical data in mineral exploration: A perspective **Michael Dentith**	The use of airborne EM to investigate a coastal carbonate aquifer, seawater intrusions and sustainable borefield yield at Exmouth, Western Australia **Karen Gilgallon**	Comparative evaluation of 1D, 2.5D and 3D inversions for resolving tectonic elements in floodplains and near-surface inverted sedimentary basins **Ken Lawrie and Donna Cathro**
1105–1130		A double double-porosity model for wave propagation in patchy-saturated tight sandstone with fabric heterogeneity **Mengqiu Guo**	Could the Mesoproterozoic Kyalla Formation emerge as a viable gas condensate source rock reservor play in the Beetaloo Sub-Basin? **Carl Altmann**		Woodlawn revitalised by DHEM **Kate Hine**	Practical considerations and good protocol for the interpretation of ultramafic and mafic rock physical property data **Cameron Adams**	Developing water supplies from Saprolite Regolith **Kevin Morgan**	

1130–1155	Marine vibrator concepts for modern seismic challenges **Andrew Long**	The influence of reverse-reactivated normal faults on porosity and permeability in sandstones: a case study at Castle Cove, Otway Basin **Natalie Debenham**	Isotope constraints on intra-basin correlation and depositional settings of the mid-Proterozoic carbonates and organic-rich shales in the Greater McArthur Basin, Northern Territory, Australia **Juraj Farkas**	Budget allocation and the stopping problem in mineral exploration **Andy Green**	Mineral exploration in the Mount Lyell region of Tasmania with the Helitem$_{35C}$® System **Adam Smiarowski**	Petrophysics and exploration targeting: The value proposition **Barry Bourne**	Focused attributes derived from AEM surveys using the continuous wavelet transform **Niels Christensen**	Rapid assessment of groundwater salinity and seawater intrusion hazard in the Keep River floodplain, Northern Territory, Australia **Ken Lawrie**
1155–1220	Fibre-optic VSPS: Borehole seismic revolution in Australia **Konstantin Galybin**	Portable XRD for unconventional and conventional petroleum exploration **Dane Burkett**	Ranking DHI attributes for effective prospect risk assessment applied to the Otway Basin, Australia **Sebastian Nixon**	How a systems thinking approach to mineralising geosystems is opening new search spaces for ore discovery **Tim Craske**	Combined gravity and magnetic studies of satellite bodies associated with the giant Coompana reverse magnetic anomaly in South Australia **Clive Foss**	Defining petrophysical properties of ultramafic and mafic rocks in terms of alteration **Cameron Adams**	Structural analyses aiding identification of water conductive fracture zones in crystalline rock **Kevin Morgan**	VTEM ET: An improved helicopter time-domain EM system for near surface applications **Jean Legault**
1220–1320	**Lunch** *(Exhibition | The Gallery)*							
1320–1345	**Poster Session** *(Pyrmont Theatre Foyer)*							
	SESSION 10							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
	New Technology Seismic	**New Technology CO2**		**Strategy & Geological Models**	**Geophysical Case History**	**Magnetics**	**Groundwater**	**Groundwater**
Room	**C2.2 / C2.3**	**E3.10**		**Pyrmont Theatre**	**C2.5 / C2.6**	**C2.4**	**E3.2**	**E3.1**
	Chair: Natasha Hendrick	**Chair: Peter Gunn**		**Chair: Mike Smith**	**Chair: Neil Hughes**	**Chair: David Clark**	**Chair: David Allen**	**Chair: Simon Williams**
1345–1410	Least square Q-Kirchhoff migration: Implementation and application **Joe Zhou**	CA-IDTIMS and biostratigraphy: Their impact on exploration **John Laurie**		Dykes, synclines and geophysical inversion – Is geology important? **Desmond Fitzgerald**	An assessment of Geotem, Falcon® and ZTEM surveys over the Nebo Babel deposit, Western Australia **Ken Witherley**	Extending magnetic depths past 1000 m **Roger Clifton**	Gaining insight into the T2*–T2 relationship through complex inversion of surface NMR free-induction decay data **Denys Grombacher**	Novel methods for near-surface hydrogeological feature enhancement from high-resolution airborne magnetic data **Peter Milligan**
1410–1435	Modelling complex near-surface features to improve shallow seismic exploration **Shaun Strong**	Analysis of time-lapse seismic and production data for systematic reservoir model classification and assessment **Rafael Souza**		Common uncertainty: Research explorer uncertainty estimation in geological 3D modelling **Evren Pakyuz-Charrier**	Geophysics for sediment hosted copper and gold mineralisation, the role of 3DIP **Barry Bourne**	Using AMS and palaeomagnetic data to assess tectonic rotation: A case study from Savannah Nickel Mine, WA **Jim Austin**	Constrained magnetotelluric inversion for characterisation of complex aquifer systems **Ralf Schaa**	Recent advancements and applications of logging and surface magnetic resonance for groundwater investigations **Elliott Grunewald**
1435–1500		Integrating geophysical monitoring data into multiphase fluid flow reservoir simulation **Trevor Irons**		Multidimensional topology transforms **Mark Jessell**	Geophysics of the Patterson Lake South Uranium Deposit, northwestern Saskatchewan **Jean Legault**	Magnetic field surveys of thin sections **Suzanne McEnroe**	Loupe – a portable EM profiling system **Andrew Duncan**	Improved groundwater system characterization and mapping using hydrogeophysical data and machine-learning workflows **Michael Friedel**
1500–1530	**Afternoon tea** *(Exhibition | The Gallery)*							
1530–1630	Closing Plenary							

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General Manager Commercial, Dave Palmer
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Generative Manager, Mark Hartley
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Monday 19 February 2018

Poster number	First name	Last name	Paper title	Theme
P001	Mohinudeen	Faiz	Carbon isotope fractionation in coal and marine source rocks and implications for exploration	Energy
P002	Lian	Jiang	Biomarker signatures of Upper Cretaceous to Paleogene hydrocarbon source rocks from the Latrobe Group, Gippsland Basin	Energy
P003	Mitchell	Levy	Identification of clay minerals within the Springbok formation, Surat Basin	Energy
P004	Marina	Pervukhina	VTI anisotropy in the Browse Basin: case study of Torosa-6 well	Energy
P005	Romain	Beucher	The structural evolution of the North West Shelf: a thermomechanical modelling approach using stratified lithospheric rheologies and surface processes	Energy
P006	Chris	Elders	Multiphase deformation of the Northern Carnarvon Basin	Energy
P007	Megan	Lech	Triassic provenance analysis of the Roebuck Basin, North West Shelf of Australia	Energy
P008	Shastri	Nimmagadda	The North West Shelf (NWS), a digital petroleum ecosystem (PDE) in a big data scale	Energy
P009	Victorien	Paumard	Full-volume interpretation methods: applications for quantitative seismic stratigraphy and geomorphology of the Lower Barrow Group, Northwest Australia	Energy
P010	Tegan	Smith	Recalibrating Australian Triassic palynostratigraphy to the international geologic timescale using high resolution CA-IDTIMS dating	Energy
P011	Ruken	Alac	Surface process models of the Lake Eyre Basin using Badlands software	Mineral Geoscience
P012	Bradley	Cave	U-Pb geochronology of apatite and calcite at the Ernest Henry Deposit, NW Queensland; implications for hydrothermal evolution and ore genesis	Mineral Geoscience
P013	John	Davidson	3D mapping of NSW Project: Sydney–Gunnedah Basin	Mineral Geoscience
P014	Xuesong	Ding	Modelling rifting sequence stratigraphy coupled with surface process and thermo-mechanical modelling	Mineral Geoscience
P015	Rhiannon	Garrett	Constraining upland erodibility in catchments delivering sediment to the Gulf of Papua	Mineral Geoscience
P016	Ben	Kay	Data visualisation and integration: an undergraduate perspective on the Frank Arnott Award	Mineral Geoscience
P017	Irena	Kivior	Improved imaging of the subsurface geology in the Mowla Terrace, Canning Basin using gravity gradiometry data	Mineral Geoscience
P018	Jean	Legault	Groundfloor EM: a new adaptation	Mineral Geoscience
P019	Chris	Van Galder	Enhancing the RL Smith Test Range – a demonstration of improved processing and noise results using full spectrum Falcon data	Mineral Geoscience
P020	Xiuyan	Ren	Research on DC resistivity for an arbitrarily anisotropic Earth using circular scanning measurement	Mineral Geoscience
P021	Meng	Zhaohai	Acceleration of 3D potential field data inversion using a BB iterative algorithm	Mineral Geoscience
P022	Nikolce	Aleksieski	Trace elements and naturally occurring radioactive material associated with produced waters in coal seam gas and shale gas resources and the mechanisms that influence fluid migration	Near Surface and Groundwater
P023	Tim	Dean	The use of geophysics as an aid for cricket umpires	Near Surface and Groundwater
P024	Anthony	Finn	Use of electrical geophysics to delineate shallow groundwater pathways	Near Surface and Groundwater
P025	Timothy	McMillan	Structural evolution of the Thirlmere and Mount Toma monoclines Southern Sydney Basin NSW – a groundwater perspective	Near Surface and Groundwater

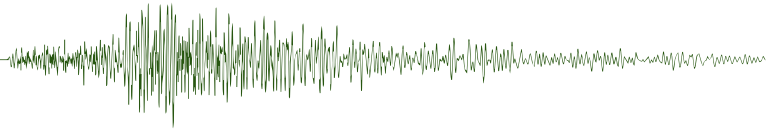
Tuesday 20 February 2018

Poster number	First name	Last name	Paper title	Theme
P026	Hasbi	Fikru Syabi	Determining upflow/outflow zone and fluids flows in geothermal prospect area based on geoindicator comparison value: a case study of Mt Telomoyo, Central Java, Indonesia	Energy
P027	Hasbi	Fikru Syabi	Soil and fluids geochemistry analysis to determine non-volcanic geothermal potential, case study of Bayah, Banten, Indonesia	Energy
P029	Rifqi Alfadhillah	Sentosa	Structural geology analysis using remote sensing method and its correlation to geothermal occurence in Bayah District, Banten	Energy
P030	Carmen	Braz	Geodynamic and surface process evolution of New Guinea since the Jurassic	Energy
P031	Aurio	Erdi	New perspective of mesozoic hydrocarbon prospectivity within West Timor	Energy
P032	Guillaume	Sanchez	Unravelling deep structures along a passive-transform margin: insights from an integrated geophysical study of the Northern Perth Basin	Energy
P033	Chris	Southby	Structural characteristics of the Northern Houtman Sub-basin, Perth Basin	Energy
P034	Chris	Southby	Tectono-stratigraphic development of the Northern Houtman Sub-basin, Perth Basin	Energy
P035	Jade	Anderson	Towards a U–Pb age map for northern Australia	Mineral Geoscience
P036	Casey	Blundell	Interpreting geology from geophysics in polydeformed terranes: The Otago Schist, New Zealand	Mineral Geoscience
P037	Astrid	Carlton	How to access New South Wales geophysical data	Mineral Geoscience
P038	Magdel	Combrinck	Using representative synthetic data to analyze effects of filters when processing full waveform airborne TEM data	Mineral Geoscience
P039	Graham	Heinson	Electrical resistivity maps of the Australian lower crust	Mineral Geoscience
P040	Graham	Heinson	Why do we need to know the electrical resistivity structure of oceanic lithosphere?	Mineral Geoscience
P041	Andrew	King	Constraining airborne electromagnetic regolith mapping with landscape evolution	Mineral Geoscience
P042	Alison	Kirkby	Development of the MTPy software package for magnetotelluric data analysis	Mineral Geoscience
P043	Laura	Phillips	Detrital zircon analysis from the Galilee Basin, Queensland	Mineral Geoscience
P044	Daniel	Sattel	Square-wave processing of MEGATEM data	Mineral Geoscience
P045	Rifqi Alfadhillah	Sentosa	Mercury and soil carbon dioxide analysis to determine geothermal resources in Mt Telomoyo, Central Java, Indonesia	Mineral Geoscience
P046	Janelle	Simpson	Exploring magnetotelluric model space	Mineral Geoscience
P047	Janelle	Simpson	Using downhole resistivity to better understand magnetotelluric inversion	Mineral Geoscience
P048	Huang	Xin	3D airborne EM anisotropic effect and identification modeling by SE method	Mineral Geoscience
P049	Gilles	Brocard	Transcontinental cenozoic paleovalleys of Western Australia	Near Surface and Groundwater
P050	Shigeo	Okuma	Magnetic imaging of ultramafic bodies on the site of the Ohi nuclear power station, central Japan	Near Surface and Groundwater
P051	Laura	Gow	Using hydrogeophysical techniques to characterise and map sea water intrusion and preferential flow paths in Howards East Aquifer, Darwin Rural Area, Northern Territory	Near Surface and Groundwater

Wednesday 21 February 2018

Poster number	First name	Last name	Paper title	Theme
P052	Andrew	Kelman	Middle Ordovician conodonts and fish from the Stairway Sandstone, Amadeus Basin	Energy
P053	Alison	Kirkby	The conductivity structure of the Georgina-Arunta region from magnetotellurics	Energy
P054	Julie	Pearce	Metal mobilisation during water reaction of the Roseneath and Murteree shales of the Cooper Basin	Energy
P055	Shakil	Ahmed	Drained pore modulus determination using digital rock technology	Energy
P056	Zubair	Ahmed	Optimum image resolution of a micro-CT image to characterise shape descriptors and microstructure of an unconsolidated sand	Energy
P057	Roman	Beloborodov	Coupled measurements of hydraulic permeability and full stiffness tensor compaction trends in artificial shales	Energy
P058	Julia	Correa	A comparison of conventional borehole tools and distributed acoustic sensing at a dedicated field laboratory	Energy
P059	Se	Gong	Caron isotope fingerprinting palaeo fluid inclusion gases using a crushing-trapping technique	Energy
P060	Lance	Holmes	Integrated Earth data interpretation workflow - a recipe for success in onshore frontier hydrocarbon exploration	Energy
P061	Mosayeb	Khademi Zahedi	Volcanics: a commonly underestimated part of petroleum exploration	Energy
P062	Shastri	Nimmagadda	Are an upstream business data, big data? Does the size matter in the data and business analytics	Energy
P063	Wenhui	Tan	Analysis on brittleness characteristics of tight oil siltstones	Energy
P064	Chris	Van Galder	Full spectrum gravity – high quality gravity data for all applications	Energy
P065	Chitra	Viswanathan	A cloud-based well log database prototype	Energy
P066	Alexey	Yurikov	Experimental and theoretical study of water retention effect on elastic properties of opalinus shale	Energy
P067	Dmitry	Popik	Time-lapse surface seismic processing for stage 2C of CO2CRC Otway Project	Energy
P068	Tim	Dean	The seismic signature of rain	Energy
P069	Tim	Dean	Noise in urban land seismic surveys	Energy
P070	Boris	Gurevich	Seismic signatures of fractured reservoirs: theory versus numerical simulations	Energy
P071	Dave	Marchant	3D inversion of large scale marine controlled-source electromagnetics	Energy
P072	Vassily	Mikhaltsevitch	The impact of water saturation on the elastic anisotropy dispersion in the Wellington shale at seismic frequencies	Energy
P073	Nazanin	Nourifard	Effect of amplitute on wave propagation	Energy
P074	Michel	Nzikou	Forward and inversion modelling of the ultrasonic wave in a homogeneous medium using p-wave transducers	Energy
P075	Abdulwaheed	Ògúnsàmì	Permeability and seismic-frequency elasticity of cracked glass	Energy
P076	Jacob	Smith	Interpretation using explicitly encoded phase, amplitude and fault data	Energy

P077	David	Clark	Borehole measurements within highly magnetic bodies – corrections of measured magnetic fields and gradients	Mineral Geoscience
P078	Clive	Foss	Magnetic field surveys with a source of known magnetisation	Mineral Geoscience
P079	Adouley	Guirou	Petrophysical characterisation of South East Dome copper gold deposit, Northwestern Zambia	Mineral Geoscience
P080	Matthew	Hutchens	Depth estimate of a remnantly magnetised source using multi-level magnetic data	Mineral Geoscience
P081	Matthew	Hutchens	Depth estimation of source bodies using 2D magnetic gradient ratios	Mineral Geoscience
P082	Harrison	Jones	Geophysical signature of the southern-Gurubang base metal occurrence in southeastern NSW	Mineral Geoscience
P083	Duy Thong	Kieu	Integration of borehole data in geophysical inversion using fuzzy clustering	Mineral Geoscience
P084	Tom	Neville	Continuous hydrogeological characterisation in iron ore deposits using borehole magnetic resonance	Mineral Geoscience
P085	Tim	Hopper	Continuous dry bulk density evaluation using borehole magnetic resonance and density measurements	Mineral Geoscience
P086	Shastri	Nimmagadda	Digital opencast mining ecosystem (dome) for managing the Australian mining industry in a big data scale	Mineral Geoscience
P087	Anastasia	Pirogova	Effect of finely-layered stiff carbonates on a seismic response, Carnarvon Basin synthetic study	Mineral Geoscience
P088	Xiaodi	Tan	Application of image processing methods in edge detection of potential field data	Mineral Geoscience
P089	Dailei	Zhang	Fast three dimensional density inversion based on multi-scale analysis of wavelet	Mineral Geoscience
P090	Craig	Annison	The new generation tempest system	Near Surface and Groundwater
P091	Alexander	Costall	Rapid estimation of volumetric groundwater recharge in the vadose zone via ground penetrating radar	Near Surface and Groundwater
P092	Laura	Gow	Assessing aquifer compartmentalisation in the Daly River Basin, Northern Territory: a hydrogeophysical approach	Near Surface and Groundwater
P093	Tania	Ibrahimi	Developing regional-scale hydrogeological frameworks for remote parts of Australia – the role of digital terrain data coupled with fine-scale geophysical and geological data	Near Surface and Groundwater
P094	Kevin	Morgan	Structural analyses aiding identification of water conductive fracture zones in crystalline rock	Near Surface and Groundwater
P095	Bibirabea	Sedaghat	Magnetotelluric, basin structure and hydrodynamic; south west of Western Australia	Near Surface and Groundwater
P096	KokPiang	Tan	Application of magnetic resonance data for groundwater prospectivity in the Fitzroy Basin, Western Australia	Near Surface and Groundwater
P097	Donna	Cathro	Utilisation of AEM methods for cost-effective mapping of shallow neogene intra-plate fault systems in Eastern Australian coal seam gas basins	Near Surface and Groundwater



Saturday 17 February 2018

Title:	Epithermal Au-Ag and porphyry Cu-Au exploration (1)
Date:	3 days: 17–18 and 22 February 2018
Presenter(s):	*Greg Corbett and Stuart Hayward*
Venue:	ICC Sydney
Room:	E3.1

Title:	Vectoring to mineralisation: exploration geochemistry workshop (@UNSW)
Date:	Saturday 17 February 2018
Presenter(s):	*David Cohen, Neil Rutherford, Anita Andrew and Graham Carr*
Venue:	UNSW

Title:	Using geology and geophysical data to interpret models for mineral exploration
Date:	Saturday 17 February 2018
Presenter(s):	*Tim Chalke, Glenn Pears and James Reid*
Venue:	Novotel Sydney Darling Harbour

Sunday 18 February 2018

Title:	Epithermal Au-Ag and porphyry Cu-Au exploration (2)
Date:	3 days: 17–18 and 22 February 2018
Presenter(s):	*Greg Corbett and Stuart Hayward*
Venue:	ICC Sydney
Room:	E3.1

Title:	Practical geological interpretation of potential field data sets and the importance of basement
Date:	Sunday 18 February 2018
Presenter(s):	*Lynn Pryer*
Venue:	ICC Sydney
Room:	E3.2

Title:	Structural interpretation in exploration geology, extension, compression and salt
Date:	Sunday 18 February 2018
Presenter(s):	*Dr Kevin C. Hill*
Venue:	ICC Sydney
Room:	E3.3

Title:	Mining petrophysics: extending the value of borehole geophysics data in mineral exploration and mine development through integration
Date:	Sunday 18 February 2018
Presenter(s):	*Dr Tim Hopper and Tom Neville, NMR Services Australia and Dr Benjamin Birt, Kinetic Logging Services*
Venue:	ICC Sydney
Room:	E3.10

Title:	Find your voice – present with confidence
Date:	Sunday 18 February 2018
Presenter(s):	*Doug Knight*
Room:	Adina Apartment Hotel Spinnaker B Room Darling Harbour

Tuesday 20 February 2018

Title:	From Faxes to FaceTime: building intergenerational relationships through networking and mentoring
Date:	Tuesday 20 February 2018
Presenter(s):	*Dr Ali Burston*
Sponsored by:	BHP
Venue:	C3.4 @ ICC Sydney

Thursday 22 February 2018

Title:	AI/machine learning; opportunities and challenges for minerals exploration
Date:	Thursday 22 February 2018
Presenter(s):	*John Hart and Ken Witherly*
Venue:	ICC Sydney
Room:	E3.1

Title:	Multi-modal hyperspectral core logging for exploration
Date:	Thursday 22 February 2018
Presenter(s):	*Melissa A. Quigley (Spectral Geoscience Pty Ltd), Brigette A. Martini (Corescan Pty Ltd), Jon F. Huntington (Huntington Hyperspectral Pty Ltd) and Andy Green (OOTB Pty Ltd)*
Venue:	ICC Sydney
Room:	E3.2

Title:	Epithermal Au-Ag and porphyry Cu-Au exploration (3)
Date:	3 days: 17–18 and 22 February 2018
Presenter(s):	*Greg Corbett and Stuart Hayward*
Venue:	ICC Sydney
Room:	E3.1

Australian Government
Geoscience Australia

Exploring for the Future
minerals | energy | groundwater

Exploring for the Future: Boosting exploration for resources in northern Australia

As part of a wider Australian Government initiative to boost exploration for resources in northern Australia, Geoscience Australia (GA) is leading the four-year *Exploring for the Future* program to help identify potential mineral, energy, and groundwater resources across the region.

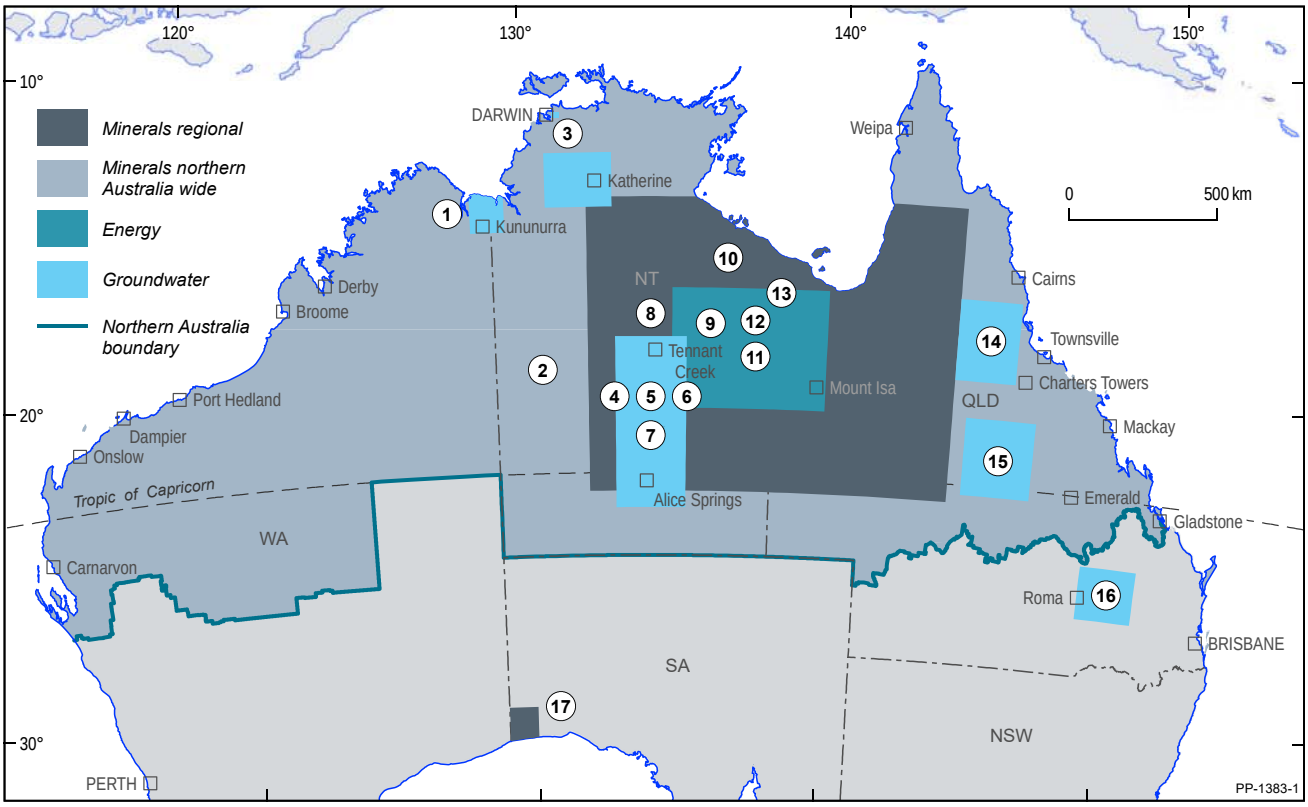
The program will deliver new pre-competitive data and information on minerals, energy and groundwater in collaboration with state and territory partners to guide and encourage investment in onshore resource exploration.

With the first year of field work now complete, our teams have collected a range of valuable research data and information across northern Australia and parts of South Australia.

Over the next three years, we will be collecting even more geoscientific data and then processing and compiling it to make it freely available for public use.

Our scientists and technicians are using innovative tools and techniques to gather new data using geophysical surveys, geochemical sampling, hydrological mapping and stratigraphic drilling.

An overview of current *Exploring for the Future* activities



1. *AEM survey, East Kimberley*
2. *Solid geology map*
3. *AEM survey, Northern Stuart Corridor*
4. *AusAEM survey, Mt Isa to Tennant Creek*
5. *Onshore drilling assessment, Mt Isa to Tennant Creek*
6. *AusARRAY survey, Mt Isa to Tennant Creek*
7. *Southern Stuart Corridor AEM survey*
8. *Hydrogeochemistry sampling, Tennant Creek*
9. *AusLAMP survey*
10. *Hydrogeochemistry sampling, McArthur Basin*
11. *South Nicholson gravity survey*
12. *South Nicholson seismic survey*
13. *North Australia geochemistry survey*
14. *Bore hole monitoring, Upper Burdekin*
15. *AEM survey, Galilee Basin*
16. *AEM survey, Surat Basin*
17. *Coompana drilling program*

Minerals

The minerals component of the *Exploring for the Future* program focuses on identifying geological provinces that have the greatest potential for various mineral deposits.

Our main aim is to characterise the geology of the northern part of the Australian tectonic plate from the surface down to its base through a multidisciplinary approach of data collection and synthesis, to unravel the fingerprints of ore-forming systems, which transect these scales.

An area between Tennant Creek and Mount Isa has been selected to carry out focused integrated studies for mineral potential assessments. These assessments will focus on copper, gold, lead, zinc and uranium and will involve additional geoscientific data acquisition and knowledge generation.

Image: Vibroseis trucks acquiring seismic data

Activities

- **AusAEM surveys:** a series of airborne electromagnetic (AEM) surveys will take place across a large region of northern Australia, using a broad line spacing of 20 km. It is the largest AEM survey of its kind ever undertaken. In the 2017 field season, 20 000 line-km were acquired. Public release of this data is expected by March 2018. An additional 40 000 line-km will be acquired in the 2018 field season.
- **South Nicholson gravity survey:** 2724 gravity stations collected at 4km spacing. The data was released October 2017.
- **AusLAMP surveys:** The $3.1 million Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP) commenced late in 2016, with instruments installed around Tennant Creek, and is continuing throughout regions of the NT and Queensland. The project will measure the electrical conductivity structure of the crust and upper mantle to detect ancient pathways of mineral-bearing fluids, thereby providing vectors to mineral deposits. Data from 160 sites have been acquired in northern Australia.
- **AusARRAY surveys:** The Australian Passive Seismic Array Project (AusARRAY) is a collaborative, national survey that acquires seismic velocity data. Launched in July 2017, data from 120 sites are being acquired in northern Australia. This first array will be installed for a year, spaced approximately 55 km apart in an area spanning the NT–Queensland border.

- **Hydrogeochemistry sampling:** 20 unique groundwater samples collected from sites around Tennant Creek and McArthur Basin.
- **North Australia geochemistry survey:** 782 overbank surface sediment samples were collected during a helicopter assisted program between May and June 2017. The data is currently being processed and interpreted.
- **Solid geology map:** A solid geology interpretation of the area from Mt Isa to Tennant Creek and Darwin which progressively strips off Cenozoic, Mesozoic and Palaeozoic rocks has been generated and is out for review with state and territory geological surveys. This is a first step towards a national 3D geology map.
- **Isotopic atlas:** Samples have been collected from drill core libraries and submitted for analysis to measure neodymium and lead isotopes to map the main crustal boundarie s of northern Australia. A compilation of argon data has commenced.
- 25 new uranium-lead geochronological age dates of key rock types of northern Australia has been completed and delivered in three reports.
- **Coompana Drilling Program:** More than 1800 metres of high-quality drill core samples have been collected from eight stratigraphic drill holes in partnership with the Geological Survey of South Australia.
- **Onshore drilling assessment:** Desktop based investigations are underway to assess the potential of the Tennant-Isa region for iron oxide-copper-gold and basin-hosted mineral systems. This desktop assessment, in addition to geological interpretations arising from new data acquisition, will inform stratigraphic drill targeting for the 2019 dry season.

ga.gov.au/eftf

Energy

The energy component of the *Exploring for the Future* program will concentrate on the evaluation of the oil and gas prospectivity and resource potential of sedimentary basins.

Historically, the most valuable data to predict oil and gas resources has been seismic reflection data to understand the architecture of the basins and corresponding well data to analyse the potential of an active petroleum system. These techniques will also be the primary acquisition techniques for the new data due to their effectiveness; however, they will be supplemented by a variety of innovative techniques and interpretations to ensure the best outcomes.

Activities

- **South Nicholson Basin:** seismic surveys were conducted over the South Nicholson Basin in 2017. The processed data will be available in early 2018. Stratigraphic drilling will take place over the next two years to collect rock samples that will provide information on the resource prospectivity.
- **Kidson Sub-basin:** Planning for geophysical data acquisition is underway for the 2018 field season and the interpretation of the data will inform the location of stratigraphic drilling to acquire rock samples. This activity will enable improved understanding of the sub-surface geology and provide detailed information on mineral and hydrocarbon prospectivity.

Groundwater

The groundwater component of the *Exploring for the Future* program will assess the location, quantity and quality of potential groundwater resources in five regional areas to underpin future opportunities for irrigated agriculture, mineral and energy development, and community water supply.

The program will comprise both targeted regional investigations and analysis of groundwater prospectivity more broadly across northern Australia. Five regional areas have been selected for new targeted geoscience studies:

- East Kimberley
- Northern Stuart Corridor (Howard East and Daly River Basin)
- Southern Stuart Corridor (Tennant Creek to Alice Springs)
- Upper Burdekin
- Surat and Galilee Basins.

Activities

- **Southern Stuart Corridor:** 9613 line-km airborne electromagnetic survey completed; 21 bores logged for induction and gamma geophysics.
- **Northern Stuart Corridor:** 5423 line-km airborne electromagnetic survey completed; 50 bores logged for induction and gamma geophysics.
- **East Kimberley:** 13 379 line-km airborne electromagnetic survey completed with financial contribution from NT Department of Environment and Natural Resources from the Commonwealth National Water Infrastructure Development Fund for the Ord Stage 3: Keep River Project; 7920 km2 LiDAR elevation data acquisition completed; 1071 station passive seismic and gravity survey completed; 161 station surface nuclear magnetic resonance survey completed; 25 water samples collected and analysed.
- **Surat and Galilee Basin AEM surveys:** 4477 line-km of airborne electromagnetics completed.
- **Upper Burdekin:** eight new water bores drilled; water level loggers installed at 14 water bores; 56 water samples collected and analysed.

For Further Information:

Geoscience Australia
Website: www.ga.gov.au/eftf
Email: eftf@ga.gov.au
Ph: (02) 6249 9111
(Monday–Friday, 9am to 5pm AEST)

Sunday 18 February 2018

Welcome reception

Time: 6:00 pm – 7:30 pm

Venue: Exhibition in The Gallery @ The ICC Sydney

A ticket to the welcome reception is included with full delegate registration

The welcome reception will be a cocktail style event held in the exhibition to welcome delegates to Sydney. It will be a time to catch up with old friends and meet new ones in a relaxed atmosphere, away from the hustle and bustle of the conference sessions.

Tuesday 20 February 2018

Conference dinner

Time: 7:30 pm – 11:30 pm

Venue: Parkside Ballroom @ ICC Sydney

Master of Ceremonies: Tom Gleeson

A ticket to the Conference dinner is included with full delegate registration (where indicated 'including dinner').

Additional tickets: AU$130 per person (incl. GST).

Limited additional tickets are available for sale. Please visit staff at the registration desk for more information.

Other social functions

Please visit staff at the registration desk for more information about these social functions.

Monday 19 February 2018 and Wednesday 21 February 2018

Rocks geology, history and pub tour

Tickets: $50 per person per tour **Limited to 20 places*

The AEGC Conference is providing a fantastic opportunity to learn about the geology of the Sydney City area, whilst also taking in some of its early history, as a British penal colony! The Rocks pub tour is 2–3 hour walking tour that will visit numerous sites in Sydney's historic Rocks district. We'll learn a bit about the geology, a bit about the history, eat kangaroo, emu and crocodile pizza, and visit some of Australia's best pubs along the way (see map and itinerary for details). Price includes tour guides, pizza and beer tasting paddle (or similar).

Tuesday 20 February 2018

Student trivia night

Time: 6:00 pm

Venue: Pyrmont Bridge Hotel

Tickets: $20 per person **Limited to 60 places*

The AEGC Conference provides a fantastic opportunity to learn about the ever-evolving geoscience industry and network with not only professionals but also students! The student trivia night aims to bring together students in a relaxed environment to not only learn about what other students are studying, but also establish contacts and networks within the student community. The trivia will not be too technical, but rather fun, and discussed over food and drink with views over stunning Darling Harbour, at Sydney's iconic Pyrmont Bridge Hotel.

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Specialists in ground Electro Magnetic Surveys
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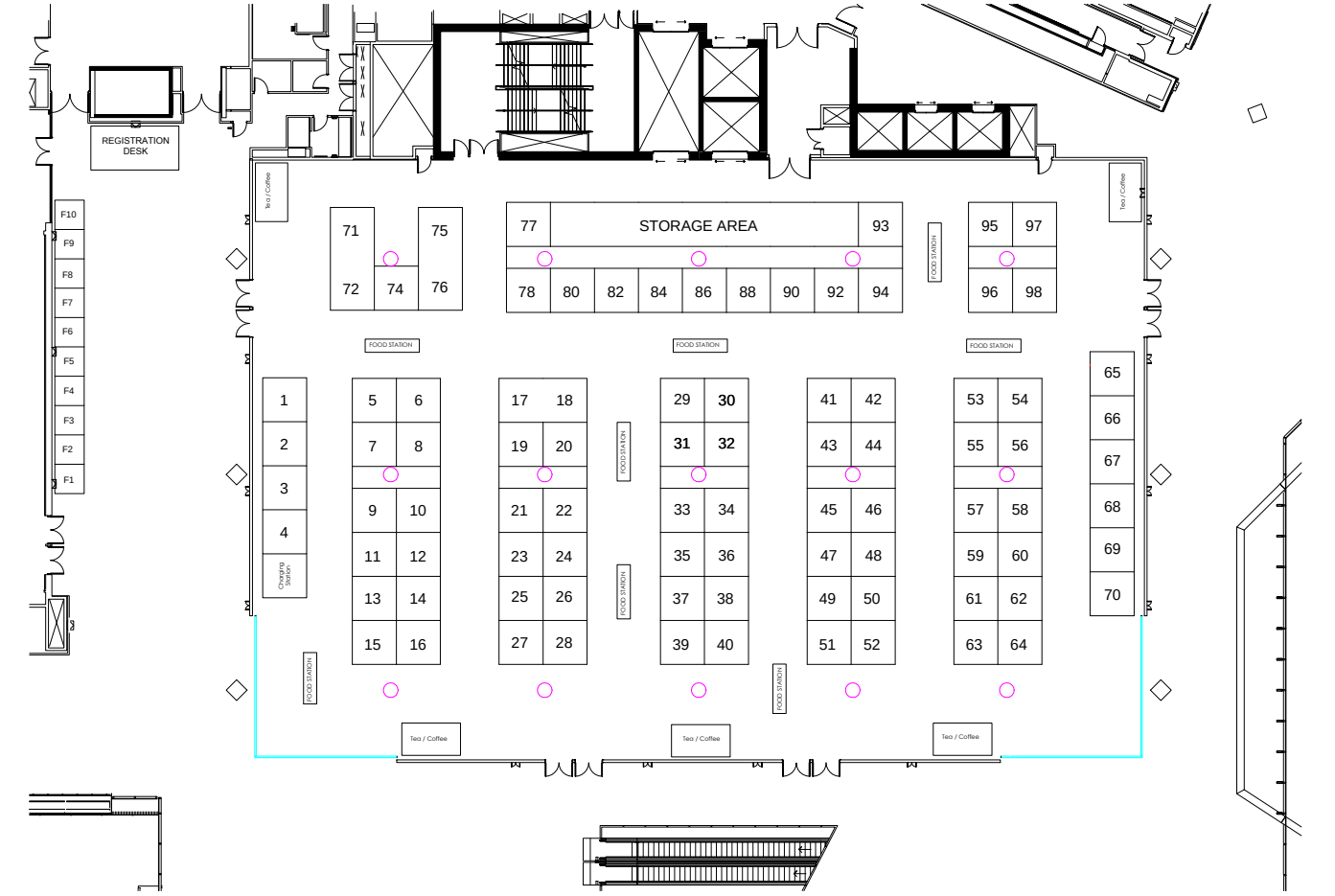
w: www.gemgeophysics.com.au

SECTION 2
EXHIBITION

Australian Society of Exploration Geophysicists

PESA Petroleum Exploration Society of Australia

AUSTRALIAN INSTITUTE OF GEOSCIENTISTS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STORAGE AREA
FOOD STATION
Tea / Coffee
Charging Station
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TABLE TOP DISPLAY
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Exhibition

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F9	**The Australian Society of Exploration Geophysicists** ***Host***
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One of the best small company portfolios in Australia…
Bridgeport
ENERGY
A New Hope Group company

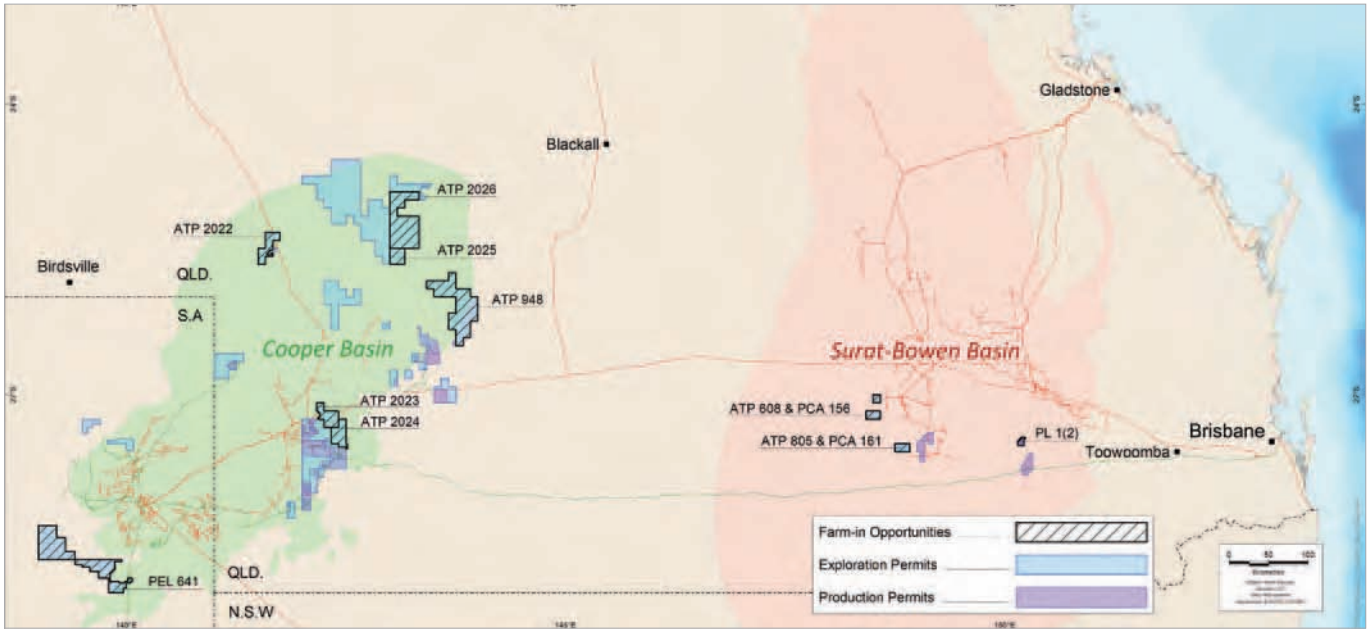
Bridgeport Energy Limited (BEL) is an exploration and production company with a large holding of quality exploration tenements in the Cooper-Eromanga and Surat-Bowen basins of Queensland and South Australia.

Both basins are prolific in terms of oil and gas production, yet remain relatively under-explored. The Cooper Basin is the most productive onshore Australian petroleum basin with over 6 trillion cubic feet of gas and 300 million barrels of oil recovered to date. Although, the mean field size in the basin is 2-3MMboe, recent new play-opening discoveries have uncovered +20MMboe fields, which have become company makers.

The company boasts an experienced technical and management team with significant knowledge of conventional and unconventional exploration and development in eastern Australia, and in other basins across the world. Much of Bridgeport's exploration asset portfolio is ready for early drilling activity in known hydrocarbon fairways, which have demonstrated good exploration success historically. Plans are in place to acquire new, high quality seismic data and subsequent mapping will progress a number of current leads to drillable prospects.

THE COOPER BASIN IS THE MOST PRODUCTIVE ONSHORE AUSTRALIAN PETROLEUM BASIN WITH OVER 6TCF GAS AND 300MMBBLS OIL PRODUCED TO DATE.

Bridgeport has undertaken extensive regional studies including Play Based Exploration, identifying a range of play types and follow-up opportunities across more than 7,000 km^2 of exploration acreage. As a result, common risk segment maps are available to assist in "sweet spot" identification, and a fully vetted oil and gas lead and prospect portfolio has been generated containing Permian- through to Cretaceous-aged reservoir targets.



The majority of exploration permits have environmental and native title agreements in place and are close to existing transportation infrastructure. Demonstrated commodity prices in these basins has oil at 'Brent' plus a $2-4 premium, and gas contracts have been established in the $7-10/GJ range. ►

PLANS ARE IN PLACE TO ACQUIRE NEW, HIGH-QUALITY SEISMIC DATA, AND SUBSEQUENT MAPPING WILL PROGRESS A NUMBER OF CURRENT LEADS TO DRILLABLE PROSPECTS.

Exploration Assets at a Glance...

Northern Cooper-Eromanga Basin, Queensland

ATPs 269 and 948

These two tenements are in the eastern Cooper-Eromanga basin comprising approximately 2,400 km^2 in area and are 100% Bridgeport controlled. Both permits are close to producing oil fields; Kenmore, Bodalla South, Tintaburra, Utopia and others. Potential hydrocarbon plays range from the four-way structural closures to stratigraphic pinch-outs and encompass the Late Cretaceous to Permian reservoirs. Primary targets are known reservoir quality sands within the Early Cretaceous Murta formation, and the Jurassic-aged Birkhead, Hutton, and Poolowanna formations. There is also 'elephant sized' play-opening potential in the deeper Devonian sediments.

Extensive work has been completed to reprocess, tie and interpret existing 1980s and '90s vintage 2D seismic across these permits. Additionally, interpretation of existing 3D seismic has resulted in a rejuvenated portfolio of drill ready opportunities and follow up leads. The prospects and leads are up-dip and surrounding known oil production such as the Tintaburra, Glenvale, Monler and Bargie fields.

Nearby gas discoveries include Solitaire, Cocos, Bunya, and Mt Howitt- all producing wet gas from the Permian-aged Toolachee and/or Patchawarra formations.

Furthermore, existing wells in ATP 269 may be easily recompleted for additional reserves. Bridgeport has extensive experience in revitalizing mature oil fields and have demonstrated success at recovering 'behind pipe' opportunities.

PREVIOUS WELLS DISCOVERED EXCELLENT HYDROCARBON SHOWS, WITH MOBILE OIL AND GAS TO SURFACE, INCLUDING OIL OBSERVED IN THE HUTTON SANDSTONE WHOLE CORE.

ATP 2022

The ATP 2022 exploration permit covers 440km2 and surrounds the multi-million barrel Inland oil field, which currently contributes hundreds of barrels per day to Bridgeport's production. Just up-dip of Inland Field, the large Morney structural high dominates the permit. All vintage wells on the Morney high were drilled on older sparse 2D seismic. Nevertheless, the wells discovered excellent hydrocarbon shows, with mobile oil and gas to surface, including oil in the Morney-1 Hutton Sandstone whole core.

New drilling locations will be identified using planned 2D and 3D seismic data. The use of 3D seismic on the Western flank oil fairway was key to the identification of Birkhead channel prospects and has been crucial in achieving the high exploration drilling success rate. Exploration success through the use of 3D seismic is demonstrated by nearby oil fields such as; Inland, Cuisinier and Cook. Additionally, large areas of the permit lack any seismic data, which are on trend, but severely underexplored.

South-west Flank Cooper Basin Oil and Gas, South Australia

PEL 641

Exploration tenement PEL 641 is an extensive (2,000 km^2) permit that lies along trend and south of the 'Western Flank' of the Cooper Basin, one of the hottest and most prolific on-shore oil and gas provinces in Australia. Despite recent success along this trend, extensive areas on the flank of the Cooper-Eromanga Basin remain critically under-explored.

There is plenty of romance in the PEL 641 permit which surrounds prolific deep source rock depo-centers. Targets include Triassic/Permian and Cretaceous/Jurassic sandstone reservoirs, with strong potential for migrated hydrocarbons to be discovered beyond the Permian and Triassic zero edge. More than a dozen leads and prospects have been identified in the tenement, including the prolific Namur and Murta plays, as expressed in nearby oil fields such as Worrior, Padulla, Harpoono and Taloola (> 6 million bbls oil recovered to date), which can all be found within 30 km of PEL 641. The prolific Jena field which produces from a high-permeability facies within the Murta/McKinley formations is less than 40 km to the northeast.

Not only does the permit off-set proven production along several play trends, but there is strong potential for existing by-passed pay in the Maslins structure, based on very strong shows and oil recovered from a well test. Maslins-1 was plugged and abandoned prior to successful formation stimulation in look-a-like reservoirs at Padulla-2 & -3, a short distance to the northwest.

Notwithstanding the limited seismic data and few wells, ~2300 line km of existing 2D seismic data within block has helped define an extensive lead portfolio. Consequently, high resolution 2D and 3D seismic programs are being planned to firm up drill ready prospects. As a testament to the trends and plays in the area, substantial commitments have been made by industry in adjacent gazettal permits. Bridgeport's commitment 2D & 3D seismic acquisition and a three well exploration program by 2020 with a contingent four additional wells to be drilled by 2023.

PEL 641 is in a favorable location, both geologically and logistically with direct access to infrastructure connecting to Eastern Australian gas markets, and the Moomba to Port Bonython liquids pipeline runs through the eastern portion of permit.

The permit has only recently been awarded, with official grant to be confirmed in early 2018, so there is a long lead time to pursue exploration opportunities. ►

Bridgeport ENERGY
A New Hope Group company

Jundah Shale Project Cooper Basin, Queensland

ATP 2026

ATP 2026 is vast permit located approximately 20 km southwest of Jundah Township in South East Queensland. It covers over 1800 km². Eight PCAs have been granted over the tenement. The PCAs give 10 years (2028) to prove commerciality. The PCA applications were based on the recent Obelix-1 discovery. The well encountered the laterally extensive, thick Toolebuc Formation in an optimal position to make it prospective as an unconventional resource. The potential source/reservoir formation is thicker and deeper in ATP 2026 than previously identified in the Eromanga Basin in southwest Queensland. The results from the preliminary evaluation of Obelix-1 well data (logs, cuttings, and analyses) support the view that the conditions are right for hydrocarbon production from the Toolebuc Formation. Recent studies by the Geological Survey of Queensland (GSQ) supports this view and have concluded the Toolebuc Formation is prospective for oil and gas within the area. The Toolebuc Formation exists throughout the entire ATP 2026 tenement area.

BRIDGEPORT'S EXPERIENCED AND ENERGETIC TEAM IS COMMITTED TO SUCCESS ACROSS THE EXPLORATION PORTFOLIO.

The Toolebuc Formation may hold significant hydrocarbons in-place. Initial estimates calculate 400 mmboe of mean recoverable resource within the tenement. The ultimate prospectivity and commerciality of the play would be enhanced by the occurrence of associated gas. Bridgeport Energy Limited (Bridgeport) has existing egress options for transporting these liquids to market.

The work plan in 2018 includes the acquisition of whole core in an offset well to Obelix-1, fracture stimulation, flow test and additional wells to de-risk a larger area. Success with the appraisal program will lead to a multi hundred million dollar project. Bridgeport's multidiscipline effort has been coined the Jundah Project.

Surat Basin Queensland, Conventional Oil

ATP 608/PCA 156 (Rookwood) & ATP 805/PCA 161 (Donga)

Located ~60 km west of Surat Township in SE Queensland, the permits cover 380 km² along the oil-prone western flank of the Surat Basin. Primary targets within the permit are sandstone reservoirs of the Triassic-aged Moolayember Formation and Jurassic-aged Boxvale Member of the Evergreen Fm, with a secondary target in the Hutton Sandstone above.

The closest hydrocarbon discoveries include Rookwood (within PCA 156) and Emu-Apple oil fields (2 km east), and the Beldene and Avondale gas fields a short distance east of the tenement. A 3D seismic survey was acquired (2015) over the Donga and Bineanna structures within PCA 161 tenement, where the Donga-1 & Donga-3 wells have established oil pay in the Moolayember Fm and Donga-5 has untested potential in the Boxvale member. There are two drill ready prospects, and two additional follow-up leads identified in this area.

The Potential Commercial Area (PCA) designations have been received only recently, allowing 10 years and 5 years, respectively for PCAs 156 and 161 to address commercial success.

Naccowlah Area conventional oil and gas area, Queensland

ATPs 2023 & 2024

These permits cover ~850 km² of the central Cooper-Eromanga basin, just north of the huge Jackson oil field (> 50 million bbls) near the Queensland-South Australia border. The northern permit (2023) is a mere 5 km south and east of the Wareena and Tartulla gas fields. As such, the area is in a proven petroleum system. Official title grant is still pending and there is a long period of exploration. The extensive 2D seismic grid shows various structural leads that have not been tested. The planned work program includes 3D seismic survey, which would firm up drillable prospects likely totally over 50 million barrels recoverable.

Bridgeport is excited to share our exploration story. As a junior on-shore explorer, Bridgeport's asset portfolio is as good as it gets, with prospects in every play, at every stratigraphic interval, and most geological environments of the past 400 million years. The company's prospective resources are in excess of a 100 million barrels of oil equivalent in conventional plays alone, while the Toolebuc unconventional shale play of the Jundah Project holds billions of barrels of oil-in-place within Bridgeport held acreage. Success in any one of Bridgeport's assets would propel the company to the next tier of Australian oil and gas producers.

While continuing to prepare seismic and drilling opportunities, Bridgeport's team is seeking like-minded partners to join them on this exploration journey. Find out more and meet the team at booth #39 during the Australia Exploration Geoscience Conference, 18-21 February 2018 at the Sydney Convention & Exhibition Centre. ■

Aarhus Geophysics

Booth Number 55

Aarhus Geophysics is an independent consultant specializing in airborne EM, servicing both the mineral exploration and groundwater industry, worldwide.

Aarhus GeoSoftware

Booth Number 92
Web: www.aarhusgeosoftware.dk

Aarhus GeoSoftware is a leading provider of software for processing, inversion and visualization of geophysical electromagnetic- and ERT data.

Advanced Geophysical Operations and Services Inc. (AGCOS)

Booth Number 47
Web: www.agcos.ca

AGCOS Inc. (Toronto, Canada) manufactures super-multifunction ground and marine broadband EM instruments and provides wide range of geophysical services for mining exploration and geological mapping.

Advanced Logic Technology sa (ALT)

Booth Number 86
Web: www.alt.lu

ALT – Advanced Logic Technology is a developer of borehole logging systems with leading expertise on imaging tools and WellCAD data processing software.

Australian Institute of Geoscientists

Host

Booth Number F10

The Australian Institute of Geoscientists (AIG) is the leading professional institute representing geoscientists employed in all sectors of industry, education, research and government throughout Australia. AIG is a not for profit organisation, run by members for members, which aims to advance the skills, status and public perception of more than 3000 members both within Australia and overseas.

AIG, ASEG, PESA

Booth Number F7
Web: https://www.aig.org.au/education-training/graduate-portal/early-career-geoscientists/ ; https://www.aseg.org.au/about-aseg/aseg-young-professionals

Facilitating continuing education, multidisciplinary collaboration and personal development opportunities for the new age geoscientist.

ALPHA GEOSCIENCE Pty. Ltd.

Booth Number 15
Web: www.alpha-geo.com

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We assist people to fast track attainment of their personal financial security, using a scientific-based approach based on the petroleum industry proven risk management system.

Exhibition

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Platinum Sponsor

Booth Number 29–32
Web: www.australiaminerals.gov.au

Australia Minerals is a collaboration of Australia's federal, state and Northern Territory government geoscience agencies working together to offer ground-breaking information, unrivalled expertise and a record of innovation that supports mineral explorers to realise investment opportunities.

Australian Geoscience Council

Booth Number F6
Web: www.agc.org.au

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Sponsor

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Bridgeport Energy Limited

Silver Sponsor

Booth Number 39
Web: www.bridgeport.net.au

Bridgeport is an Australian oil & gas exploration, development and production company with onshore petroleum assets in the Cooper-Eromanga Basin (NE South Australia and SW Queensland) and Surat-Bowen Basin (SE Queensland). Bridgeport is a wholly-owned subsidiary of New Hope Corporation Ltd, an ASX-listed resources company.

CGG

Booth Number 65 and 66
Web: www.cgg.com

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Booth Number 78
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CoRMaGeo Instruments Pty. Limited

Booth Number 9
Web: www.cormageo.com.au

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Web: www.dataco-global.com

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Web: www.dmt-group.com

DMT provides geophysical services and is one of the leading geophysical instrument suppliers for exploration and monitoring.

DownUnder GeoSolutions

Booth Number 44
Web: www.dug.com

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Earth Signal Processing Ltd.

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Web: www.earthsignal.com

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ElectroMagnetic Imaging Technology Pty Ltd

Booth Number 98
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Fender Geophysics

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Web: fendergeophysics.com.au

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First Quantum Minerals Ltd

Sponsor

Web: www.first-quantum.com

First Quantum Minerals operates seven mines globally, developing three more in Panama, Peru, and Argentina. The company focus is on porphyry and sediment-hosted copper.

Gap GeoPhysics

Booth Number 23
Web: www.gapgeo.com

Gap GeoPhysics develops advanced geophysical technologies and provides services to the exploration, environmental and ordnance detection industries.

GBG Group comprising GBG Australia Pty Ltd/ GBGMAPS Pty Ltd

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Horizon Oil is headquartered in Sydney, Australia and is listed on the Australian Securities Exchange (ASX code: HZN).

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MALA GPR Australia is the authorised exclusive distributor of MALÅ Geoscience Ground Penetrating Radar instruments and ABEM products in Australia.

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PESA

Host

Booth Number F8
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The Petroleum Exploration Society of Australia is a non-profit association of individuals involved in the exploration of oil and gas.

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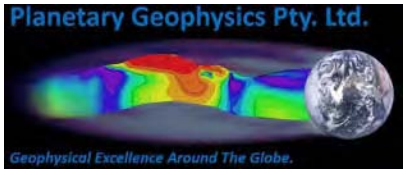

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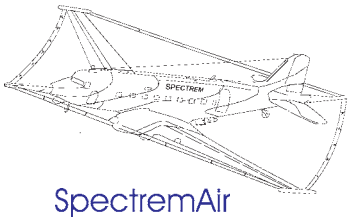
SGC is a group of highly experienced geophysicists based in Perth, WA, providing independent, specialised consulting services to the mineral and petroleum exploration industries globally.

SPECTREM AIR



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TERREX SEISMIC

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The Australian Society of Exploration Geophysicists

Host

Australian Society of
Exploration Geophysicists

Booth Number F9
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Regional Australian offices in Western Australia and Tasmania, as well as in Africa and Asia assist Thomson Aviation to now routinely fly geophysical surveys around the world.

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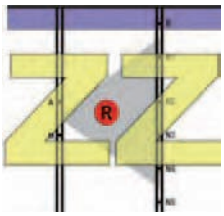

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GEOSCIENCE AUSTRALIA

We are Australia's pre-eminent public sector geoscience organisation and the nation's trusted advisor on the geology and geography of Australia. We are a proud Opal sponsor of the AEGC.

One of Geoscience Australia's key priorities is leading the **Exploring for the Future** program to identify potential resources across northern Australia. This includes:

- **Minerals:** identifying areas with the greatest potential for various mineral deposits
- **Energy:** exploring sedimentary basins to better understand the potential for oil and gas resources
- **Groundwater:** assessing the location, quantity and quality of potential groundwater resources.

This $100.5 million Australian Government initiative will deliver new pre-competitive data and information in areas where the resource potential is poorly known. This will enable industry to explore and invest in Australia with confidence, and inform policy and planning decisions within government.

Geoscience Australia has already collected a range of valuable data across northern Australia and parts of South Australia, in collaboration with state and territory partners. By 2020, the Exploring for the Future program will provide publicly available information that gives a holistic picture of the potential mineral, energy and groundwater resources available in those regions.

www.ga.gov.au/eftf

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Geoscience Australia

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SECTION 3
ABSTRACTS

Australian Society of Exploration Geophysicists

PESA Petroleum Exploration Society of Australia

AUSTRALIAN INSTITUTE OF GEOSCIENTISTS

BOLDLY GO...

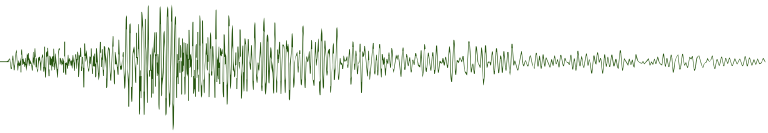
Bridgeport Energy Limited is an active exploration & production company led by an energetic management team with over 150 years of combined petroleum expertise in Australia and around the world. Bridgeport is a wholly owned subsidiary of New Hope Corporation, a proud Australian resource company.

The company has been operating petroleum exploration, development and production projects in Australia for the past 9 years. With over 160 wells currently under direct management and over 12,000 km2 of high working interest exploration acreage, we are an established operator and explorer in the Cooper-Eromanga and Surat Basins.

Bridgeport is actively looking for interested parties to participate in an exciting exploration program with seismic acquisition and drilling slated for later this year. **For more information about these opportunities please visit our team at the AEGC 2018 Exhibition (booth 39), Sydney International Convention & Exhibition Centre.**

Bridgeport ENERGY
A New Hope Group company

To learn more about Bridgeport Energy visit www.bridgeport.net.au or email cfink@bridgeport.net.au



Monday 19 February 2018

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1A COAL

COAL IN NSW

*Kevin Ruming**
Geological Survey of NSW
*kevin.ruming@industry.nsw.gov.au

Coal was first recorded in NSW in the late 1790s and first mined in Newcastle in 1799. 85 tons were exported from Newcastle to England in 1805 and today Newcastle is the largest coal export port, shipping approximately 170 million tonnes in 2015–2016, primarily to Asia. Approximately 25 different product specifications of high quality thermal and metallurgical coal are now sold, representing around 80% of the total value of NSW mineral production.

The world class coalfields of NSW were laid down in Gondwana during three periods of coal measure formation. The occurrence of numerous volcanic ash beds (tuffs) throughout these coal measures and the advent of chemical abrasion-isotope dilution thermal ionisation mass spectrometry (CA-IDTIMS) provided the opportunity to acquire a new dataset for use not only in coal geology but in broader basin studies.

CA-IDTIMS has revolutionised U–Pb dating of zircon with a high level of precision and accuracy (less than 100 K for a 255 Ma date). A project commenced in 2010 to accurately determine the ages of tuffaceous sediments of the eastern Australian sedimentary basins. The project, still ongoing, is headed by Geoscience Australia with support from the Geological Survey of NSW, industry and universities.

The project has delivered 146 age dates with more in progress. These data have been used to constrain stratigraphic correlations and sedimentation rates, improve the understanding of basin evolution and permitted an improved calibration of biostratigraphic schemes to the numerical time-scale.

These new age data and advances in the understanding of basin geology can be applied to coal exploration. However, in the context of the current debate about the future of coal and forecasts of an increasing decline in global coal demand – is more exploration needed?

Coal played an important part in the Industrial Revolution. It provided most of the energy for steam engines – a key source of industrial power. Coal was also a key manufacturing material, enabling the economic production of large volumes of iron and steel.

The term ‘Renewable Energy Revolution’ is increasingly used to describe the transition of the global energy mix from a reliance on fossil fuels to a mix based on renewable energy. Just as in the Industrial Revolution, coal will play an important role in a successful transition. Coal is still a key material in the manufacture of iron and steel – crucial to the entire supply chain of renewable energy infrastructure – from the mining of the raw materials to the delivery of finished wind turbines, solar panels and battery storage. Coal will continue to be an important source of base load power, as the energy transition continues, over the coming decade.

DISCOVERY THROUGH THE AGES – A JOURNEY OF COAL RESOURCE DISCOVERY IN QUEENSLAND’S BOWEN BASIN FROM THE 1960S AND THE 2000S

Lex Hansen[1] and Darren Walker[2]**
[1]lex.w.hansen@gmail.com
[2]U&D Coal Ltd
*darren.walker@udmining.com.au

Exploration methods, technology and equipment may have changed greatly over the last few decades but still does not replace sound geological principles in making new coal resource discoveries. Starting with a case history of the early big discoveries in the Bowen Basin, Central Queensland, author and co presenter Mr Lex Hansen will provide an overview of the methods, techniques, equipment and successes of exploration during the early 1960s in the Bowen Basin.

Mr Hansen was a member of the team of three geologists working for Utah Development Company (purchased by BHP Ltd in the 1980s) that made the first big coking coal discoveries in the Bowen Basin extending from Blackwater in the south along the western side of the Basin to Goonyella in the north. The majority of these discoveries are still in production today, some 50 years later.

These will then be contrasted with a more recent case study involving greenfields discoveries at the Meteor Downs and Rockwood Projects as well as the world class brownfields coking coal discovery at Saraji East, located also in the Bowen Basin Central Queensland. This will provide a unique opportunity as to recent coal exploration methodology, technology and successes. Co-author and co-presenter Mr Darren Walker led the teams responsible for these discoveries.

The authors will then contrast and compare exploration from the ‘then’ and ‘now’ and discuss the importance of ‘grass roots’ geological field work, data analysis and principles in successful exploration regardless of the perceived exploration or resource maturity of a mineral province.

THE USE OF FWI IN COAL EXPLORATION

Mehdi Asgharzadeh and Milovan Uorosevic*
Curtin University, Perth, Western Australia
*mehdi.asgharzadeh@curtin.edu.au

3D reflection seismic is routinely used for a precise structural mapping of coal seams in Australia. Seismic images are used to analyse and predict underground hazards such as faults and folds, week strata, gassy zone, etc. Structural analysis of 3D seismic images is then utilised to help plan underground mining operations. While time seismic images are of a high quality; issues with depth conversion, fault through estimate, coal quality, presence of fractured and gassy zones, week strata, etc. are still to be fully resolved from seismic images. A step change in solving these issues could happen by incorporating Full Waveform Inversion (FWI) into seismic borehole and surface imaging flows. The seismic data quality in Bowen and Sydney basins is such that FWI could be applied over a wide frequency

band to produce high resolution P-wave and more importantly density images, particularly from VSP data that can be used for both depth imaging and directly for coal characterisation. We evaluate the potential of FWI for coal exploration in Australia by conducting comprehensive, log-derived simulation studies.

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1B WEST AUSTRALIAN BASINS SYMPOSIUM

HIGH IMPACT DATA CREATES HIGH IMPACT OPPORTUNITIES

*Peter Baillie**
CCG, Perth
*peter.baillie@cgg.com

Modern developments in seismic imaging integrated with traditional geological methods have created exciting new exploration opportunities in areas traditionally considered frontier and low prospectivity or mature with very limited opportunities for significant new discoveries.

Extreme examples are presented, from opposite ends of the Australian continental plate and in vastly different tectonic regimes, illustrating the opportunities this new approach offers.

The horseshoe-shaped Banda Arc, north of Australia, has long been of interest to the exploration community because sedimentary rocks outcropping within islands of the region are essentially the same as those occurring on Australia's Northwest Shelf. Abundant oil and gas seeps on these islands, together with deep-sea seeps, attest to a working petroleum system in the area.

The Banda Arc (in reality an arc in the geometric not the geological sense), defined by two strongly curved, sub-parallel ridge systems with intervening troughs, is the site of collision between the northwards-moving Australo-Indian (continental/oceanic) Plate, the SW-moving oceanic Pacific Plate and the (relatively stable) southern promontory of the continental Asian Plate known as Sundaland. The present-day complex geology results from two opposing tectonic forces: northwards movement of the Australian Plate and sinistral shear on the Greater Sorong Fault System (the plate boundary between the Australian and Pacific plates).

Interpretation of new broadband seismic data and detailed geoscientific analysis has significantly improved understanding of geological development of the area.

Geological development has occurred in several distinct phases:

- Formation of a jagged passive margin (non-volcanic with hyperextension) and generation of oceanic crust in late Jurassic times.
- Cenozoic subduction of the Jurassic oceanic crust; slab rollback from about 15Ma.
- Arrival of continental crust into the subduction system around 10Ma, partial subduction until the system jammed, together with fold-and-thrust belt formation and the development of foredeeps (Timor, Tanimbar and Seram troughs) developed in front of the active fold-and-thrust belts.
- Continuing slab-push from the mid-ocean ridge (far) to the south resulting in widespread strike-slip faulting and wrench basin formation together with some obduction and isostatic rebound.

It is believed that the region is in the initial stages of orogenesis, comparable to the Eocene "soft collision" of Greater India with Asia which ultimately resulted in the formation of the Himalayas.

The Gippsland Basin in southeastern Australia is one of Australia's most prolific hydrocarbon systems, having historically generated approximately two thirds of the country's cumulative oil production and one third of its gas.

The basin has a long and proud history – 1964 Esso took over as operator of a joint venture with BHP and spectacular exploration successes followed.

The creaming curve for the basin is essentially flat since the mid-1970s, with no significant kick from either the application of 3D or deepwater success (as has occurred in many other basins of the world). While it could be argued that the curve flattened because the big discoveries have all be made, it could also be argued that imaging problems have masked significant opportunities.

Imaging issues in the basin have long been known: challenges include limited resolution at reservoir level, distortion from shallow complex overburden and poor imaging in the deep section.

Significant new exploration opportunities in the basin have been generated by a major reprocessing project involving application of several technologies. Technologies used include broadband processing, Full Waveform Inversion (FWI) and least squares Q PSDM (LSQPSDM).

Prospects with the potential to contain several trillion cubic feet of gas have been generated, highlighting the impact of enhanced imaging.

MAPPING NORTHERN AUSTRALIA'S PRESENT DAY STRESS FIELD: THE CANNING BASIN

Adam Bailey and Paul Henson*
Geoscience Australia, Canberra, ACT
*adam.bailey@ga.gov.au

The Canning Basin is one of Australia's most prospective onshore petroleum basins, with proven petroleum systems and current production from conventional reservoirs. However, the majority of recent interest has been in unconventional hydrocarbons within the deeper basin depocentres, particularly the Ordovician Goldwyer Formation and the Lower Carboniferous Laurel Formation. Understanding the regional stress regime and geomechanical properties of reservoir units are some of the critical factors required to determine the basin's unconventional resource potential. Fluid flow pathways within the sub-surface units in unconventional plays are controlled by local and regional stresses and so understanding the present-day stress regime is integral to modern petroleum exploration and production. This study characterises the regional stress regime within the Canning Basin using existing well data and well tests to derive stress magnitudes and forms part of a greater effort from Geoscience Australia to understand the present-day stress field of northern Australia.

Generally, interpreted stress magnitudes in the Canning Basin indicate a strike-slip faulting stress regime. However, one-dimensional mechanical earth models constructed from dipole

sonic data indicate a consistent transition from strike-slip to normal faulting with depth, as well as limited local transitions to both normal and thrust faulting primarily due to significant local variations in vertical stress magnitude due to varying carbonate thickness and localised uplift, but also as a result of lithology. Borehole failure features interpreted from wellbore image logs yield an approximately NE–SW striking maximum horizontal stress azimuth with noticeable variations that are attributed to local stress perturbations.

REGIONAL JURASSIC SEDIMENT DEPOSITIONAL ARCHITECTURE, BROWSE BASIN: IMPLICATIONS FOR PETROLEUM SYSTEMS

Nadège Rollet[1], Dianne Edwards[1], Emmanuelle Grosjean[1], Tehani Palu[1], Lisa Hall[1], Chris Boreham[1] and Andrew Murray[2]*
[1]Geoscience Australia
[2]Murray Partners PPSA Pty Ltd
*nadege.rollet@ga.gov.au

The Browse Basin hosts considerable gas and condensate resources, including the liquefied natural gas (LNG) developments at Ichthys/Prelude and Concerto fields. However, oil discoveries have been sub-economic and confined to the Caswell Sub-basin and Yampi Shelf. This multi-disciplinary study has mapped the hydrocarbon sources and areas of increased liquids prospectivity within the gas-prone basin.

Isochore maps and depositional models suggest multiple Jurassic and Cretaceous source rock units in compartmentalised pods, resulting in four geochemically distinct petroleum systems.

Organic-rich shales of the Upper Jurassic–Lower Cretaceous J40–K10 supersequences (Vulcan Formation) are believed to have sourced the gas in the encasing K10 sandstone reservoir (Brewster Member) in the Ichthys/Prelude and Burnside accumulations, and potentially other similar plays in the southern Caswell and Oobagooma sub-basins.

The gas sourced by the Lower–Middle Jurassic J10–J20 supersequences (Plover Formation) has assisted migration toward the basin margin, and is reservoired within the J10–J20 supersequences on Scott Reef Trend, the K10 supersequence in the Ichthys/Prelude field, and the shallow Lower Cretaceous K40 supersequence on the Yampi Shelf.

The Jurassic J10–J50 supersequences (Plover and lower Vulcan formations) in the Heywood Graben have generated fluids with a unique composition within the basin, and resemble a petroleum system in the Bonaparte Basin. These data integrated into a pseudo-3D petroleum systems model identified liquid-prone plays in the southern and northern Caswell Sub-basin, on the basin margins and in the Heywood Graben.

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1C EAST AUSTRALIAN BASINS SYMPOSIUM

TECTONICS AND GEODYNAMICS OF THE EASTERN TETHYS AND NORTHERN GONDWANA SINCE THE JURASSIC

Sabin Zahirovic[1], Daniela Garrad[2], Gilles Brocard[1], Jeremy Iwanec[2], Kevin Hill[3], Nicolas Flament[4], Rakib Hassan[5], Michael Gurnis[6] and R. Dietmar Müller[7]*
[1]EarthByte Group and Basin GENESIS Hub, School of Geosciences, University of Sydney
[2]Oil Search, Sydney
[3]School of Earth Sciences, University of Melbourne
[4]School of Earth and Environmental Sciences, University of Wollongong
[5]Geodesy and Seismic Monitoring Branch, Geoscience Australia
[6]Seismological Laboratory, California Institute of Technology
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The tectonic and geodynamic evolution of the eastern Tethys since the Jurassic drove the opening of important hydrocarbon-bearing basins and emplacement of ore deposits on the northern margins of Gondwana and the southern margins of Eurasia. However, the geological record of these events is obscured by multiple subduction and collision events in equatorial regions where weathering and inaccessible geography has led to poor data coverage. We synthesise constraints from the geology to create end-member global plate motion models with regional refinements for Southeast Asia and the New Guinea margin using the open-source community GPlates software. The plate reconstructions are applied as boundary conditions in forward numerical models of mantle convection using CitcomS, with present-day mantle structure predictions validated using P- and S-wave seismic tomography. This approach enables us to use the deep Earth as an additional constraint to help refine the chronology of major rifting, subduction and collisional episodes. Our results suggest that the Philippine Arc and the Sepik terrane rifted from the Gondwana margin through slab rollback and back-arc opening processes. The Sepik back-arc basin was consumed from the Late Cretaceous, with accretion of the Sepik composite terrane occurring sometime in the Eocene (~52 to 35 Ma). The sinking of the Tethyan and Sepik slabs beneath the northward-moving Australian continent also modulated the regional topography that results from convection in the mantle. This evolving dynamic topography forms an important input for surface process models that provide insights into the depositional history of basins in New Guinea and Australia.

PREDICTING AND DETECTING CARBONATE CEMENTED ZONES WITHIN LATROBE GROUP RESERVOIRS OF THE GIPPSLAND BASIN

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A wireline log model predicts carbonate cemented zones within Late Cretaceous to Paleocene reservoir sandstones of the Latrobe Group, Gippsland Basin. Predictions match published evidence. These sandstones were once heavily cemented prior to development of secondary porosity that produced the world-class petroleum reservoirs we see today. Cemented zones that remain must act as obstructions to reservoir fluid migration. They may also react with the mild carbonic acid that will be introduced by CO_2 storage operations of the future. Model predictions show that cemented zones are sparse, spatially sporadic and fall well below seismic resolution at modern-day reservoir depths. Their significance and irregular spatial occurrence mean there is a need to map their distribution.

Synthetic seismograms generated for a number of Gippsland Basin wells predict high amplitude seismic reflectors away from major lithostratigraphic boundaries. Many occur where cemented zones are predicted. An investigation of the complex seismic trace demonstrates seismic sensitivity to these zones in the frequency range 100–125 Hz. An elevated moving average of instantaneous frequency correlates with some of them. Others are indicated by a change in the difference of normalised instantaneous amplitude between the original frequency-filtered complex trace and a frequency-filtered complex trace composed of sinusoids with the same magnitude and phase (arithmetic averages of the original complex trace). These subtle phase disturbances at high seismic frequencies are hypothesised to be caused by the presence of thin cemented zones. This idea is tested using instantaneous attributes of 3D seismic survey data available across the Gippsland Basin.

IMPACT OF SEQUENCE STRATIGRAPHIC FRAMEWORK ON STATIC AND DYNAMIC RESERVOIR MODELS: EXAMPLES FROM THE PRECIPICE-EVERGREEN SUCCESSION, SURAT BASIN, QUEENSLAND

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CO_2 storage in the subsurface is a key aspect of climate mitigation. The UQ is investigating whether the Precipice Sandstone and Evergreen Formation in the Surat Basin, Queensland, are an appropriate reservoir-seal pair for the long-term storage of greenhouse gases. However, the Precipice-Evergreen succession remains poorly constrained from a paleo-depositional and stratigraphic standpoint. Studies have mostly applied lithostratigraphy for local correlation, and the understanding of time-stratigraphic relationships across the basin needs development. This has greatly hindered the capacity to construct robust reservoir models and is an active area of research.

We utilised core, wireline logs, seismic data, as well as pressure data to compare the dynamic response to various CO_2-injection scenarios with contrasting stratigraphic architectures. A lithostratigraphic prediction of reservoir and seal intervals in the Myall Creek area, consisted of a layer-cake model of fluvial channel deposits. The model suggests that reservoirs are well connected with the gas plume primarily migrating in the lateral direction. In contrast, a sequence stratigraphic arrangement of facies resulted in greater reservoir compartmentalisation with some vertical fluid transmission across certain play segments. This is due to the fact that mudstone intervals baffle the CO_2 plume and compartmentalise the reservoir. The contrasting models show different geological realisations arising from the same dataset, interpreted in different ways.

Fluid flow is highly sensitive to the stratigraphic arrangement of reservoir intervals. Refining static and dynamic models using sequence stratigraphy results in a significant improvement in history matching. Modelers should carefully consider the implications of stratigraphic correlations during static model construction.

ORGANIC GEOCHEMISTRY AND PETROLEUM POTENTIAL OF OUTCROP AND CORE SAMPLES OF THE PERMIAN IN THE SOUTHERN SYDNEY BASIN

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Permian sediments occur throughout the southern Sydney Basin, exposed on the coastline south of Wollongong, and penetrated by various boreholes. This study uses outcrop samples and samples from three boreholes held by NSW Resources and Energy at the core library at Londonderry (Callala-1 from near Callala Bay, Elecom Clyde River DDH7 from near Nowra, and Elecom Clyde River DDH1 from near Wingello). Formations analysed include the Berry Siltstone, Nowra Sandstone, Wandrawandian Siltstone, the Snapper Point Formation, the Pebbley Beach Formation and the Yarrunga Coal Measures. The objectives are to determine the depositional environment, organic matter inputs, thermal maturity and petroleum generation potential of these formations, which were deposited when Australia was close to the South Pole. The rocks are thermally mature and were deposited in oxic to suboxic depositional environments. The Wandrawandian Siltstone contains biomarkers dominated by very high amounts of diahopanes and diasteranes, whereas these biomarkers are of lower relative abundance in the other formations. This is suggestive of a clay-rich sediment in an oxic, acid-catalysed depositional environment, with enhanced diagenetic alteration of the biomarkers, or alternatively an unusual organic input. The Pebbley Beach and Snapper Point formations are characterised by biomarker distributions dominated by terrestrially sourced terpanes (e.g. C_{24} tetracyclic terpane; C_{19} tricyclic terpane), corroborating their deltaic and shallow marine depositional environments, respectively. In contrast, the Wandrawandian Siltstone contains dominantly C_{21}, C_{23}, and C_{24} tricyclic terpanes. The Pebbley Beach Formation contains high amounts of C_{29} relative to C_{28} and C_{27} steranes, also consistent with a dominant terrigenous input.

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1D GEOLOGY CASE HISTORY

LITHOGEOCHEMISTRY OF PEGMATITES AT BROKEN HILL: AN EXPLORATION VECTOR TO MINERALISATION

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Pegmatites hosted in granulite and upper amphibolite facies metamorphic rocks are leucogranites, quartz-feldspar-mica or feldspar-rich pegmatites. These locally form large, sill-like, largely stratabound complexes within the lower part of the Willyama Supergroup. They are interpreted to have formed during anatexis and considered to be mostly *in situ*.

Those hosted in lower grade amphibolite and greenschist facies rocks are feldspar poor and quartz-muscovite rich, with tourmaline on their margins and as replacements of the surrounding protolith. They are volumetrically smaller than anatectic pegmatites and intrude and alter psammo-pelitic sequences in the upper parts of the Willyama Supergroup.

Data suggests a geochemical continuum from poorly evolved pegmatites hosted in high grade metamorphic rocks, lower in the stratigraphy, to more highly evolved types hosted in lower grade metamorphic rocks located in the upper parts of the stratigraphy.

Economic element content is similarly divided into two broad end-members. High grade metamorphic rocks host elevated Pb-Zn-Ag-Mn whereas lower grade metamorphic rocks host Sn-W mineralisation and elevated incompatible elements; Li-Nb-Cs-Rb-Tl-Ga-Ta.

We attribute elevated base metals in anatectic pegmatites to the enriched nature of those elements in the host protolith; the Broken Hill Group, the primary host to the Broken Hill Pb-Zn-Ag deposits and numerous BHT occurrences. In contrast, we attribute the Sn-W and incompatible element-enriched pegmatites to fractionation processes.

Exploration using systematic pegmatite geochemistry has the potential to enable vectoring toward buried BHT deposits in high grade metamorphic rocks. Similarly, the potential for Sn-W deposits and/or LCT (lithium-caesium-tantalum)-bearing pegmatite can be assessed in lower grade rock.

ORE AND GANGUE MINERALS OF THE HERA AU-PB-ZN-AG DEPOSIT, COBAR BASIN, NSW

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The Hera Au-base metal deposit, 5 km southeast of Nymagee, central New South Wales is on the eastern margin of the Palaeozoic Cobar Basin within the Lachlan Orogen. Discovered by Pasminco in 2001, the current total resource is 2.7Mt @ 4.1 g/t Au, 34 g/t Ag, 3.67% Pb and 4.86% Zn. The deposit occurs in a strongly altered and deformed sequence of shelf and turbiditic siltstones and fine-grained sandstones, members of the Nurri and Amphitheatre groups, with the majority of mineralisation occurring in the latter.

Ore minerals comprise pyrrhotite–sphalerite–galena ± chalcopyrite ± pyrite ± cubanite ± arsenopyrite ± tetrahedrite ± native Sb ± gudmundite, gold and scheelite occurring as massive and disseminated sulfides in vein/breccia zones. The main sulfides have composition as follows: pyrrhotite 60.5 wt% Fe and 38wt% S with traces of Co, Pb, Bi, Sb and Zn; sphalerite 56.4 wt% Zn, 8.9 wt% Fe, 33.5 wt% S, and traces of Pb and Bi; galena 86.4 wt% Pb and 13.4 wt% S with traces of Fe, Bi and Zn. Major gangue minerals consist of quartz, chlorite, biotite, and muscovite, with minor carbonate, actinolite/tremolite, Ca-rich garnet and rare titanite and fluorite. Relatively coarse-grained albite–quartz–chlorite rocks were recently discovered; however, their significance and emplacement mechanism is as yet unknown. The occurrence of skarn-like assemblages and albite-quartz-chlorite rocks suggests that at least some of the lodes at Hera differ significantly from typical sediment-hosted 'Cobar-style' deposit as previously suggested. This is also supported by field observations, petrographic analysis and XRD and shows that the host rocks have been metamorphosed to upper greenschist to lower amphibolite facies.

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1E IP FROM EM SURVEYS

MODELLING IP EFFECTS IN AIRBORNE TIME DOMAIN ELECTROMAGNETICS

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The presence of chargeable material can significantly impact the data in electromagnetic (EM) surveys. This affected data has traditionally been treated as noise that must be removed prior to interpretation or inversion. The ability to extract induced polarisation (IP) information from an airborne platform would be a valuable tool in the mineral exploration industry and the

pursuit of this ability has recently led to significant interest in the interpretation of IP effects in airborne data. A variety of interpretation methodologies have been proposed to aid in the identification and extraction of information from time domain EM data containing IP effects.

Any interpretation scheme needs to be thoroughly tested on realistic synthetic examples so that the strengths and weaknesses of the method are well understood. In this work, we present a methodology for accurately and efficiently simulating the response of a time domain EM experiment by modelling the convolution that occurs in Ohm's Law in the presence of a frequency dependent conductivity. This method is free of any assumptions about the dimensionality or frequency dependence of the chargeable material and can be used to simulate the response of any time domain system. The importance of considering the problem in three dimensions is demonstrated, and the problems that could arise from working with a reduced dimensionality are demonstrated.

A THOROUGH SYNTHETIC STUDY ON IP EFFECTS IN AEM DATA FROM DIFFERENT SYSTEMS

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IP effects in AEM data are subject of current research around the world, due to the recent recognition of their significance for exploration and general (hydro)geological mapping. There is however a need to study more accurately the boundaries of the effect and of its relevance. In this paper we present, based on synthetic modelling, a systematic, extended analysis of AIP effect from different AEM (TEM) systems in different pseudo geologies. Its goal is to provide a clear overview of possible AIP effects in the data space, without imposing simplistic assumptions (e.g. fixing some parameters to arbitrary values or limited boundaries). We produce 1D FWD responses with dispersive resistivity for hundreds of thousands of combinations of Cole–Cole model parameters and AEM system transfer functions. The results are analysed using various metrics (e.g. sum of negative voltages, exponential fitting) that capture different AIP signatures in the transients. Experiments include half spaces, 2 and 3 layer models, combined with different waveforms, Rx types (dB/dt and B), Tx–Rx geometries, flying heights, transients' binning, base frequencies. The results, presented as 4D hyperspaces, each with 10^4 transients obtained from the combinations of 4×10 different Cole-Cole parameters, allow a clear assessment of the AIP effects over a wide range of geophysical situations. Some of the main observations are: AIP effects are increased by the presence of a resistive bedrock, using slow turn-off of the waveform and better observed recording the B field instead of its derivative and in any case adopting low base frequencies.

AIRBORNE EM AND IP BELOW 10 HZ

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Most good time domain AEM systems use a base frequency at or above 25 Hz. This keynote describes progress towards the development of viable extremely low base frequency 3 Hz base frequency airborne system. Suspended vector magnetic field sensors, whether B or dB/dt, rotate in the earth's magnetic field and pick up large unwanted signals, often called 'motion noise'. It is this low-frequency noise that has in the past constrained commercial AEM systems to operate at base frequencies of 25 Hz or more. There are four conceptual mechanisms to improve signal/noise ratios in an AEM system: increase transmitter dipole moment by several orders of magnitude, engineer more stable suspension systems, make rotation measurements and correct the measured B field response, or devise new waveforms and processing strategies that better separate and reduce noise levels.

Power supplies and weight constraints are close to their limit in appropriate aircraft, implying that increasing dipole moments by an order of magnitude or two is impossible using current technology. Most research effort by contractors has addressed suspension systems, with limited successes reported to date. The BIPTEM (B field IP; Time domain EM) system currently under development in Australia has used a combination of rotation rate sensing, waveform optimisation and an improved suspension to collect useful inductive magnetometer B and dB/dt field data at extremely low base frequencies, and been successfully tested over known IP targets.

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1F INVERSION MODELLING METHODS

COOPERATIVE INVERSION: A REVIEW

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Cooperative inversion is increasingly recognised as having the potential to significantly improve subsurface imaging for a range of parameters. However, there is no doubt success or failure is also highly dependent on a good knowledge of the underlying site specific geological and petrophysical relationships. Combinations of structural or textural seismic attributes can be used with geostatistical clustering methods to provide a framework able to carry inversion of lower resolution EM or potential field data to much higher resolution. Cross gradient type methods use direction of change of petrophysical parameters as a lever to push inversion towards an improved outcome. But again, the outcome is highly dependent on the presumption that the direction of change of petrophysical parameters like velocity and electrical conductivity are somehow linked. We need some way to build relationships between petrophysical parameters which could come in the form of new multiscale, multiparameter measurements made during drilling. We will: (1) examine theoretical possibilities; (2) give examples

of practical successes and failures; and (3) consider the future of cooperative inversion.

APPLICATION OF GEOLOGICALLY CONDITIONED PETROPHYSICAL CONSTRAINTS IN JOINT INVERSION: A CASE STUDY

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Quantitative integration of geology, petrophysics and geophysics in a single inversion scheme is a complex, yet theoretically powerful method to solve challenges faced in exploration scenarios. In this work, we present a case study illustrating the improvements in subsurface imaging and uncertainty reduction brought by the integration of probabilistic geological modelling and petrophysical constraints in three-dimensional geophysical joint inversion. The area investigated is located in the Yerrida Basin (Yilgarn Craton, Western Australia). The main difficulty encountered by previous studies was to characterise the thickness of the overburden, thought to be in contact with a potentially mineral-rich basement. Using gravity and magnetic data, results show that the use of constraints derived from the statistics of petrophysical measurements in inversion permits to retrieve sharp contrasts and to delineate geological units directly. The use of probabilistic geological modelling to condition the petrophysical constraints allows to (1) refine the inverted model by enforcing geological consistency, and (2) reduces the impact of inversion's inherent non-uniqueness. Finally, statistical and structural analysis of the results suggest that areas previously considered too uncertain may show good prospectivity, highlighting areas for future exploration targeting.

CONSTRAINING AN INVERSION TO FOLLOW CURVING TRENDS IN AN IMAGE

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This paper addresses the question of how to include structural information, for example from a magnetic image, into an airborne electromagnetic (AEM) inversion.

The kind of information we are interested in is the trend directions seen in the magnetic image, such as strike directions of dipping bodies, or the shape of palaeochannels.

A commonly-used technique for including prior information is to use a model covariance matrix, describing the spatial covariance between different model points. However, these covariances are usually constructed from a stationary covariance function which is dependent on the vector distance between two points, but is the same for the entire model. However, if a palaeochannel is visible in the magnetics, then we know that the AEM model is more likely to be similar along the channel than away from the channel. We therefore wish to construct a covariance matrix that can take curved and branching structure into account.

We construct an inhomogeneous covariance matrix from an image by breaking the image up into multiple windows, and then computing an elliptical distance metric in each window, such that distances in the direction of the features in that window are shorter than distances across those features. This collection of distance metrics then allows us to compute, between any two points in the image, a shortest path that curves to follow the directions of trends in the image. Using this curved-path distance allows us to generate a covariance matrix that encourages the inverted model to follow the trends in the image.

EXPLORING INVERSION SOLUTION SPACE: A CASE STUDY OVER A CU-AG DEPOSIT IN THE KALAHARI COPPER BELT

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Interpretation of geophysical data remains an extremely challenging task in spite of improvements in instrumentation, acquisition, inversion and visualisation. The root cause of this difficulty is well known: different earth manifestations can give rise to the same geophysical response. Given this root cause it is inescapable that any workflow based solely on inverting geophysical data to produce a single earth model is incomplete at best, and at worst, misleading. To reduce this incompleteness we recommend extending the usual process of inversion yielding a single model to include an exploration of the solution space of models all of which give rise to the same geophysical observations. As an illustration we present an inversion case study revolving around a 3D DCIP data set obtained over the recently discovered T3 Dome Cu-Ag deposit in the Kalahari Copper Belt (KCB) in Botswana. We explore the inversion solution space using a suite of models produced by introducing various constraints. In our study standard unconstrained inversion yields a deep smooth chargeability model however drilling results appear to suggest a different chargeability distribution. The exploration question becomes: how robust is the deep chargeable target, is it indicative of new sulfides or is it a manifestation of model equivalence? We demonstrate how to attack such problems, which leads us to suggest that by default all geophysical inversion algorithms should produce several equivalent models to help move the exploration community beyond the idea that a single inversion result is 'the model'.

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1G REGIONAL TECTONIC

PALAEOMAGNETIC TEST OF OROCLINAL ROTATION IN THE DUNDAS TROUGH, TASMANIA

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Palaeozoic units of the Dundas Trough in western and northern Tasmania, which include the richly endowed Mount Read

Volcanics, form an arcuate trend in outcrop and aeromagnetic images, wrapping around the Pre-Cambrian Tyennan region. Previous interpretations attributed the arcuate shape to sedimentation in pre-existing curved rift and graben systems, without rotation. New studies have reinterpreted the Trough as the result of oroclinal rotation of a former linear orogen. Palaeomagnetic samples were collected from selected early Palaeozoic sedimentary sequences at 22 localities around the Dundas Trough and correlative formations in the Adamsfield–Jubilee region. Low-temperature and thermal demagnetisation was conducted on most samples with selected units also demagnetised with the alternating field technique. From the 22 localities sampled, 11 produced clear demagnetisation results. Principal component analysis was used to determine characteristic remanent magnetisation (ChRM) directions.

Oroclinal rotation was tested by plotting ChRM declinations against regional strike (the 'palaeomagnetic orocline test'). Declination correlates with strike, verifying the orocline hypothesis. Average declinations in the north-east limb of the trough (Dm 97.2°, Im 36.2°) suggest a clockwise rotation ~90°. A paleomagnetic pole determined from the western limb of the trough falls on the early Palaeozoic Gondwana apparent polar wander path, confirming that this limb was fixed to cratonic Australia.

These results both confirm the oroclinal curvature of the Dundas Trough, implying its continuation under Jurassic cover in eastern Tasmania, and more broadly support the hypothesis that oroclines played a fundamental role in crustal accretion in eastern Australia.

MAPPING METASOMATISED MANTLE BY INTEGRATING MAGNETOTELLURIC, PASSIVE SEISMIC AND GEOCHEMICAL DATASETS – SE AUSTRALIA

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There is growing evidence that the distribution of giant magmatic and hydrothermal ore deposits are linked to the presence or absence of metasomatised lithospheric mantle. It follows that mapping the distribution of this mantle should be an important component of exploration programs for world class deposits, yet to date there has not been a robust means of spatially constraining the distribution of metasomatised mantle. Classically, metasomatism has been identified through petrological and geochemical analysis of mantle xenoliths and mantle derived melts which provide information on the vertical distribution of metasomatism beneath magmatic centres. Here, we show this classical information integrated with constraints on lithospheric thickness and conductivity, derived from passive seismic and magentotelluric imaging of the lithosphere provide an effective means of mapping both the lateral and vertical distribution of mantle metasomatism. As a case study we show the integration of the aforementioned datasets over south-eastern Australia where the Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP) was started.

GEOSCIENCE AUSTRALIA'S CONTRIBUTION TO AUSARRAY – PASSIVE SEISMIC IMAGING OF AUSTRALIA

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Geoscience Australia (GA), as a part of the exploring for the future program, is aiming to create a high resolution three-dimensional (3D) seismic model of Australia to infer physical properties of the lithosphere from depths of few meters to hundreds of kilometres. This work is based on new data collected from national seismological network and a new movable seismic array complemented by legacy seismological data obtained by universities. GA has deployed a movable array of 135 broadband seismic stations for one year between Mount Isa and Tennant Creek arranged in a grid pattern with interstation distance of approximately 55 km in order to attain horizontal resolution of at least 20 km. This dense network is reinforced by 15 semi-permanent higher sensitivity broadband seismic stations located predominantly in the Northern Territory and Western Australia in order to increase imaging resolution within the array and within areas where national seismological network has gaps. Multiple seismological methods are being combined together to obtain robust constraints on 3D lithospheric architecture. For the first time, particular attention is focused on shallow structures located at depths of less than 1 km.

COORDINATING AND DELIVERING A 1.8 MILLION LINE KILOMETRE MAGNETIC AND RADIOMETRIC SURVEY – A STATE GOVERNMENT PERSPECTIVE

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In January 2017 the largest airborne magnetic, radiometric and elevation survey in South Australia's history began in the Gawler Craton. The aim of the South Australian Government is to use the survey as an opportunity to achieve best practice in relation to the coordination, landholder liaison, reporting and quality control of the survey, in tandem with collaborative partners at Geoscience Australia. Some of the outcomes include a landholder and stakeholder information website, subscriber email updates, close liaison with field capture teams, timely delivery of survey data and results, and a proactive approach in ensuring the data captured is of consistent, high quality across the entire survey region. The survey is been performed in three stages and each stage provides an opportunity to assess approaches and fine tune requirements. It is expected that the end result will set a benchmark for other jurisdictions performing similar work.

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1H GEOTECHNICAL AND ENVIRONMENTAL

TRACKING THE DIPROTODON – MICROTREMOR PASSIVE SEISMIC PROFILING AS A TOOL FOR LOCATION OF MEGAFAUNA BONE BEDS

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Bone beds containing Pleistocene megafauna remains dated to between 35 ka and 60 ka occur near Lancefield (Vic). The bones lie within clays above gravels and extensive Quaternary basalt flows. Evidence that the bones have been subject to alluvial transportation suggests that profiling the basalt basement for paleo-channels will assist with locating further bone beds. Passive seismic (microtremor) methods, as developed variously for earthquake hazard studies and regolith studies, have been applied to this problem, using both H/V methods and two-station SPAC (spatially averaged coherency) methods. Clay layers have shear-wave velocities (Vs) in the range 100–150 m/s and thicknesses 3.5 to 4.5 m. Microtremor data in the frequency band 10–50 Hz provides excellent resolution of the Vs and thickness of the clay layers, allowing the bedrock profile to be established to an accuracy of 0.5 m or better.

AN INTEGRATED ANALYSIS OF GEOPHYSICAL DATA FOR LANDSLIDE RISK ASSESSMENT

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In May 2014, a severe storm caused substantial damage in the Balkan area by floods and landslides. As a contribution of geophysicists and geotechnical engineers to the effort of prevention of further damage, a Geoscientists *without* Borders (G*w*B) project was organised by Association of Geoscientists and Environmentalists of Serbia to assess the potential of further occurrence of landslide in the region. This project was supported by SEG and many other organisations, governments and individuals of many countries. Local and international experts conducted field data acquisition with students from four countries. The project benefited the students to get practical experience in geophysical fieldwork, local governments received information of landslide risk in their area and the residents of the area were made aware of landslide potential of around their home land.

Geophysical surveys with seismic and electric methods were carried out in three phases, June and September 2015 and June 2016, in six locations in Serbia and Bosnia and Herzegovina. About 7000 m of seismic data were acquired at the sites where landslide potential is considered high. A lesser number of electrical surveys were conducted at the same locations. This paper presents some of the results of the geophysical surveys at some of the project areas comparing seismic reflection, MASW and electric resistivity methods, and subsequent assessment of risk of landslide. This information is being used by the engineers of local government in their plan for mitigation of disasters.

THE APPLICATION OF VSP IN THE PILBARA

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The construction of geotechnical models in typical Pilbara iron ore environments is vital to enable an optimised mine design while maintaining pit wall integrity. These models require the measurement of geomechanical properties, such as the modulus of elasticity, in-situ stress, unconfined compressive strength, and pressure and shear wave seismic velocities, from diamond core samples. Ideally these velocities would be measured in Reverse Circulation (RC) boreholes as their spatial density is far higher than diamond drilled holes. Unfortunately, despite its value, such data is seldom collected as a large proportion of the holes are above the water table, limiting the use of sonic-logging tools. Even if measurements are possible, damage to the borehole caused by drilling biases the resulting velocity measurements.

This paper details the results of a trial using the vertical seismic profile method to directly measure *in situ* seismic velocities in RC boreholes. The method was successful in determining the velocities of the formations; which turned out to be lower than those measured directly from core samples. This has implications for the pit designs including pit walls angles and locations, which can affect the cost of mining. The data in several boreholes was of sufficient quality for more advanced processing methods, important for geological mapping and the processing and interpretation of surface seismic data.

The success of this first trial has implications for future iron-ore developments in the Pilbara. The widespread acquisition of accurate seismic velocity data will enable the creation of more accurate geotechnical models and improved development decisions.

APPLICATION OF THE PASSIVE SEISMIC HORIZONTAL OVER VERTICAL SPECTRAL RATIO (HVSR) TECHNIQUE FOR EMBANKMENT INTEGRITY MONITORING

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Embankments are common features in mine sites necessary for tailings storage, surface water management or general infrastructure such as dewatering ponds. Differing construction methodologies, from loosely placed waste material to engineered and individually compacted lifts, will achieve varying density, strength and permeability. Conventional construction quality assurance is however not always possible without causing significant interruptions to the construction program and compromising the embankment integrity. Estimating levees' bulk shear wave velocities via passive seismic HVSR surveying as a proxy for stiffness is a practical, continuous and non-invasive

method that can be carried out with limited construction interruption. This also provides a continuous dataset throughout the embankment as opposed to discrete observations using conventional geotechnical methods.

Field data acquired over the length of several embankment types demonstrate the very good correlation between estimated bulk shear wave velocities and the levees' degree of compaction. As a result, alternative construction methodologies can be quantitatively benchmarked against a bulk density spectrum with fully engineered embankments and loose waste dumps as end-members. Collection of repeated measurements over time also discriminated stable embankments from settling ones, and constitutes a cost-effective way to identify possible zones of weakness before hazardous failure.

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2A COAL

SEISMIC DIFFRACTION IMAGING FOR IMPROVED COAL STRUCTURAL DETECTION IN COMPLEX GEOLOGICAL ENVIRONMENTS

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Faults and dykes are the most significant geological structures that have the potential to disrupt underground coal mining operations. Seismic reflection surveying, especially 3D seismic, is the primary technique for structural delineation ahead of any longwall development in the Australian coal mining industry. It is generally accepted that seismic reflection surveys have the ability to locate faults with throws greater than 5–10 m for 2D and 2–5 m throws for 3D seismic data, but detection of faults with smaller throws, shears and dykes with widths of a few metres remains a challenge to seismic methods. Near the seismic detection limit the risk of interpreting non-existent structures also increases.

In this paper, we describe a moving average error filter (MAEF) applied in the neighbouring traces to extract diffractions from post-stack reflection seismic data. The filter estimates the reflections with the average values of the neighbouring traces along the reflection direction or dip, which can be computed by the gradients of seismic data. The difference (or error) between the original data and the estimated reflections, yields the diffractions. By identifying diffractions, small faults and other minor features that are difficult to detect using conventional seismic reflection processing can be detected. Numerical and real data examples are used to illustrate the effectiveness of the proposed method in small coal seam structure detection by extracting diffractions from reflection seismic data in a relatively complex geological environment.

INTEGRATION OF DOWNHOLE GEOPHYSICAL AND LITHOLOGICAL DATA FROM COAL EXPLORATION DRILLHOLES

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The primary variable of interest in a coal resource study is the volume of coal as estimated from the coal thicknesses in each drillhole. It is therefore essential to accurately determine, down to the centimetre level, the thickness of each seam. To attain this accuracy, every drillhole is geophysically logged as the geophysical logs are a much more accurate indicator of seam boundary depths than the geologist's log. Currently, coal geologists spend large amounts of their time integrating their logs with depth information from the geophysical logs. They do this by displaying the two logs next to each other and then manually changing the depths in their logs. Most of this process is relatively routine and thus rather tedious and boring but like many seemingly simple cognitive tasks, not easily transformed into a computer algorithm. The manual methods also suffer from being subjective.

Previous methods to automate this process have used multivariate statistical techniques to assign lithologies down the hole based on the geophysical values at each reading depth. However, despite these methods having been developed and publicised for over thirty years they still have not been widely adopted as they still do not integrate the two sets of data. Geologists still must manually integrate two separate logs.

This current study has successfully managed to develop algorithms to automatically determine both coal/non-coal and clayey/non-clayey boundaries based on the gradients and inflection points of the geophysical logs and then integrate this information with the geologist's log.

QUANTIFYING GAS CONTENT IN COALS USING BOREHOLE MAGNETIC RESONANCE

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Evaluating gas content in coals has significant commercial and operational importance. In coal seam gas exploration and development, gas contained in coal seams is the resource of interest. In coal mining, quantifying gas content and evaluating the effectiveness of degassing is essential to safe mining operations.

Traditional approaches to saturation evaluation in conventional oil and gas reservoirs rely on relationships between resistivity and water saturation. These relationships are challenging to apply in coals due to complexities in their pore systems and gas trapping mechanisms. Therefore, geophysical log-based methods are not commonly employed for saturation evaluation, and core canister desorption measurements are the standard approach for gas content evaluation. Desorption measurements present their own challenge due to the unknown and variable volume of gas lost during core recovery, so an *in situ* measurement of gas content is desirable.

Advanced magnetic resonance measurements are one method of resistivity-independent saturation evaluation that have been employed in the oil and gas industry for the past approximately fifteen years. However, previous approaches to these types of measurements have focused on the evaluation of conventional reservoirs and hence free gas and oil volumes, and have lacked sensitivity to adsorbed gas, which has a different magnetic resonance response. A novel magnetic resonance acquisition scheme has been developed that provides sensitivity to both adsorbed and free gas, as well as water, allowing for the complete evaluation of fluid content in coal seams. This measurement has been employed in evaluating coal gas content for mining optimisation with encouraging results.

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2B WEST AUSTRALIAN BASINS SYMPOSIUM

EVOLUTION OF 'TRES HOMBRES' - A LARGE MID-CRUSTAL DOME STRUCTURE WITHIN THE NORTHERN BEAGLE SUB-BASIN WESTERN AUSTRALIA: AN INTEGRATED GEOPHYSICAL INVESTIGATION

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The Tres Hombres structure is a large enigmatic, mid-crustal structural feature that that underlies the Permian – Late Jurassic mega-sequences of the Northern Beagle Sub-basin, Western Australia. Originally identified on regional 2D seismic lines, the Tres Hombres structure has now, for the first time, been fully imaged by high quality, deep record, modern 3D seismic data. The area is also covered by modern gravity and magnetic datasets which were acquired together with the seismic survey. Seismic mapping reveals a dome-like structure with a diameter of more than 30 km, and with vertical relief of over 5 km. This paper integrates seismic and potential fields datasets to explore the origins of this intriguing structure.

Potential mechanisms considered for the emplacement of this feature include; basement cored compression, reactivated extensional basement faulting, remnant Palaeozoic topographic relief, salt-related diapirism, or plutonic/igneous intrusive activity. The actual mechanism responsible for the evolution of the Tres Hombres feature has important implications for adjacent and overlying petroleum systems within the Beagle Sub-basin – in particular trap timing, and thermal history.

Detailed mapping of the new 3D seismic dataset enables structural and stratigraphic restorations to be generated, which provide valuable insights into the timing of the Tres Hombres feature. Variations in the thicknesses of overlying sequences show the influence that this structure had on the stratigraphic evolution of the basin. Gravity and magnetic datasets have also been integrated into this study. These datasets provide valuable controls on potential lithologies within the core of Tres Hombres, which in turn have important implications as to the origin of this structure, and relationships to the tectonic evolution of the Beagle Basin.

CONTROLS ON MESOZOIC RIFT-RELATED UPLIFT SYN-EXTENTIONAL SEDIMENTATION IN THE EXMOUTH PLATEAU

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The Exmouth Plateau, part of the Northern Carnarvon Basin, has experienced a multi-phase extensional history, which is associated with regional scale uplift, as well the uplift and erosion of individual footwall blocks. Detailed interpretation of 3D seismic surveys over the area shows that fault activity began in in the latest Triassic, mainly on NE–SW trending faults. This created barriers to sediment transport, resulting in sediment starved half graben and onlap of sediments onto upthrown fault blocks. Further erosion of pre-rift Triassic sediment occurred during the Jurassic, though uplift had ceased and only the larger faults remained active. The Late Jurassic brought about a new phase of uplift in the south, possibly associated with the reactivation of north-south trending faults. By the earliest Cretaceous all major faults were once again active. A significant change in sediment supply in the Early Cretaceous associated with progradation of the Barrow Delta resulted in the infilling of previously starved half-grabens. Fault activity had slowed by the end of the Cretaceous, with limited activity confined to major faults.

The high quality of the 3D seismic data allows a detailed examination of the way in which rift related fault activity affects sediment distribution. In addition to creating fault block traps in pre-rift Triassic sediments, understanding syn-extesnional sediment patterns and fault reactivation has implications for syn-rift plays and seal integrity.

SHELF-MARGIN ARCHITECTURE AND SHORELINE PROCESSES AT THE SHELF-EDGE: CONTROLS ON SEDIMENT PARTITIONING AND PREDICTION OF DEEP-WATER DEPOSITION STYLE

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The Lower Barrow Group (LBG; Latest Tithonian – Early Valanginian) is a shelf-margin that prograded during a late phase of rifting under various subsidence regimes and supply-dominated conditions. A 3D semi-automatic, full-volume seismic interpretation method allow identifying high-order clinothems presenting an estimated cyclicity of ~40 000 years, in which a quantitative analysis of the shelf-margin architecture and shorelines processes was conducted. Overall, three and four main types of hydrodynamic regimes and deep-water systems were identified, respectively.

Falling to flat shelf-edge trajectories are associated with sediment bypass, whereas rising shelf-edge trajectories are linked with increasing sediment storage on the shelf. While fluvial to wave processes can be dominant in all A/S conditions, results show that fluvial-dominated coastlines are associated with steep high-angle slope clinoforms and short to longer run-out turbidites. Conversely, wave-dominated coastlines are linked to low-angle slope clinoforms and poor turbidite system development (occasional sheet sand and MTDs).

The short and longer run-out turbidite systems present a tripartite architecture (canyon/slope valley; channel; lobes), which mostly appear as short-lived, vertically/laterally stacked elements fed by multiple small rivers forming linear ramp systems. Due to the shallow configuration of the margin (<500 m), the presence of short slopes and overall high sand-to-mud ratio, the turbidite systems are smaller scale (<50 km) and probably shorter lived than most modern turbidite systems (100–1000 km).

This study sheds new lights on the significant role of shelf-margin architecture (slope gradient, hydrodynamic regime) in predicting the deep-water sediment delivery behavior (sediment partitioning, type of deep-water system).

ABSTRACTS

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2C EAST AUSTRALIAN BASINS SYMPOSIUM

TARGETING CORE SAMPLING WITH MACHINE LEARNING: CASE STUDY FROM THE SPRINGBOK FORMATION, SURAT BASIN

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We show how clustering algorithms and mixing models can ensure that the core intervals that are pertinent to specific objectives of a sampling campaign are actually sampled and how the amount of samples can be reduced.

Why target sampling?

The clay phases in the Jurassic Springbok Formation generally do not exhibit a prominent gamma ray signature and are therefore poorly defined in well logs. Similar, hydrological properties of the Springbok Formation are not well defined through well logs. This introduces uncertainty to groundwater models of the Springbok Formation. Hence, a better understanding of the clay distribution is thought to be a key to improve the definition of the hydrological properties of the Springbok Formation.

How we targeted the sampling.

We applied our approach to five study wells from the Surat Basin in Queensland. We tailored the application of the cluster analysis and mixing models to our working hypothesis that the variability of hydrogeological properties of the Springbok Formation is controlled by the presence and type of clays, rather than compaction. This informed our choice of logs to include in the clustering (nuclear logs) and of logs to be used for control proposes (resistivity logs).

Results

We show that identification of five clusters was the most useful number towards our sampling objectives. This allowed for example to exclude coal and siderite layers from sampling for clay analysis and to focus on the differentiation of the clastic sediments in the formation. Further, we show that certain clusters correlate with resistivity log signatures.

THE INFLUENCE OF REVERSE-REACTIVATED NORMAL FAULTS ON POROSITY AND PERMEABILITY IN SANDSTONES: A CASE STUDY AT CASTLE COVE, OTWAY BASIN

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An understanding of fault zone structure and transmissibility can have significant implications for reservoir appraisal and development within petroleum systems. Previous studies have demonstrated that porosity and permeability is significantly reduced adjacent to fault zones due to pore collapse, grain crushing, and cement precipitation during deformation. We present results from a detailed mineralogical and geomechanical investigation of the Castle Cove Fault within the Otway Basin at Castle Cove, southeast Australia. Castle Cove provides excellent exposures of the Lower Cretaceous Eumeralla Formation, which is a fine-grained volcanogenic sandstone with moderate to highly porosity (up to 27%), but with generally low permeability (mostly <1 mD). The Castle Cove Fault originated as a normal fault during the late Cretaceous and was reverse-reactivated during NW–SE mid-Eocene to Recent compression. Core plugs were sampled at distances between 0.5 to 225 m from the fault and were orientated with respect to the fault plane. We show that closer to the fault (within 75 m), porosity increases by nearly 10% (i.e. from approximately 17% to 24%) and permeability increases by two orders of magnitude (from 0.02 mD to 3.74 mD). Microstructural investigations from thin sections show an increase in microfracture intensities closer to the fault. This study highlights the importance of detailed mineralogical and geomechanical analyses when attempting to understand fault seal generation and reservoir properties in high porosity and low permeability sandstones.

HIGH FREQUENCY REFRACTION/ REFLECTION FULL-WAVEFORM INVERSION CASE STUDY FROM NORTH WEST SHELF OFFSHORE AUSTRALIA

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The robustness of diving wave Full-Waveform Inversion (FWI) has been proven in industry, but the effectiveness is limited by its penetration depth. To target deeper reservoirs, the application of FWI using reflection energy is necessary. This paper presents a real data 25 Hz VTI FWI case study from North-West Shelf (NWS) Australia utilising the full wave-field. Starting from a high-quality reflection tomography VTI model, a top-down approach has been adopted. Diving wave FWI updates the

shallow, then reflection FWI is introduced to further update the deeper section. The updated FWI model demonstrates significant uplifts in increasing resolution and conformance with underlying geology. Two promising aspects can be observed: (1) the fairly solid uplifts in mitigating the imaging challenges: FWI reduces wave-field distortions, leads to overall improved focusing, gather flatness, continuity, and better positioning in depth; and (2) uncovers geological features beyond imaging: high-resolution FWI delineates small shallow anomalies and velocity boundaries across faults, and reveals the strong acoustic impedance contrasts at reservoir level. It demonstrates FWI can aid both in reducing the velocity uncertainty as well as understanding underlying geological formation.

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2D GEOLOGY CASE HISTORY

PATHFINDER EXPLORATION TECHNIQUES TO TARGET PORPHYRY AND EPITHERMAL STYLE ALTERATION SYSTEMS IN THE TEMORA COPPER-GOLD BELT

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The Temora project lies in the Lachlan Fold Belt between West Wyalong and Temora in the central-west of NSW. A number of mineralised systems are defined within the Late Ordovician Gidginbung Volcanic Complex including the mined Gidgingbung high sulphidation gold mine and a number of mineralised porphyry prospects.

Mineralisation is related to narrow intrusive dykes within a coeval volcanic pile of volcaniclastics, sediments and lavas. Quartz-magnetite-feldspar-pyrite-chalcopyrite veins are associated with a chlorite-magnetite-carbonate alteration. A later quartz-sericite-pyrite alteration postdates the mineralisation (B. Mowat and S. Smith, 2006).

Sandfire Resources targeted the district considered to retain excellent potential for large economic discoveries, purchased 100% of the project in 2015, and commenced a detailed review prior to field exploration drilling starting in late 2016. Availability of historical drill pulps, chip samples and drill core facilitated re-analysis of numerous holes with multi-element geochemistry and by Short Wave Infrared (SWIR) analysis using an Analytical Spectral Device (ASD). The white mica compositions, eg illite, sericite and muscovite and their spectral wavelengths, provided a zonation of alteration minerals highlighting potential vectors towards higher temperature fluids.

Priority targets were highlighted across the belt, including targets at depth associated with the Gidginbung high sulphidation epithermal gold system and the northern and eastern margins of the Rain Hill monzodiorite intrusive centre (Internal reports, Kitto 2016).

Drilling during the 2016–2017 field season in the Rain Hill has encountered a new prospect with porphyry style mineralisation at the Donnington prospect, (Sandfire QR March 2017).

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2E EM & DEEP RADAR

2.5D VS 1D AEM FORWARD AND INVERSION METHODS AT A SURVEY SCALE: A CASE STUDY

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The McArthur basin/EMU fault study has a classic 2D fault feature and a buried conductor with an off-end effect with other 2D/3D effects away from the EMU fault. The collected AEM data has demonstrable AIP effects. This has stimulated an investigation of a simple 2D geology cross-section of a dipping fault with a strong conductor on one side of the fault.

A forward model of the predicted response near the EMU fault represents a synthetic observed signal from the cross-section in agreement with the AEM data. Our modelling shows that the 1D inversion gives results which do not reproduce the survey data whereas 2.5D performs well reconciling the inverted section with the observed EM response. Away from the 2D geology region and other 2D/3D EM effects, 1D does perform well as expected. Therefore 2.5D gets it right in significantly more situations by honouring the information in the observed data raising questions about the use of 1D.

Emerging AEM systems can provide estimates of economic rock unit thicknesses, dips, faults and anticline/syncline definition at an accuracy that mitigates the need for pattern drilling. The use of 2.5D allows marker beds of more conductive material to stand out at a depth of 500 m or more on sections created beneath individual flight lines. Routine treatment of all survey data is now possible without supercomputing capability.

CSIRO has also recently undertaken comparative studies of the available AEM 1D, 2.5D and 3D inversion codes. Their work raises some stark reminders of what is different in the methodologies and how the progression to higher-order geophysics methods requires not just careful test work but also effective education of the user community.

We explain the fundamental differences between 1D and 2.5D and point out issues with the 1D forward modelling and inversion technology. Importantly, Maxwell's equations are used to constrain 2.5D whilst empirical methods are commonly used in 1D.

This leads to the situation where a near zero average misfit using stitched 1D models can be achieved with families of 1D inversions, whilst incorrectly predicting the geology. Therefore a low misfit does not necessarily indicate a good solution for 1D. The 2.5D method is a least-squares best fit of the observations and so the quoted misfit for 2.5D is a very different measure than for 1D.

The study demonstrates that 2.5D yields a much more satisfactory geology section and a better reconciliation with information contained in the survey data.

OTZE – AIRBORNE EM INVERSION ON UNSTRUCTURED MODEL GRIDS

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An efficient, accurate, multi-grid algorithm has been implemented for the modeling of airborne, land and marine controlled source electromagnetic data, providing accurate 3D depth inversions of frequency and time domain data with cost-effective compute timelines.

The forward kernel can either be a 1D solver for layered models, or 2.5D or 3D solvers based on a finite difference approach. The inverted resistivity model mesh is constructed from rectangular cells similar to conventional finite difference approaches. While these cells form a standard rectilinear grid in the horizontal plane, vertically they can be arranged arbitrarily. This vertically unstructured nature of the model grid requires a mapping to the finite difference grids, which is performed on-the-fly in the solver.

This feature, together with an appropriately arranged smoothness constraint, is useful in a variety of workflows. It helps in the presence of topography and also can be used to incorporate general *a priori* information about the survey area for blind inversions, as well as specific structural information for hypothesis testing. However, the potentially complex model geometry requires changes to some of the other available regularisations like the cross-gradient operator which is used to include for example surface geology dip and strike observations or for joint inversions with gravity gradiometry or magnetics.

We discuss the technical aspects of the implementation, illustrated with example workflows from diverse applications: stand-alone AEM inversions, joint inversions including frequency and time-domain EM.

REALISTIC EXPECTATIONS FOR DEEP GROUND PENETRATING RADAR PERFORMANCE

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Ground penetrating radar (GPR) is unique amongst geophysical tools in its diversity of applications and imaging resolution. Since its commercialisation four decades ago, GPR has also been unique in the prevalence of some of its purveyors to oversell the method's capabilities, relying largely on the end users' lack of understanding. Early adopters in the 1980s and 90s were dismayed to find that environments suitable for its purported ubiquitous deep penetration capabilities were rare, and required resistivities well into the 1000s of Ohm m. Regardless of advances made in electronics and antennas design, the fundamental limitations have not changed.

Misconceptions, 'specsmanship' and hype continue to abound in the GPR marketplace, particularly in recent years. Systems purporting to penetrate hundreds of metres using 'megawatt' transmitters from the former Eastern Block have been promoted for mineral exploration, particularly in Australia and Africa. Other pseudo-radar concepts, such as the use of beam forming to achieve kilometres of penetration with centimetre accuracy, or THz laser scanners which can detect individual diamonds deep underground have generally targeted junior exploration groups who lack in-house geophysical guidance.

This work will overview the fundamentals of non-dispersive EM wave propagation in the ground, and will examine the recent published performance claims of some GPR and pseudo-GPS systems within the context of accepted EM theory. Also discussed will be accepted methods of potentially increasing GPR performance given emerging technologies, such as very low-cost systems, phased-array radars, novel transmitter and receiver designs, and new GPR antennas.

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2F EXPLORATION

UNDERSTANDING GEOLOGY AND STRUCTURE: AN ESSENTIAL PART OF MINERAL RESOURCE ESTIMATION

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The JORC Code states that assumption of continuity of mineralisation between sampling points, requires a "*confident interpretation of the geological framework*". The elements of relevance to a geological framework vary greatly depending on the commodity and style of mineralisation. In general terms, at least two elements must be considered to underpin a geological framework: space and time.

The geometry and location of a mineralised body are controlled by physical and/or chemical elements, which can be unraveled by sound geological mapping, adequate geochemical and structural interpretations and by 3D geological modelling. These elements may involve, among other, aspects of stratigraphy, chemical or physical properties of the rocks and structural features such as faults, fractures and folds.

Mineralisation events that lead to economic deposits are often relatively short-lived periods of focused fluid transfer and element-exchange, which result in mobilisation and deposition of metals in well-defined areas. Understanding the temporal framework of structural elements and mineralising events results in the development of more accurate geological models and can lead to predictive capabilities that can result in new discoveries.

We present case studies in regional metamorphic, igneous, sedimentary and surficial geological environments, demonstrating how understanding the mineralisation system not only results in increased confidence in the Resource, but also facilitates reduction of exploration risks.

BUILDING 3-D MODEL OF ROCK QUALITY DESIGNATION ASSISTED BY CO-OPERATIVE INVERSION OF SEISMIC AND BOREHOLE DATA

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Rock quality designation (RQD) is an important factor for geo-techniques in mining production. RQD is defined by the percentage of total length of core pieces that is greater than ten centimetres in the total length of core run. This factor is influenced by rock properties such as fracture and hardness. In nature, the fracture and hardness of the rock also relate to seismic velocity. Thus we can use the seismic information to build an RQD model if we can define the relationship between RQD and seismic velocity. This model is significant for mining design. In practice, the mining design needs information of the whole mine area, but, the borehole is localised valuable. Meanwhile, the surface seismic method can provide information of the whole survey areas, but the resolution is smaller than the borehole data. The seismic and borehole data may provide very useful information for geo-techniques if we can exploit seismic data as a mean of interpolating the borehole data to the whole model of geo-techniques factor like RQD. In this work, we analyse borehole data to establish the relationship between RQD and seismic P-wave velocity. This relationship is used to convert 3D seismic model that obtained by co-operative inversion of seismic and borehole data into a 3D model of RQD.

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2G REGIONAL TECTONIC

EVOLVING 3D LITHOSPHERIC RESISTIVITY MODELS ACROSS SOUTHERN AUSTRALIA DERIVED FROM AUSLAMP MT

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The Australian Lithospheric Architecture Magnetotelluric program (AusLAMP) is a continent-wide deployment of long-period (10–10 000 s) MT instruments roughly every 50 km to map the electrical resistivity structure of the Australian continental lithosphere. The coverage of sites in South Australia is nearing completion with large funding from SA's Pace initiatives and in collaboration with the University of Adelaide and Geoscience Australia (across the Maralinga-Tjarutja Lands). We present the latest 3D resistivity models of the state across the southern two-thirds of South Australia. The area covers the Archean-Proterozoic Gawler craton, and its western and eastern margins, extending across to the east and covering the Flinders Ranges and Curnamona Province. The central Gawler Craton is imaged as a resistive zone with conductive margins surrounding the core of the cratonic block. Contrary to seismic tomography models, showing a fairly homogeneous and fast velocity structure, the Curnamona Province shows a highly heterogeneous resistivity distribution with low resistivity zones in the crust beneath the Province. Currently, the AusLAMP grid in South Australia is expanding across the NE of the state in the Cooper Basin and the Simpson Desert, an area that has not been covered by any deep-probing geophysical techniques. We aim to also present preliminary results of this extension.

The results of the inversion of the AusLAMP data highlight the correlative significance with other geochemical data and points towards MT as a geophysical fertility vector for mineral discovery.

IMPRINTS OF TECTONIC PROCESSES IMAGED WITH MAGNETOTELLURICS AND SEISMIC REFLECTION

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Co-located seismic and magnetotelluric (MT) profiles provide fundamental geophysical data sets to image the crust of Australia. Despite their overlapping nature, the data are processed and interpreted separately based on legacy workflows. We qualitatively compare 2D resistivity inversion models derived from MT and uninterpreted seismic reflection profiles across Proterozoic Australia to address the long-standing cross-cutting nature of interpreted seismic faults and low resistivity zones derived from MT. We find that a good correlation exists between high/low reflectivity in seismic sections and low resistivity in MT sections. These relationships elucidate signatures of past magmatic and fluid-related events and constrain zones of weakened rheology in the crust. Depending on their characteristics, these signatures may signify fossil melting of the crust due to underplating or magmatic invasion into the crust or reworking associated with redistribution of fluids along newly developed faults. These findings have implications for constraining mineral deposit genesis and location.

IDENTIFYING LITHOSPHERIC BOUNDARIES AND THEIR IMPORTANCE FOR MINERAL DISCOVERY

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Domain boundaries under cover have commonly been recognised through tracing of potential field anomalies such as extensive magnetic boundaries representing margins of upper crustal packages in conjunction with density contrast. Here, we extend the investigation of domain mapping to include isotope geochemistry and deep-probing magnetotelluric data. These data sets map the deeper crustal and mantle lithosphere. We demonstrate with examples across the Kalinjala Shear Zone, South Australia, and the Eastern Gawler craton, that major lithospheric domain boundaries exert a primary control on the location of mineral deposits near the surface.

We show examples of correlating of magnetotelluric models derived from the Australian Lithospheric Magnetotelluric Project (AusLAMP) and higher density broadband magnetotelluric deployments along profiles with isotope geochemistry across major lithospheric boundaries in South Australia. As one

example, the Kalinjala Shear Zone in the southern Gawler craton can be better constrained using the additional geochemical and magnetotelluric data sets and solve a long-standing debate about the northern extension of the Kalinjala Shear Zone towards the prospective Olympic domain hosting major IOCG deposits. These insights motivate future exploration programs which focus on in-fill broadband deployments for MT and isotope mapping to trace the lithosphere boundaries to the surface to reduce risk for mineral exploration.

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2H GEOTECHNICAL AND ENVIRONMENTAL

HOW TO BUILD YOUR OWN SIMPLE, LOW-COST, SEISMIC SYSTEM

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Acquiring seismic data has typically been an expensive pursuit due to the high price of the acquisition systems. Such systems are also typically not easily adaptable to suit different acquisition scenarios. In this paper we detail the manufacture and performance of an easily adaptable, low-cost (~$40/channel), seismic acquisition system. Data recorded using the system is comparable to that obtained using a far more expensive commercial seismograph.

Seismic sources are similarly expensive with the only low-cost option being a sledgehammer. In the second part of this paper we describe how to manufacture a small vibroseis unit from easily available components at a cost of less than $3000. This unit has a wider, more controllable, bandwidth than an impact source and can be easily adapted to create a shear wave source for MASW surveys.

FEASIBILITY STUDY OF NEAR-SURFACE DISPERSION IMAGING USING PASSIVE SEISMIC DATA

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Multichannel Analysis of Surface Waves is a seismic technique used to define the near-surface structures and rock properties. It has been vastly used through active seismic surveys for seismic/geotechnical engineering as well. It can also provide information about regolith heterogeneity that is of relevance to reflection seismic data processing. However, active surface wave investigations are not always possible due to site restrictions and environmental constraints. In this research, we studied the feasibility of passive seismic for the analysis of surface waves caused by different type of ambient noise and ground motion. The example presented comes from a data set collected over a hard-rock environment. We showed that the achieved results from passive data have a considerable correlation with the results from active data of the same acquisition survey.

REFRACTION MICROTREMOR FOR DELINEATION OF LAYERS AND LENSES, AND ASSESSING LIQUEFACTION POTENTIAL WITHIN AN ALLUVIAL SETTING – MOROBE PROVINCE, PAPUA NEW GUINEA

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Refraction Microtremor (ReMi) is a relatively new method in the geophysics industry. ReMi provides high resolution seismic shear wave velocity models up to 200 m depth and as such has the potential for being an efficient method for assessing the soil liquefaction potential in seismically active regions.

This paper presents a geophysical investigation carried out as part of a geotechnical feasibility study for a proposed Tailings Storage Facility (TSF) in the Morobe Province of Papua New Guinea. The primary objective of the investigation was to use geophysical methods to obtain subsurface parameters to assess the liquefaction potential within an interbedded and lensed clay/gravel alluvial setting. ReMi together with down hole and cross hole seismic methods were used to generate shear wave velocity information of multiple layers with depth, and in particular to define seismic velocity inversions.

ReMi data was acquired using two array setups specifically targeting the top 100 m of subsurface material and the top 50 m of subsurface material at increased layer resolution. The data was inverted to produce shear wave velocity soundings which were correlated with the cross hole and down hole seismic methods, and with borehole Standard Penetration Tests (SPT). The soundings were compiled to generate high resolution shear wave velocity sections, analysis of which proved pertinent in defining the interconnectivity of the lensed clay/gravel and shear wave velocity variations for the calculation of liquefaction potential thresholds.

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3A COAL

COOPER BASIN DEEP COAL – THE NEW UNCONVENTIONAL PARADIGM: DEEPEST PRODUCING COALS IN AUSTRALIA

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Up to three years of gas production from Permian-aged coals, in the SA Cooper Basin has exposed them as a potentially sustainable unconventional gas resource. The success of this play is a result of many years of research, laboratory tests and field trials to de-risk the play, following a well defined road-map.

Since 2012, production variability has been tested in over 50 wells across the SA Cooper Basin. As an add-on frac stage in a conventional gas development well, coal targets are regularly yielding incremental reserve. This is providing an uplift in

production and the opportunity to access a new tranche of gas. Production from the coal reservoirs is now accepted as 'base-business' for the Cooper Basin Joint Venture partners.

The key to progressing the play from its earliest inception to a productive reservoir, lies in a focused approach to de-risking each economic barrier. These risk factors include frac containment, formation water production, gas composition, permeability, deliverability, completion design and cost.

Next steps are to prove economic viability of deep coal as a stand-alone development. In these projects, planned for late 2017 – early 2018, both vertical and horizontal completions specifically targeting deep coal will be tested for commercial flow rates in existing productive fields.

PREDICTING STRUCTURAL PERMEABILITY IN THE DEEP COAL PLAY, TIRRAWARRA-GOORANIE FIELDS, COOPER BASIN

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The Tirrawarra-Gooranie oil and gas field complex in the Cooper Basin, South Australia has produced from a large number of vertically stacked conventional and unconventional targets. The unconventional Permian coal seams remain largely untapped, with only a limited number of hydraulic fracture stimulation trials commingled within conventional vertical wells. Variability in the coal zone frac treating pressures, gas rates and EURs has been observed. This is thought to be driven by variability in the in-situ reservoir properties; local stress field; occurrence of natural fractures; stimulation design and the interaction between these factors.

In a 2D study, a numerical stress model based on the distinct element method (DEM) was applied to a rigorous structural framework model, in order to understand how paleo- and present-day regional stress fields have interacted with faults in the Tirrawarra-Gooranie structure at the Patchawarra VC40/50 coal horizon. Areas of high differential stress are interpreted to be more prone to natural fractures, which may improve the coal productivity but may also require different stimulation treatments to areas with lower permeability. The model was calibrated against well data including 1D mechanical earth models, fracture initiation pressures, image logs and drill cores. Predicting areas of enhanced structural permeability using DEM is shown to be useful for early stage appraisal of unconventional reservoirs requiring large amounts of hydraulic fracture stimulation, and is also informative in helping to predict potentially problematic areas with higher breakdown and treating pressures.

TOWARDS UNDERSTANDING PHOSPHORUS DISTRIBUTION IN COAL: A CASE STUDY FROM THE BOWEN BASIN

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In coal phosphorus can occur in a variety of minerals but fluorapatite $Ca_5(PO_4)_3F$ is the most common. This mineral is often observed within the cell-lumens of inertinite macerals and interpreted as an early diagenetic mineral phase, although fracture-infilling fluorapatite has also been reported. Its small size and predominant occurrence within the cell lumens of the inertinite group macerals, means the fluorapatite cannot easily be liberated by current coal beneficiation strategies. Its occurrence may also reduce porosity and clog flow paths for gas drainage.

Understanding the spatial distribution, which reflects the origins and geological history of the coal and fluids moving through it, assists in developing mitigation strategies. The compilation and spatial analysis of elemental data within Permian coal deposits in different structural settings in the Bowen Basin provides the framework in which samples were collected and analysed by microscopic and spectroscopic techniques.

Preliminary results in the study area show elevated phosphorus contents are common in the roof and floor of the coal seam. However, these contents transgress lithotypes, up-dip along the flanks of an anticline, proximal to a fault, a dyke and sill and a rider seam split. At least two apatite mineral phases have been identified: cell-lumen- and fracture-infilling. However, a relationship between mode of occurrence and proximity to geological structures has not yet been observed. Although mode of occurrence appears to be indiscriminate, the analysis performed on phosphorus contents suggests a relationship between spatial distribution and geology. This infers that geology could be used to predict *in situ* elevated phosphorus contents within coal.

EVIDENCE FOR GLACIAL AND POLAR IMPACTS IN THE PERMIAN COAL MEASURES OF THE SYDNEY BASIN

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Since the 1840s, geologists have speculated about the degree and timing of contributions by glacial processes in the formation of the Permian coal bearing and marine sequences of the Sydney Basin. Unambiguous classical glacial evidence occurs in the underlying Carboniferous but later Glendonites and dropstones were seen only as contributions from cold water and floating ice.

Continuing improvement in the resolution of the 'polar path' throughout time, place the Sydney Basin at latitudes of 75S to 90S from the Early to Late Permian (Klootwijk 2016). Current evidence of climate change and its influence on glacial environments demonstrate there is more evidence of glacial processes in the Permian coal measures themselves.

Major elements, of the Newcastle Coal Measures are suggested to have glacial signatures and the Sydney Basin coal seams themselves display enigmatic properties that are suggestive of high latitude 'interglacial' environments. The Teralba and Bolton Point Conglomerate strata, shown in the 1980s to form elongate, high energy, channel like, coarse clastic deposits, sit enigmatically in the supposedly flat and marshy coal forming environments. A coal forming model of freshwater lakes with 'Gilbert' deltas, (Conaghan 1981) is revisited but with compelling current global evidence. Recent observations in the Arctic, of waning ice sheets and melting processes clearly illustrate 'moulins', sub-glacial drainage and their links to 'tunnel valleys' and 'eskers'.

A high latitude, cyclical, glacial model for coal measure formation is suggested, which is similar to that now discernible

in recent Arctic landforms. The required time scale and cyclicity are supported by Permian CA IDTIMS zircon age dating.

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3B WEST AUSTRALIAN BASINS SYMPOSIUM

INFLUENCE OF PERMIAN AND CARBONIFEROUS EXTENSIONAL HISTORY ON THE NORTHERN CARNARVON BASIN AND ITS INFLUENCE ON MESOZOIC EXTENSION

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The North-West Shelf of Australia is a marginal rift system related principally to the fragmentation of Gondwana. Permian-Carboniferous structures along the margin have long been recognised as fundamental events responsible for the formation of the offshore basins that comprise the prolific hydrocarbon producing region. However, the tectonic setting in which this rifting occurred remains unclear.

Detailed mapping of the geometry of Permian and Carboniferous structures on the southern margin of the Carnarvon Basin is possible using regional scale interpretation of publically available 2D and 3D seismic data. Seismic interpretation, combined with 2D structural reconstruction of major faults reveals two distinct orientations of structures. NNE trending faults were initiated in the Carboniferous or Devonian but were underfilled, resulting in erosion of the fault block crest and filling of the remnant rift-related topography by conformable sequences of later Permian and Triassic sediments. By contrast, NE-SW oriented faults experienced a distinct phase of Permian activity and are unconformably overlain by Triassic sediments.

This older rift architecture has clearly affected the geometry of the subsequent Upper Triassic to Middle Jurassic rift and can account for the en-echelon style of faulting on the northern margin of the Dampier Basin. Reactivation of the eroded fault block crests results in complex fault geometries and significant deformation of hanging wall strata during Mesozoic extension. The crustal scale geometry of these fundamental faults may also account for the unusual nature of the Lewis Trough in which the syn-rift sequence forms a broad syncline, rather than the more typical rotated fault blocks and syn-rift wedges.

INTERPRETATION OF A PERMIAN CONJUGATE BASIN MARGIN PRESERVED ON THE OUTER NORTHWEST SHELF OF AUSTRALIA

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The Northwest Shelf (NWS) of Australia is characterised as a series of northeast-southwest trending Mesozoic offshore depocentres which both juxtapose and partially overprint a series of onshore, northwest-southeast trending Paleozoic basins. An integrated interpretation of well bore data, regional seismic data and plate tectonic models suggests that the Paleozoic section is also present below the Mesozoic depocentres. Referred to as the East Gondwana Interior Rift, the primary rift axis is oriented in a (present day) NE–SW direction, below the Mesozoic section, with orthogonal marginal rift basins such as the onshore Canning and Southern Carnarvon basins.

While precise age dating for the initial formation of the axial rift is speculative, our integrated interpretation suggests that a significant portion of the pre-existing rift was modified by a Mid-Permian extensional event, forming the Northern Carnarvon basin. Interpretation of recent acquired 3D reflection seismic data suggests that the conjugate basin margin from this Permian rifting event is preserved, and is visible below the Mesozoic section. A series of back-stepping, Late Permian carbonate ramps and banks is interpreted to form on a thermally subsiding rift flank. Our interpretation of these carbonate banks is based primarily on seismic geometries, and is supported by area well control and regional paleogeographic models.

This interpretation suggests that deep marine intra-continental basin bisected the NWS in the Late Permian. Then shallow marine conditions persisted across the conjugate margin through the Triassic and into the Jurassic. Only after Late Jurassic rifting associated with Gondwanan break-up, did the region subside into deep water.

NEW INSIGHTS INTO EARLY TRIASSIC RIFTING IN THE NW SHELF HELP EXPLAIN REGIONAL STRUCTURAL STYLES AND ASSOCIATED DEPOSITION MODEL

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The offshore Canning is an amazingly complex and unexpected piece of geology. Large seismic geometries appear to be lava deltas associated with a rift volcanic complex. Gravity and magnetic modelling can be shown to support this geological model and its apparent thickness of up to 8 km in places. This is therefore volumetrically comparable to global end-Permian flood basalts analogs such as the Siberian and Emeishan traps.

The location of this outpouring can potentially be associated with a failed triple junction. The impact of this rifting is felt regionally. Syn-rift growth faulting is easily identified and can be shown to extend along a Northern rift arm up to the proto-Barcoo and proto-Caswell sub-basins. Strike-slip motion, previously known as the Fitzroy movement, along the eastern rift arm propagates through the Fitzroy Trough creating the numerous trans-pressional and trans-extensional features. Uplift along the third Western rift arm, to the north of Wombat plateau, sets up the elliptical bowl like geometry of the Northern Carnarvon basin that is clearly visible from an isopach of the early Triassic. This uplift also helps to explain the long-lived shallow marine Cossigny limestone and the expected sudden influx of eroded clastic sediment into the Northern Carnarvon basin can be tied to a large prograding Triassic shelf visible on 2D regional seismic data.

This large volcanic province may help explain the small percentage of Triassic-aged detrital zircons found throughout the Triassic Mungaroo formation.

This paper highlights Woodside's view that a regional approach, incorporating data from multiple sources, geographical areas and formations, assists with our broader understanding of tectonic history of the North West Shelf during the Early Triassic to Middle Triassic.

MODELLING RESERVOIR DELIVERABILITY WITHIN THE NORTHERN BEAGLE SUB-BASIN, WESTERN AUSTRALIA

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Reservoir deliverability* is a critical component affecting the viability of petroleum systems within a sedimentary basin. Calculating deliverability relies on estimates of reservoir pressure, permeability and thickness as well as fluid viscosity, all of which are difficult to predict in a frontier basin. Burial and erosional processes exert a fundamental control on these rock and fluid properties. If this erosion is not uniformly distributed across an area then complex variations in deliverability may result. This paper presents a novel approach to quantifying predictions of reservoir deliverability within the Northern Beagle Sub-basin of Western Australia, via the use of a 3D basin-scale model that provides spatial and temporal estimates of variations in rock and fluid properties.

Active extension began in the Northern Beagle Sub-basin during the Early Jurassic and resulted in deposition of proposed source and reservoir intervals. A thick (>5 km) succession of progradational Middle Jurassic deltaics overlies the early Jurassic petroleum system. During the Late Jurassic, the basin underwent a complex phase of erosion (attributed to rift flank uplift), which resulted in upwards of 3 km of sediment being locally removed on footwall blocks of active faults, as well as over structural highs. In other areas, however, such as contemporaneous structural lows, amounts of erosion are minimal. This complex spatial pattern of erosion has implications for both the thermal history (affecting fluid viscosity), as well as reservoir quality (permeability).

The final product generated from this workflow was an integrated, basin-scale 3D model of reservoir deliverability for the Northern Beagle Sub-basin.

* Reservoir Deliverability $\boldsymbol{Q} = (\Delta \boldsymbol{p}\ \boldsymbol{KH})/\boldsymbol{\mu}$, where

$\Delta \boldsymbol{p}$ = Reservoir Pressure – Surface Pressure

$\boldsymbol{K}$ = Reservoir permeabilty

$\boldsymbol{H}$ = Reservoir Thickness

$\boldsymbol{\mu}$ = Fluid viscosity

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3C EAST AUSTRALIAN BASINS SYMPOSIUM

PETROLEUM PLAYS OF THE BOWEN AND SURAT BASINS

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A petroleum play is an exploration concept that groups fields together based on similar characteristics, generally lithological or structural, that can be applied at regional or local scales. Conventional plays can be grouped by style of trap and geological region, or by target formation. Unconventional reservoirs, require a more complex approach to play based exploration, through mapping of several, highly variable characteristics and identification of 'sweet spots'. Examination of play characteristics and their spatial distributions can highlight areas that may contain new exploration prospects. This paper will review and summarise the types and distribution of petroleum plays in the Bowen and Surat basins. Since the 1960s, conventional exploration has targeted a number of different play types in the Bowen and Surat basins, varying from structural and stratigraphic traps on structural shelves and the flanks of the Taroom Trough, to coal seam gas, and, deep unconventional plays. Each of these are typically restricted to a geographic region (e.g. the Roma Shelf), or within a fairway (e.g. the Walloon Coal Seam Gas fairway). There is a general trend over time towards discoveries being made in older, deeper or more technologically challenging units. Extensive exploration and development has defined coal seam gas fairways in the Bowen Basin coal measures and Walloon Coal Measures. New exploration has examined tight or basin centred gas in the deep Taroom Trough.

BOREHOLE GRAVITY IN HORIZONTAL WELLS

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In response to current horizontal well technology, the latest borehole gravity logging tools are now capable of measurements in wells deviated from vertical to past horizontal. Historically oil and gas field borehole gravity data have been presented in the form of deep investigation, through casing, density logs, where the borehole gravity density is proportional to the vertical gravity gradient. This provides an excellent way to measure total porosity in heterogeneous carbonate reservoirs due to the large sampling volume. However the simple BHG density calculation is no longer applicable in horizontal wells and the data are similar to surface gravity profiles with differences due to being imbedded within or in close proximity to the target horizons.

Data acquisition in highly deviated wells brings new challenges largely associated with tool positioning. One mode of running the tool involves using a tractor to push the tool to the end of the well and then pulling back along hole to pre-set station locations. This can result in noticeable cycles of tool sticking and then rapid up-take, making it challenging to place a tool accurately at a pre-determined location.

Data processing for highly deviated BHG well logs has to take into account the well geometry to establish accurate 3 dimensional coordinates for each gravity station. Latitude corrections and terrain effects also assume more significance.

Time lapse monitoring of gravity changes in can be made much closer to or within the reservoir. The difference signal between logging runs is then solely due to the changes in the reservoir fluids or changes in porosity associated with formation fracturing. Data from single logging runs are influenced by all surrounding rock formations.

THE STRATIGRAPHIC SIGNIFICANCE OF PARALIC DEPOSITS IN THE PRECIPICE – EVERGREEN SUCCESSION, SURAT BASIN, QUEENSLAND

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The Precipice Sandstone and Evergreen Formation in the Surat Basin, Queensland, are being examined as a reservoir-seal target for future geosequestration of CO_2. Effective reservoir modelling, and prediction of dynamic storage capacity, however, depends upon accurate depositional interpretations and an understanding of stratigraphic architecture. Throughout most of the basin, the Precipice Sandstone is freshwater-bearing, attesting its reservoir properties and lateral continuity. Refined depositional models and a widely applied sequence stratigraphic framework will enhance prediction of the most prospective play segments for CO_2 injection.

We utilise integrated ichnological-sedimentological facies analysis from core to interpret the Precipice Sandstone as a fluvial/alluvial to delta plain succession, overlain by estuarine embayment deposits of the Evergreen Formation. Facies maps, based on core-calibrated wireline logs show brackish-water influenced deposits at several stratigraphic intervals. Brackish-water influenced deposits conformably overlay braided and meandering fluvial sediments, and generally cap parasequences. Seismic surveys resolve lower-order cyclicity, showing parasequence sets within the Precipice succession back stepping and aggrading. This stratal arrangement reflects the lowstand and early transgressive systems tracts. Late transgressive and early highstand systems tracts comprise the lower part of the Evergreen Formation.

Depositional and sequence stratigraphic interpretations suggest the precipice sandstone has a higher degree of reservoir compartmentalisation than previously appreciated. Moreover, we show that the Evergreen Formation is not a simple basin-wide sealing unit due to the presence of sandstone geobodies that may act as vertical fluid conduits. The sequence stratigraphic characteristics of the reservoir-seal pair should be carefully considered when selecting locations for CO_2 sequestration.

NEXT GENERATION RESERVOIR ENGINEERING

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Our mission is to advance knowledge about energy in transition with the aim to aid the industry in the imminent energy transformation. To this end we use an approach based on developing a fundamental physics based understanding of the chemical, mechanical, thermal and hydrological processes and their interactions that operate over long time scales to form and characterise the porosity/fracture networks in conventional and unconventional oil and gas reservoirs. We apply that understanding to engineer that structure for the purpose of energy extraction and resource discovery. The interdisciplinary approach links geoscience, engineering and computational science disciplines with the result of providing a step change in exploration and exploitation technologies with significant reduction in onshore gas development costs without compromising OHSE or environmental protection and assurance.

Numerical simulation has played a pivotal role in the dynamic reservoir modelling and for testing competing hypotheses in complex, typically data-poor environments. Though our ability to rigorously describe key processes in petroleum reservoirs is still imperfect (in particular unconventional plays), there have been substantial advances over the past several decades. These advances owe mainly to the steady growth of computational power and the concomitant development of numerical models that have gradually minimised various simplifying assumptions. They include incorporation of more accurate description of the fluid chemistry and its multiphase evolution and fluid flow rock interaction, an increased ability to represent geometric complexity and heterogeneity, and faster and more accurate computational schemes. In collaboration with international partners we have prototyped a multiphysics, multiscale simulator based on the Open Source **M**assively **O**bject **O**riented **S**imulation **E**nvironment (MOOSE), originally designed for running synchronous multiphysics calculations for a nuclear power plant. The Multi App framework allows coupling processes at grain level through to the fission in the reactor core, including the large-scale fluid flow in the pipe network of the heat exchangers of the power plant.

In this presentation, we will show the first results that allow incorporation of important processes in unconventional plays. Surprisingly, diagenetic processes such as the smectite-illite transition are found to create natural fractures under tectonic load that form the permeable reservoirs in shale gas/oil reservoirs. Results indicate that the fractures triggered by natural fluid release reaction on geological time scales are supported by a critical fluid pressure that must not be crossed to avoid sudden loss of the reservoir. Upon crossing this threshold reservoir damage can be substantial. No amount of proppant or other engineering interaction can rescue the reservoir on a human time-scale. Our novel framework allows to link the long-time scale geological processes with the design of an injection-extraction protocol to maintain critical fluid pressure. We are also able to incorporate micro-structural changes and fluid-solid interaction at grain scale. The latter has only been benchmarked for conventional carbonate plays, but the Multiscale results are encouraging for the entire spectrum of conventional and unconventional traps/source rocks. Our theoretical framework and the forward simulator is specifically designed to interface

with geophysical inversion techniques for multi-scale geophysical data. Completing this data-assimilation step in the future will define next generation reservoir engineering.

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3D GEOLOGY CASE HISTORY

CARGO PORPHYRY CU–AU DEPOSIT – WHERE IS THE HIGH GRADE CORE?

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The Cargo Copper-Gold Porphyry deposit lies within the world class porphyry belt of Ordovician Macquarie volcanic arc. It is one of several porphyry complexes in Lachlan Orogen including Cadia Valley (42.8 MOz Au) North Parkes, Cowal and Copper Hill.

The Cargo Porphyry Intrusive Complex is a calc-alkaline suite of late Ordovician age (467 Ma) intrusive comprising quartz monzodiorite and diorite intruded by coeval andesitic and trachyandesitic volcanics. The most prominent NW trending structural zone is characterised by areas of strong silicification, pyritisation and tectonic brecciation together with stockwork and sheeted quartz veining. It is up to 300 m wide bounded on the southern side by a major 60° SW dipping normal on the northern side by 75° SW dipping shear zones.

Mineralisation and alteration is zoned from a western core of fracture controlled, potassic altered porphyry Cu-Mo-Au to a peripheral zone of phyllic altered gold rich quartz-sulphide veining up to 200 m wide, surrounded by an outer propylitic zinc rich halo.

The peripheral zone of Cargo contains gold rich sheeted quartz veins which hosted 14 small gold workings in the late 1800s. Two lode systems, Dalcoath and Spur, have JORC inferred resource of 4 Mt @ 1.19 g/t gold 154000 Oz Au.

A classically zoned porphyry Cargo's geochemical footprint is comparable in size to the famous Bingham Canyon and the Bougainville Panguna deposit despite the fact that Cargo's porphyry deposit's western half has been faulted away.

IMPLICIT MODELLING OF THE LAS BAMBAS DEPOSITS, PERU

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The primary objectives of any 3D implicit geological model are to better visualise, understand, and demonstrate the data you have, to provide an environment fostering robust interpretation, to build on those interpretations and extrapolate into theoretical space, to quantify our economic variables, and to encourage the scientific method by allowing competing theories to be explored virtually, maximising discovery and expansion.

Recent advances in understanding MMG's Flagship project, the Las Bambas Mine, Apurimac, Peru, its mineralising system and analysis of the opportunities for expansion have been assisted by the construction of an implicit geological model that not only effectively demonstrates the major features of the system, but has provided a versatile experimental environment within which geological theories and generation of predictive geometries are constantly queried.

Las Bambas is a world class suite of Cu deposits in the high Andes. The system can be described as a series of Eocene igneous stocks, sills and dike swarms intruding lower cretaceous limestones of the Ferrobamba formation, resulting in the generation of garnet-pyroxene-epidote-magnetite skarns, which have mineralised through syn-epigenetic fluid interaction, filling voids and introducing chalcopyrite and bornite, with later molybdenite mineralisation.

In this presentation, the implicit model serves as an effective medium for illustrating the Las Bambas deposit geometries and mineralisation relationships, leading to analysis of near mine exploration opportunity.

WHAT IS DOWN PLUNGE OF THE DOBROYDE HILL HIGH-SULPHIDATION EPITHERMAL DEPOSIT, NEAR JUNEE, NSW?

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The Dobroyde Hill high-sulphidation epithermal gold prospect sits within the 4 km long calc-alkalic andesitic Dobroyde Volcanic Complex, 50 km north of Wagga Wagga and 10 km north of Junee and is in the southern section of the Junee-Narromine Volcanic Belt. The Hill was the focus of episodes of exploration from the mid-1970s until 1990. Revival of the Prospect came when recent drilling intersected carbonate base-metal style alteration with associated gold mineralisation and in another hole a package of younger conglomerates containing pebbles of mineralised quartz stockwork in altered porphyry.

These targets were derived by the recognition of widespread dickite, pyrophyllite, silica alteration during mapping, favourable IP and magnetic anomalies and barium geochemistry.

One of the holes was targeting 700 m down plunge from the high-sulphidation epithermal Dobroyde Hill mineralisation. This hole intercepted long intervals of carbonate base-metal epithermal alteration and wide low-grade mineralisation and shows some key similarities to the 8M Oz Cowal E42 gold mine owned by Evolution Mining. This is different in style to the high-sulphidation Dobroyde Hill mineralisation.

The newly intersected geology, alteration and mineralisation is interpreted to be the outer shell of a larger zone of mineralisation. Clay mineralogy suggests the hotter core of the deposit may be within a few hundred metres away.

When the calc-alkalic Dobroyde Volcanic Complex was forming, it is thought to have been long lived, multifaceted and the chemistry of the fluids evolved over time hence the Complex may have the potential to host one or more major deposits.

THE DISCOVERY OF THE EDNA BERYL DEPOSIT – A JOURNEY WITH A DESTINATION!

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Edna Beryl was discovered by prospectors in 1936 and mined underground until the closure of the mine in 1942. Mining recommenced at Edna Beryl in 1945–46 when several shafts and drives were developed to a maximum depth of approximately 50 m before encountering the water table. However it was not until June 2016 following a systematic exploration program by Emmerson, did the extent of the Edna Beryl mineralisation emerge.

Since inception, Emmerson's strategy has been firmly focussed on discovery from the implementation of a science-based approach to exploration but within a clear, risk-based business framework. Our technical approach includes integrating both the Prediction and Detection elements of our exploration model across all geological scales. With the assistance of Kenex Limited, we have adopted an objective, probabilistic targeting methodology, whereby target ranking is derived from a solid understanding of ore processes and their fingerprints – the critical step of turning data into information. No one data layer is definitive; rather the more robust targets are derived from multiple geoscientific data that are highly correlated to the mineralisation.

The application of various detection techniques are aimed at precisely pinpointing the location of the mineralisation for drill testing. The Au–Cu–Bi mineralised ironstones (generally hematite-dominant) are notoriously difficult to detect both from the geophysical and geochemical perspective. To date, Emmerson (and JV partners) have trialled gravity geophysics, a number of electrical techniques (including airborne EM), high resolution magnetics, and various geochemical techniques including ironstone fertility indices. The journey continues this field season with the testing of ultra-high resolution gravity and passive seismic methods.

In summary, Emmerson (and JV partners) have invested considerable resources in the Tennant Creek Mineral Field, all within a risk-based business framework and with the clear aim of discovery. We are increasingly confident that this approach will continue to be supported by our shareholders and provide a point of difference for retaining and attracting new joint ventures, such as at our recently acquired Rover and NSW projects.

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3E AIRBORNE GRAVITY

VALIDATING THE GEDEX HD-AGG™ AIRBORNE GRAVITY GRADIOMETER

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The Gedex High-Definition Airborne Gravity Gradiometer (HD-AGG™) was designed and developed to deliver measurements of the gravitational field with improved signal-to-noise and resolution. The system has been under development for more than 10 years and is approaching the point of commercial deployment. Knowledge of the gradiometer components being measured, noise character and resolution of the system will allow end-users to appropriately select exploration targets and to determine eventual survey parameters.

The validation of the Gedex system has been progressive in nature consisting of laboratory tests and flight tests in a Cessna Caravan after successive modifications. The lab experiments consist of static tests to establish the noise floor, signal confirmation tests and dynamic testing on a 6 degree-of-freedom shaker. The airborne testing includes high altitude flights to confirm the noise level and character of the system over long periods. Low-level flights have been carried out to establish resolution and noise levels under survey conditions. These have been conducted over areas where high resolution terrain data and ground gravity exists and geology is known. We present datasets from our validation program and discuss our path forward.

AIRBORNE GRAVIMETRY TAKES OFF IN THE WESTERN AUSTRALIA 'GENERATION 2' RECONNAISSANCE GRAVITY MAPPING PROJECT

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In 1974, the Australian Bureau of Mineral Resources, Geology and Geophysics completed a 15-year systematic reconnaissance gravity survey of Australia with stations spaced at 11 km. The 1976 Gravity Map of Australia was a seminal product; half a century later, the data still provide the only coverage for substantial parts of the continent.

In 2005, the Geological Survey of Western Australia, supported by Geoscience Australia, commenced a program of regional ground gravity surveys with 2.5 km station spacing, a sixteen-fold improvement of resolution over the 'first generation' BMR data. In 2013, GSWA declared its aim of completing 'second generation' reconnaissance gravity coverage of WA by 2020.

In 2016, with 45% of the State yet to be surveyed in the north and east, and ground access issues slowing progress and making uniform coverage increasingly difficult, GSWA and GA

undertook the first government-commissioned regional aerogravity survey in Australia, using the Sander Geophysics' AIRGrav system. The 38000 line-km survey covering 84000 km^2 in the East Kimberley was flown at 2.5 km line-spacing for compatible spatial resolution with GSWA's regional ground surveys.

We compare airborne with ground gravimetry in the context of the East Kimberley project and conclude that, for reconnaissance surveys: aerogravity costs now approach those of ground surveys; spatial resolution is equivalent; lower aerogravity precision is not a critical factor; and airborne and ground data can be merged seamlessly for interpretation.

Consequently, two new aerogravity surveys were undertaken over 264 000 km^2 of northern WA in the Tanami–King Leopold and Kidson regions.

GRAVITY GRADIOMETER DESIGN COMPARISON BY THREE DIFFERENT METHODS

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Two gravity gradiometer designs are currently available for commercial survey operations and other instruments are in the late stages of pre-deployment research. These gradiometer systems differ from one another with respect to the number and orientation of sensing accelerometer pairs. There is a need for a theoretical framework to evaluate how these design variations, affect the expected performance of these devices.

Three methods of design comparison will be presented: (1) Transformation of noise, a calculation of the degree of noise reduction produced by the method of transforming and combining measured gradient components. (2) Inversion errors, comparison of the degree to which noise induces errors in the values of parameters determined in a parametric inversion calculation. (3) Sensitivity, analysis of the response of each system to a point source and how that source varies as a function of location in 3D space. Each of these methods focuses on a different aspect of the practice of gravity gradiometry. Specifically, noise, inversion and source detection.

Analysis will be centered on comparison between the two gravity gradiometer designs manufactured by Lockheed-Martin. The full tensor gradiometer (FTG) and the horizontal partial tensor gradiometer that is part of the Falcon survey system. All three methods predict that in order for these two gradiometer designs to yield equivalent results the noise level of the horizontal partial tensor gradiometer must be less than that of each of the three sub-gradiometers of the FTG by a factor of 3.08.

AN OVERVIEW OF TENSORS, GRADIENT AND INVARIANT PRODUCTS IN IMAGING AND QUALITATIVE INTERPRETATION

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Potential Field Gradient Tensors are a multichannel dataset combining 5 independent components in a matrix array. As such, the data can be used and combined in many ways. A very common problem right across the world of geoscience is that even standard potential field transforms are not actually well understood by users. How does one expand grid transform concepts into the realm of tensors, where so many new combinations and concepts such as Invariants and Phase exist, and create lasting basis for industry interpretation?

It is important that all images used in potential field analysis carry some sort of physical meaning which is understood by the interpreter. True understanding arises from geophysically modelling a known 3D geological model, creating the grid transforms from the forward response of the model, and comparing these to the geology.

3D forward gravitational responses of a 3D model of a simple two-body basin-basement system with conjugate faulting and a dome-basin shape are used to generate the examples. Depths to the Basin-Basement interface were computed from the model and are presented as grids and contours draped on the gravity gradient imaging products to illustrate their responsiveness to the basement architecture.

Various combinations of traditional gravity and its gradient transforms, as well as tensor invariants and phase products, are assessed against the model. It is shown that certain imaging products show more responsiveness to physical property variations, whilst others are more sensitive to geometry, but combining these in novel ways can approach understanding of subsurface mapping possibly not explored previously using potential fields.

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3F ELECTRICAL METHODS

LABORATORY CONFIRMATION OF NON-LINEAR ELECTRICAL EFFECTS IN MINERALISED ROCKS

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A search for an exploration technique that was unique to sulphides, i.e. did not respond to graphite, clays and other polarisable materials, lead to the investigation of non-linear conduction in sulphides.

Early work in the 1960s indicated that non-linear effects were only detectable at high current densities, such as those found in borehole surveys.

When currents of two different frequencies are passed through a non-linear network, the resultant output contains the original two frequencies, harmonics of the two frequencies, and inter-modulation products of the two frequencies.

If the non-linearity arises at the semiconductor interface or junction then adding a direct current bias should increase the non-linearity to the extent it could be used in the field under normal field current densities of around 1.0 μA/cm^2. Work by previous investigators found the DC bias increased the effect 3 to four-fold.

Test work on core in the laboratory indicates that the effect is detectable at field current densities, although the measured inter-modulation products are 3 orders of magnitude less than the primary signal.

At CSIRO, recent laboratory based reinvestigation into non-linear properties of sulphides has been undertaken with a view towards field application. This study used modern electronics and signal processing to ascertain if this system could be viable in the field.

This presentation highlights some of the history, theory and problems associated with using non-linear conduction in sulphide mineralisation as an exploration tool.

FIELD TRIALS OF THE BIASSED HETERODYNE METHOD OF EXPLORATION OF EXPLORATION FOR SULPHIDE MINERALS

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The Biassed Heterodyne (BH) method uses the fact that sulphides are semi-conductors hence electrical junctions between sulphide grains can be non-linear in terms of current through versus potential across the junction. Other conductors in the earth such as electrolytic pathways, clays and graphite are likely to conduct electricity in a linear fashion. By galvanically transmitting two frequencies into the ground, intermodulation frequencies are generated in areas that have a significant proportion of non-linear conduction from sulphide minerals. These intermodulation frequencies should be able to be measured to map the subsurface location of sulphide bodies. Laboratory tests have shown the desired signal is extremely weak compared to the transmitted signals, and so a DC bias signal is also transmitted to enhance the heterodyne signal and aid in noise reduction.

Field tests of the method have been conducted at the Kempfield silver barite deposit near Bathurst NSW. The tests were conducted over an area of known massive sulphide mineralisation. Three IP transmitters were used for the primary and bias signals. These were arranged in a gradient array configuration. The two primary transmitters were run to produce 50 and 80 Hz square waves such that the difference heterodyne frequency of 30 Hz lies in the minimum between telluric and sferic natural noise. The bias transmitter is a standard castle waveform IP transmitter operating at 0.03125 Hz (8 second pulses). The primary signals are transmitted by modified GGT 30 Zonge IP transmitters. The receiver is a high sensitivity, high dynamic range A to D converter and spectrum analyser.

It is hoped that processing of the data can use the difference in heterodyne signal between the different periods of bias signal, such as the difference between positive and zero bias, to reduce noise to a level such that the difference intermodulation signal can be seen above the noise and thus be used to map subsurface sulphide minerals.

GETTING A BETTER CONTROL OF IP DATASETS WITH GDD'S NEW IP POST-PROCESSING SOFTWARE

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There used to be a time when an entire Resistivity/IP acquisition day had to be re-surveyed; wrong survey parameters had been set, timing errors had occur, repeatability of readings was poor, etc. This frustrating outcome was partly due to the impossibility of accessing full wave data and/or the lack of post-processing tools provide with geophysical instruments. For both ground and borehole EM and IP surveys, the situation remained a problem for a long time until recently some manufacturers have begun to offer access to the time series along with a software to thoroughly visualise and process the data.

Instrumentation GDD, a Canadian manufacturer of geophysical instrument since 1976, is one of them. The GDD IP receivers full wave data were accessible since 2009 but users can now use the new IP post-processing software. This presentation will include many examples of real data collected in different parts of the world for which it has been possible to: validate the nature of external noise to modify acquisition parameters and improve survey results, correct synchronisation off-set between the transmitter and the receiver, manually discard noisy half-cycle to recover data in specific cases for which the receiver algorithm did not perform well, enhance the apparent resistivity calculation using real-time current measurements at the transmitter controller, modify the Vs decay windows scheme in order to fine-tune chargeability responses in specific geological environments, and more.

THE EFFECTIVE USE OF FORWARD MODELLING AND PETROPHYSICAL ANALYSES IN THE APPLICATION OF INDUCED POLARISATION SURVEYS TO EXPLORE FOR DISSEMINATED SULPHIDE SYSTEMS IN THE PATERSON PROVINCE, WESTERN AUSTRALIA

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The Citadel Project is a JV between Rio Tinto Exploration (RTX) and Antipa Minerals extending over 400 km^2. The project is targeting disseminated and massive copper sulphide systems beneath 40 to 120 m of transported Permian cover with intermittent Cenozoic sand dunes. Dipole–Dipole (D–D) and Pole–Dipole (P–D) Induced Polarisation survey configurations were chosen as a cost effective method to prioritise the 16 target areas for drilling. Induced Polarisation (IP) survey traverses over the known gold–copper–silver±tungsten Calibre and Magnum deposits and the high grade polymetallic Corker deposit illustrated the effectiveness of the IP method for detecting mineralisation and led to a 127 line km D–D and P–D Induced Polarisation surveys being undertaken in the 2016 field season. The IP surveys highlighted multiple chargeablility anomalies along the Calibre structural corridor.

On completion of drilling, forward modelling of chargeability and resistivity data combined with petrophysical analysis of selected core samples provided a platform for testing geological concepts. In addition, it allowed the correlation of the

chargeability/resistivity data with drilling results, and the validation of inversion results.

In 2017 a new Induced Polarisation survey program has been planned to further delineate Blue Steel target and evaluate the Calibre structural corridor. In spite of well-known limitations associated with the Gradient Array configuration, combining regional AEM surveys with forward modelling was able to illustrate this method as a cost effective solution for exploring the Calibre structural corridor.

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3G REGIONAL GAWLER ISA HALLS CREEK

A HIDDEN PALAEOPROTEROZOIC OCEAN-CONTINENT TRANSITION IN THE NORTHERN GAWLER CRATON

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Craton margins are known to host many major deposit styles across the globe and, constraining the spatial and temporal relation between permissive geometries and thermal drivers for alteration processes, are key for identifying prospective terranes.

Orthogonal deep crustal reflection seismic profiles provide insight into the three-dimensional crustal architecture of the north-western Gawler Craton, South Australia. Correlating between north-south seismic line 08GA-OM1 and east-west seismic line 13GA-EG1, has enabled the interpretation of a major crustal boundary separating the core of the Gawler Craton from re-worked crustal provinces to the west and north. We use seismic character, potential fields and magnetotellurics to locate and constrain the geometry of this major boundary, and isotopic signatures from sparse drillholes to characterise the crustal age and composition either side of the interpreted boundary.

In recent years, isotopic evidence has been used to infer the presence of early Palaeproterozoic oceanic crust having existed between the Gawler and Yilgarn Cratons. We present a new model for the north-western Gawler Craton, locating a transitional region between a cratonic core and this oceanic crust, and suggest that the craton margin was ~100 km inboard of current interpretations.

THERMOCHRONOLOGICAL HISTORY OF THE NORTHERN OLYMPIC DOMAIN OF THE GAWLER CRATON; CORRELATIONS BETWEEN COOLING AGES AND MINERALISING SYSTEMS

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The Olympic Domain of the Gawler Craton is home to the world class Olympic Dam Iron Oxide Copper Gold (IOCG) mineral deposit in addition to numerous other IOCG mineral deposits. The Olympic Domain preserves a complex geological history that began in the Palaeoproterozoic. However, most published work conducted on these IOCG deposits have focused on their initial formation, with only a few studies investigating the post-formation thermal history of the Olympic Domain. This study uses multi-method thermochronology by combining apatite U/Pb, muscovite and potassium feldspar $^{40}Ar/^{39}Ar$, zircon and apatite (U-Th-Sm)/He, and apatite fission track (AFT) dating to provide insights into the thermal history of the northern Olympic Domain between ~550°C and surface temperatures. Apatite U/Pb and muscovite $^{40}Ar/^{39}Ar$ record post magmatic cooling of the ~1850 Ma Donington Suite, and ~1590 Ma Hiltaba Suite. Potassium feldspar $^{40}Ar/^{39}Ar$ analyses record a cooling signal that is likely related to rifting in the Neoproterozoic Adelaide Rift Complex. A combination of AFT, and zircon and apatite (U–Th–Sm)/He dating preserves three thermal periods, at ~1000 Ma, ~430–400 Ma and ~200 Ma. The older two thermal periods are interpreted to be regional cooling. However, the youngest ages are preserved closest to known IOCG deposits suggesting that they reflect cooling of this elevated geothermal-gradient crust in the Mesozoic. These results have been modelled to produce a thermal history map of the northern Olympic Domain.

TECTONIC FRAMEWORK OF THE SOUTHERN MOUNT ISA PROVINCE

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The North Australian Craton consists of a series of latest Archean to Paleoproterozoic cratonic blocks including a number of orogenic belts. The Mount Isa Province and the Tennant Creek-Davenport Province are two components of the North Australian Craton. They are interpreted to be adjacent in the undercover section of the southern Mount Isa Province. However, there is no current understanding of the tectonic architecture of this relationship. At best, conclusions drawn from studies of outcropping relationships can be extrapolated undercover.

This study uses recently collected magnetotelluric data, combined with deep crustal seismic, to directly investigate the relationship between the Mount Isa Province and the Tennant Creek–Davenport Region. The deep crustal seismic was

collected along two orthogonal profiles capturing the relationship between the two regions, while the magnetotelluric data was collected in a regional grid over the junction between seismic lines, extending further west. The MT data was inverted before being jointly interpreted with the seismic data and available potential field data.

Magnetotelluric inversion shows a highly resistive mid to lower crust beneath the Mount Isa Province. In contrast, the mid to lower crust for the Ardmore May Downs domain (Tennant Creek-Davenport equivalent) is broadly conductive, with several discrete features. This is consistent with other MT data collected to the north and west of the project area and indicates significantly different geology or tectonic histories between the two domains. The seismic data shows a major west dipping fault which is likely to be a crustal suture between the two Provinces.

MAGMA EVOLUTION IN THE HALLS CREEK OROGEN; INSIGHT FROM GEODYNAMIC NUMERICAL MODELLING AND GEOCHEMICAL ANALYSIS

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The two plausible tectonic scenarios of the Halls Creek Orogen are examined through 2D thermo-mechanical-petrological numerical experiments based on I2VIS code. The initial constraints for model setup are appropriate to the inferred tectonic environment for the protoliths to the Tickalara Metamorphics in an intra-ocean subduction or ocean-continent subduction/collision. These numerical models allowed us to examine the conceptual models of geodynamic setting scenarios of the Halls Creek Orogen through time. With this approach, we determined experiments with specific physical parameters that are compatible with the geology observed in the Halls Creek Orogen. Finding the model most compatible with the geology can reveal geological processes which are not observable without the aid of geodynamic simulation. The results indicate that the geology of the Halls Creek Orogen is best represented by the ensialic marginal basin scenario. A further aspect of the numerical models is the degree to which they reveal magmatic activities which lead in the generation of key lithological units during the tectonic evolution of the Halls Creek Orogen. Development and closure of a marginal basin and the role of collisional magmatism are important parts of tectono-thermal evolution of the Halls Creek Orogen. The numerical models predict magma sources through time, linked to the tectonothermal evolution of the region. Whole rock and isotope geochemistry from the region has been used to verify and improve the models.

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3H GROUNDWATER

USING MICROGRAVITY TO CHARACTERISE WATER STORAGE AND USAGE AT KINGS PARK, PERTH, WA

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Kings Park in Perth is a well-known urban parkland and tourist attraction, and is one of few urban parks to preserve extensive native bushland (evergreen woody vegetation). A key question in assessing ecosystem health is water availability and use, especially in periods of drought. Since March 2015 the UWA in collaboration with the BGPA has conducted a time-lapse microgravity study of groundwater storage in Kings Park. Data collection has focused on seasonal to inter-annual change, with bi-monthly measurements extending across multiple days. Relative measurements are taken with a Scintrex CG-5 gravity meter and are referred to the Helena Valley reference station, which is located in the granite-dominated Perth Hills. Interim results (May 2017) suggest that measurement methods are sufficiently sensitive to characterise change, with measurement precision of ±2 microgals (approximately ±40 mm of stored water).

Two-month storage-changes are defined from the gravity data, and usage is further defined as rainfall minus storage-change. Storage-changes are positively correlated with rainfall ($r = +0.70$) and negatively-correlated with solar exposure ($r = -0.69$). Thus, a fairly strong signal is seen of increase during the winter wet season, and decrease during the summer dry season. Usage is positively correlated with solar exposure ($r = +0.312$) but also shows dry periods in late summer, where estimated usage is near-zero despite high solar exposure, and a high-usage period at the start of the wet season. Interannual change is substantial, and seems to be linked to the Indian Ocean Dipole, which was strongly positive in winter 2015 and strongly negative in winter 2016.

MICROGRAVITY SURVEYS ON THE NULLARBOR

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A series of 15 microgravity surveys were undertaken by the Geological Survey of South Australia to determine if cavities existed underground in specific locations on the Nullarbor Plain, South Australia. Survey spacing ranged from 10 m to 20 m in a regular grid pattern. The grids were 200 m by 200 m in size, with additional traverses extending from the centre of each grid

in the cardinal directions, the total lengths of these lines being 600 m.

An additional survey undertaken over the Koonalda Sinkhole exhibited a 1.2 mGal magnitude anomaly. The remaining sites exhibited a range of magnitudes, peaking at approximately 0.5 mGal. The gravity images display areas of high and low density suggesting variation in the density of the limestone consistent with possible cavities.

The microgravity results have been used to aid a scientific drilling program in the area. The position of the drill rig was moved to areas exhibiting high gravity to reduce the chances of the drilling intersecting caves, and to reduce the chances of heavy trucks potentially breaking the surface and falling into a cavity.

UNCERTAINTY ANALYSIS OF FAULTING AND FOLDING ON NEAR SURFACE AQUIFERS

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With advances in near surface geophysical techniques, notably Airborne Electromagnetics (AEM), great strides have been made in mapping near-surface (0–200 m) hydrostratigraphy, including aquitards and aquifers. However, an important uncertainty in the mapping of groundwater systems and resource estimation is the potential impact of faults to:

- Generate fault parallel fracture transmissivity;
- Reduce across-fault permeability; and
- Provide connectivity from one aquifer to another across aquitards.

It is vital to differentiate between faults and fault propagation folds associated with 'blind faults'. As AEM is an evolving technology a set of criteria based on sound structural geomechanical and structural geologic has been developed to discriminate between faults and folds.

Even with consistent and robust modeling there are fundamental uncertainties that require appropriate modeling using stochastic fault seal analysis. An extensive database of calibrations has been developed for the prediction of liquid hydrocarbon free water levels (FWL). Based on hundreds of hindcasting models FWL can be predicted with better than 10 m accuracy.

Despite this high accuracy prediction the juxtaposition area of across fault reservoir vs reservoir juxtaposition can vary by two or three orders of magnitude. The juxtaposition area is a key term in the calculation of across-fault Darcy Flow. Variation in area is strongly nonlinear and dependent on accounting for the thickness of aquitards and variation along strike of fault displacement. It is vital that geologically valid faults are analysed with the appropriate parameter uncertainty. Examples from the Broken Hill Managed Aquifer Project and the Sydney Basin will be used to illustrate the process.

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Accessibility, security key data management concerns, survey reveals

by VIRGINIA HEFFERNAN

The inability to find and access data via a single integrated search tool emerged as the biggest challenge for respondents to Geosoft's 2017 Geoscience Information Management Survey.

Consistent with Geosoft's past four surveys on the subject, the vast majority of respondents (83%) consider data management a critical or "top five" issue for their organization, compared with only 3% who consider it unimportant. But they continue to encounter challenges and barriers to success, especially how to find the data they need and keep that information secure.

Ranking of Data Management as an Issue

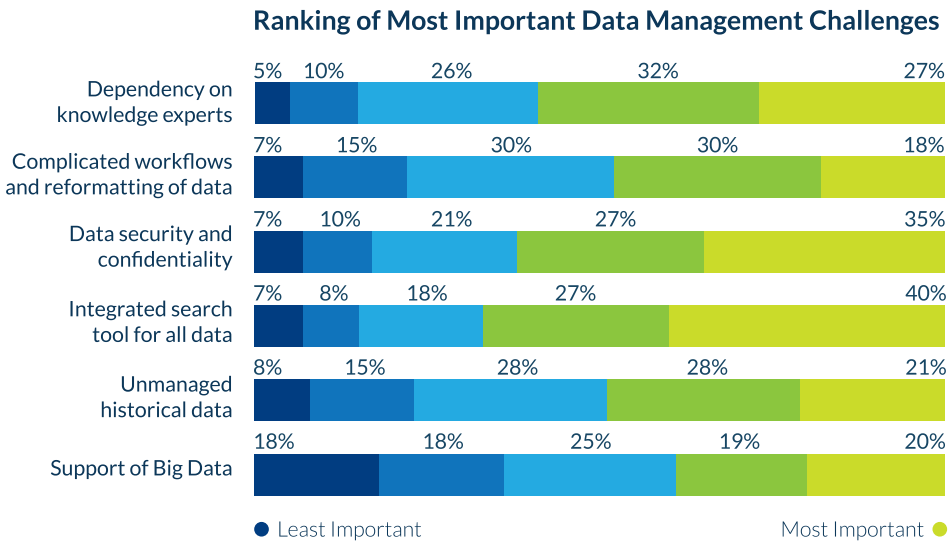
	2017	2015	2013
It is of critical importance	47%	48%	44%
Top 5 issue for our group	36%	37%	38%
On the radar, but not currently a focus	14%	12%	15%
Not important at this time	3%	3%	3%

This year, Geosoft received 1400 responses to the survey from 1000 organizations in 115 countries. Half of the respondents are from the mineral resources industry, while the remainder are from the government, energy, near surface or education sectors. Geoscientists – including geophysicists, geologists, GIS specialists and geochemists - represent 70% of the respondents. The rest identify as executives, managers, owners, data and IT administrators, teachers, researchers or students.

The top three most important data types for the participants were geological, geophysical and drill hole or well data. The majority manage this data either on their own or within a folder or file structure on a centralized server, rather than use a commercial solution. More than 60% are confident in the way their organizations handle the quantity and quality of data.

"It's promising that most respondents have confidence in their organization's current data handling, but being able to find and access all their data from a single search tool remains a challenge," says Ken Howieson, Geosoft's Vice President of Services.

In 2017 the survey was expanded with new questions to reflect the rising importance of the cloud and to gain a better understanding of the challenges organizations face when implementing a data management solution.



Here are some key observations:

Search tools need improvement

Asked to rank the comparative importance of data management challenges, respondents from all groups put the inability to find data through an integrated search tool at the top. Data security was a close second while dependency on knowledge experts also emerged as a pressing concern, especially for data administrators. By comparison, the biggest data management challenge in 2015 was the amount of unmanaged historical data.

Geoscientists spend valuable time managing data

Geoscientists spend 20-50% of their time managing data according to almost half of the respondents, time they could be devoting to other critical tasks such as exploration. In the 2015 survey, a quarter of the respondents did not know how much time their geoscientists spent on data management. But that number dropped to 11% in 2017, suggesting there is a growing awareness within organizations about the time and human resources required.

Culture and complexity outweigh cost as barriers

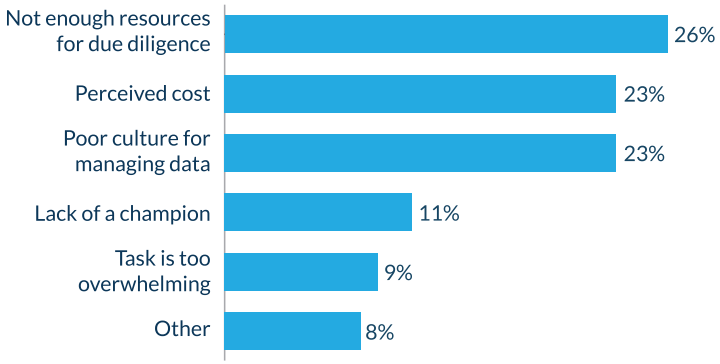
For the 2017 survey, Geosoft asked respondents what the main challenges are when selecting and implementing a data management solution. A lack of dedicated resources to complete due diligence, a poor culture for managing data and perceived cost are major, similarly ranked concerns. However, for the 47% of respondents who consider data management a critical issue, cost is less of a concern.

Most respondents would prefer to purchase an in-house (31%) or cloud-based (24%) solution while 24% - more among government and energy organizations – are inclined to develop and in-house proprietary solution. Only 12% would like to maintain the status quo, allowing end users to manage their own data, and 8% would outsource their data management.

Once a data management solution is in place, the complexity of integrating data silos becomes the main concern followed closely by the time and resources required to

maintain and fully populate the solution. Just 17% of the respondents rank cost as the most important consideration.

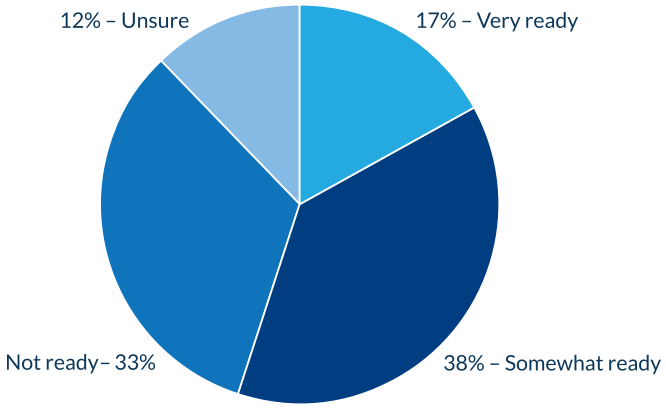
Biggest Challenge When Implementing a Solution



Security concerns limit use of cloud

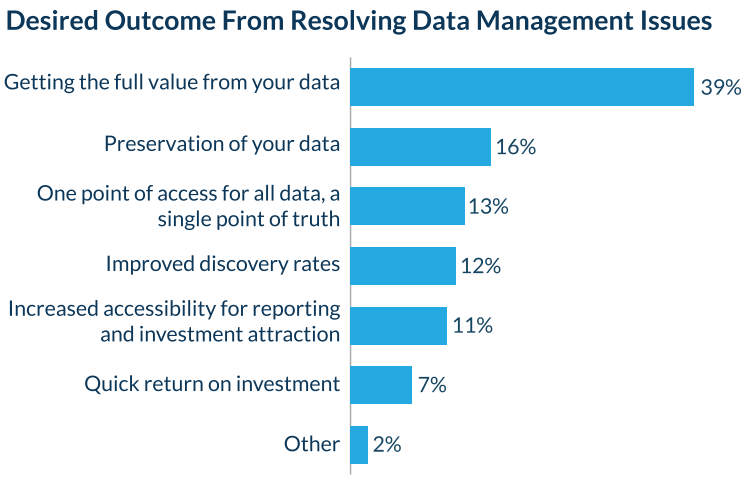
Even though more than half of respondents feel they are "very " or "somewhat" ready to leverage the cloud for geoscience data management and access – and many already are - a full 32% consider security the cloud's biggest drawback. Cost, performance and reliability are also concerns, but keeping data secure is by far the most common challenge. The exceptions are those working in the education sector or who identified as data administrators. They are more worried about cost.

Readiness to Leverage the Cloud



Getting full value tops the wish list

About 40% of the respondents feel that the most significant outcome from resolving data management issues would be to get full value from their data. Next on the wish list are preserving data, having one point of access for all data, increasing discovery rates, and improving accessibility for reporting and attracting investment. Geosoft broadened the outcomes question in 2017 to include more options based on feedback from previous surveys.



Conclusions

Accessibility and security concerns are holding organizations back from getting the full value of their data. To save time and increase efficiency, they need to a single search tool. To properly leverage the computing power of the cloud, they need better security.

Most respondents would prefer to purchase a commercial solution to outsourcing or developing a solution in-house. While cost remains a significant barrier, limited resources for due diligence or a poor culture for managing data are also preventing organizations from selecting and implementing geoscience data management solutions.

More information is available in the survey report which can be downloaded from the Geosoft website.

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4A PNG AND NZ

INNOVATIVE EXPLORATION IN PAPUA NEW GUINEA; PAST, PRESENT AND FUTURE

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Two of the recent, global gas discoveries and field extensions, Pnyang and Muruk, were in the mountainous jungle of PNG requiring innovative exploration techniques. Prior to the 1970s, PNG prospects were defined by field mapping and drilled where there was river access. Regional gravity data, refraction data and heli-supported rigs led to the drilling of wells in the Highlands in the 70s, including using slim-hole rigs, leading to major oil and gas discoveries in the 80s. These targets were almost all defined by detailed structural modelling of outcrop data as the few seismic reflection lines were of limited value. During the 90s many new techniques were tried, including passive seismic, magneto-tellurics, aeromagnetics, fission track analysis and Sr isoptope dating of the Miocene limestones, as well as improved, but expensive, seismic acquisition. The modern era of enhanced exploration has been facilitated by access to high-resolution 3D digital data, particularly topographic data that has allowed meaningful static corrections to gravity, magnetics, EM and 2D seismic data as well as the construction of detailed 3D structural models. In the future it is unlikely that reflection seismic data will significantly improve, but the order of magnitude improvements in gravity gradiometry combined with topography defined by LIDAR will make it a significant 3D exploration tool. 3D Finite element mechanical modelling of structures will become routine, constrained by new dating techniques such as limestone thermochronometry. This will facilitate 3D basin modelling and much improved exploration efficiency, likely to lead to a new wave of discoveries. The easy plays have been found. The hard plays are now increasingly detectable.

4D CHARACTERISATION OF PNG'S PETROLEUM SYSTEMS

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Mesozoic and Tertiary clastic and carbonate reservoirs are prolific producers of high quality liquid-rich gas. Onshore PNG. LNG projects are among the lowest cost and most profitable globally. Accordingly there has been a recent resurgence of petroleum exploration in PNG.

In 2015 Oil Search undertook a country-wide petroleum Common Risk Segment analysis that highlighted potential for giant new oil and gas fields of sufficient scale to support future LNG projects. It also concluded that 40 trillion cubic feet of gas plus 550 million barrels of oil resources remain to be found (representing approximately 60% of PNG's total petroleum resource).

In 2016 Oil Search completed an ambitious integrated structural, stratigraphic, burial, maturation, migration, uplift and erosion model of PNG's total petroleum system to quantify the locations for highly prospective under-explored regions.

Tectonic events at plate and basin scales were re-assessed and correlated within a new country-wide PNG chrono-stratigraphy of regionally mappable sequences and flooding events, some of global extent.

A base Tertiary mega-sequence boundary is mappable over the entire onshore to deepwater regions. 130 1D burial models combined with restored 2D structural and stratigraphic cross sections, have contributed to a new regional petroleum charge model of the foldbelts, foreland and offshore regions.

It is concluded that petroleum was generated pre-foldbelt during Late Cretaceous times in interior PNG, while petroleum is currently being generated at the present day mountain front.

A holistic 4D charge model explains why very young foldbelt traps are petroleum charged.

STRUCTURAL AND RESERVOIR DEVELOPMENT OF THE WESTERN PAPUAN BASIN GAS AND CONDENSATE FIELDS

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The Stanley, Elevala, Ketu and Ubuntu gas-condensate fields are located within the foreland of the Western Papuan Basin, PNG. Interpretation of 2D seismic across the basin has revealed the importance of basement architecture and the regional Northwest trending 3KB fault system for trap and reservoir development.

The Miocene/Pliocene compression, responsible for the thrust structures of the Papuan Foldbelt, had a relatively minor topological impact in the foreland. However, trap development within the Western Papuan Basin was influenced by this compression through inversion of pre-existing faults and enhancement of compactional drape of reservoirs over pre-existing basement highs.

Economically viable reservoirs (Elevala, Toro and Kimu Sandstones) have been intersected by several exploration and appraisal wells in the Western Papuan Basin. The Kimu and Elevala Sandstones are absent in the main producing fields of PNG, consequently very little is known about the depositional controls of these reservoirs. A detailed reservoir characterisation study was required to underpin foreland resource development and evaluate potential hydrocarbon recovery. Geophysical reservoir characterisation techniques were of limited value due to the poor vertical resolution of the reservoir on the 2D seismic, therefore core data and sedimentary analogues were used to map the spatial distribution of reservoir sands and develop palaeogeographic models.

Horizon Oil's activities within the Western Papuan Basin have contributed to the understanding of the structural regime and reservoir development of the area, proved commercial resources

and highlighted numerous prospective structures. The purpose of this paper is to present these findings from a relatively under-reported region of PNG.

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4B WEST AUSTRALIAN BASINS SYMPOSIUM

ONSHORE INVENTORY – TARGETING NEW BASINS (OFFICER, PERTH, CANNING BASINS)

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Following the 2016 publication of Volume 1 of the Onshore Basin Inventory, Geoscience Australia is continuing to provide a concise inventory of available data and current geological knowledge of onshore basins of Australia. In Volume 2, presented here, three new basins, the Canning, Officer and Perth basins expand on this work. These reports provide a comprehensive, whole of basin inventory of the geology, petroleum systems, exploration status and data coverage for these basins. They incorporate information gathered by the precompetitive work programs undertaken by Geoscience Australia and state and territory governments, as well as publically available exploration results and geoscience literature. This information, in conjunction with the eight previously released basins, will assist in advising the Australian Government, state and territory governments and other stakeholders, such as the petroleum industry, about the exploration status and potential hydrocarbon prospectivity of onshore Australian basins. Furthermore, this work provides an assessment of outstanding issues and unanswered geological questions, and provides recommendations for future work to address these.

LINEAR TRENDS OF PALEO-POCKMARKS AND FLUID FLOW PIPES IN THE JURASSIC AND TRIASSIC SEDIMENTS OF OFFSHORE NORTHWEST AUSTRALIA

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This study records 319 paleo-pockmarks with associated focused fluid flow pipes within the Jurassic and Triassic sediments over three study areas on the Exmouth Plateau, offshore Northwest Australia. The paleo-pockmarks are identified along a surface that represents the top of the Jurassic sediments, while the fluid flow pipes extend into the Triassic sediments from the base of the pockmarks. The pockmarks and pipes form in linear trends that are parallel to and laterally offset from the tops of extensional faults that extend from the top of the Jurassic sediments into the Triassic sediments where they terminate. The bases of the fluid flow pipes are observed to intersect and terminate along the extensional faults within the Triassic sediments. The pockmarks and associated fluid flow pipes are interpreted to have formed by extensional faults intersecting an overpressured unit in the Triassic sediments. This caused a localised reduction of lithostatic pressure along the overpressured sequence at the intersection which then acted as a focal point for the fluids to migrate vertically. The source of the fluid overpressure could not be confirmed in this study. The Triassic sequence is a known hydrocarbon source and 1D modelling shows that at the time of the fluid flow and pockmark formation, the Triassic sediments were entering the hydrocarbon production window. However, no evidence of hydrocarbons associated with the pockmarks was observed. Our findings identify fluid migration pathways that are seal risks for hydrocarbon reservoirs, but could also potentially be fluid migration pathways that were previously untested.

THE EFFECT OF FLEXURAL ISOSTASY ON DELTA ARCHITECTURE: IMPLICATIONS FOR THE MUNGAROO FORMATION

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The fluvio-deltaic Triassic Mungaroo Formation, North West Shelf of Australia, hosts vast resources of hydrocarbons. However, the mechanisms that generated its 4–6 km monotonous infill architecture (colloquially known as layer cake stratigraphy) remain elusive. The vertical fluctuation between fluvial and shallow marine deposits indicates that accommodation was created simultaneously with deposition. This suggests that the stratigraphic style of the Mungaroo formation was significantly controlled by the isostatic compensation of the sediment load. To test this we use a basin and landscape dynamics model, BADLANDS, that combines fluvio-deltaic processes (erosion and sedimentation) with flexural isostasy. To drive our simulations we use dimensions, gradient, water discharge and sediment flux from seismic and scaling relationships extracted from the Mungaroo Formation and different lithospheric elastic thickness (Te) to account for the effect of dissimilar lithospheric rigidities and flexural isostasy. Results show an increase in delta size and decrease in sediment thickness as the lithospheric elastic thickness increases. These models help explain how thick deltaic sequences can be generated in a lithosphere with low Te values. This is in accordance with deep seismic data that shows lithospheric thinning underneath the Triassic Mungaroo delta. Future research will focus on comparing the synthetic stratigraphy extracted from the models with the stratigraphic record. This study provides a valuable quantitative approach for understanding how the isostatic compensation of the sediment load can control the architecture of fluvio-deltaic deposits, which has implications for reservoir modelling.

MESOZOIC TO CENOZOIC DEPOSITIONAL ENVIRONMENTS AND FLUID MIGRATION WITHIN THE CASWELL SUB-BASIN: KEY INSIGHTS FROM NEW INTERPRETATION AND MODELLING OF THE SCHILD PHASE 2 3D

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The offshore Browse Basin formed as a result of several phases of tectonic development occurring throughout the breakup of the

North West continental margin of Australia. The major basin forming events which consisted of cycles of extension, inversion and thermal subsidence occurred from the Permian through to the Late Cretaceous. The basin architecture is characterised by a series of north-east trending depocenters, including the south-eastern Yampi and Leveque shelves; the central Caswell and Barcoo sub-basins; and the outboard deep water Scott Plateau. The Schild II Broadband 3D survey is located approximately 170 km off the West coast of Australia within the Caswell sub-basin, which is a major central depocenter of the Browse Basin. The survey is in close proximity to the Icthys gas field and Cornea oil field, covering approximately 2460 km², in water depths ranging from approximately 200 to 300 m. New interpretation has been undertaken, including stratal slicing and attribute analysis to identify and delineate depositional features and potential hydrocarbon targets within the Schild 3D. In addition to mapping key target intervals, primarily the Jurassic Plover Formation, the interpretation of large structures at considerable depth provides new insights into the prospectivity of older Mesozoic and Paleozoic intervals. Of key relevance is the presence of deep structures that represent potential candidates for Permian events associated with glaciogenic deposition. Structures potentially associated with salt mobilisation have also been inferred from pre-existing seismic interpretation in the area.

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4C NON CONVENTIONAL

INTEGRATED SEISMIC (IS) FOR SHALE GAS EXPLORATION AND MANAGEMENT

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Seismic integration has been a successful accessory in every data interpretation project. For shale gas exploration design, development and implementation, high-resolution seismic data are necessitated. In this context, every exploration project needs multi-disciplinary datasets and their integration that can minimise the ambiguity of the interpretative outcomes. What are integrated solutions for imaging and interpreting shale gas and how do they impact our shale prospect business? How do we organise and standardise our integrated workflows to address issues of exploration, field development, including drilling campaigns of the unconventional reservoirs? So far, the conventional reservoirs of many worldwide basins did produce even without integrated workflows. With the increase in intricacy in structural and stratigraphic settings, in particular with the fractured shale environments, exploration and field development plans have become multifaceted, complicating the field operations. How do we take on the exploration, development and drilling campaign decisions using the integrated seismic solutions? How do we suggest the 'integrated seismic' to our valued operators and service providers? Why are the conventional technologies failures and setbacks? How can we guide and recommend the petroleum companies on appropriate technologies and the reserve computations in shale gas environments? We come up with an 'Integrated Seismic' (IS) strategy, addressing these issues and challenges. The applicability and feasibility of IS in various exploration projects including their execution and implementation in worldwide shale gas basins are discussed. IS has been playing a vital role, making huge impacts on the integrated interpretation projects, especially during prospect identification and risk evaluation stages.

USING MULTIAZIMUTH SEISMIC DATA FOR ANISOTROPY ESTIMATION IN AN UNCONVENTIONAL RESERVOIR

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There are various static and dynamic reservoir characteristics that control the prospectivity and productivity of wells in an unconventional reservoir. Many of these characteristics have proxies among pre and post stack attributes that can be derived from Multiazimuth Seismic data. Amplitude and velocity variation with azimuth can be used to predict fracture strike and relative fracture density and define potential structural sweet spots. P-wave velocity and amplitude information from a Multiazimuth 3D seismic data (calibrated to wells) has been used in the Nappamerri trough, Cooper Basin to estimate fracture intensity and orientation. Stress maps were generated to identify areas of higher anisotropy and areas of lower minimum horizontal stress. The use of P-waves to detect azimuthal anisotropy represents a significant cost benefit when compared to the traditional use of shear waves for this purpose. Application of this technique provides a lower cost seismic tool (when compared to 3D multicomponent seismic), to identify reservoir 'sweet spots' and is anticipated to improve drilling results.

A NEW COMPUTATIONAL MODEL TO PREDICT BREAKDOWN PRESSURES IN CASED AND PERFORATED WELLS IN UNCONVENTIONAL RESERVOIRS

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Unconventional shale reservoirs are characterised by their extreme low permeabilities and their high *in situ* stresses. Multi-stage hydraulic fracturing therefore plays a key role in developing such reservoirs. However, depending on the *in situ* stress magnitude and/or regime, breakdown pressures can be too extreme to achieve, given the available surface horsepower capabilities. The local principal stresses surrounding perforation tunnels dictate the required breakdown pressure to induce enough stress to exceed the rock tensile strength.

This paper presents a newly developed model to predict the breakdown pressures in cased and perforated wells. Given an arbitrary azimuth and inclination of the wellbore and the *in situ* stress magnitude/regime, the model calculates the local stresses around the perforations and consequently predicts the perforations' breakdown pressure and the initial fracture plane orientation.

The results from the model indicate as to which perforation initiates first, creating a mini-fracture that extends to create a dominant fracture. This dominant fracture would be the only fracture extending, due to the induced stress shadowing on other mini-fractures and increasing the respective in-situ principal stresses. The model also aids cluster and well placement for highly deviated wells to better identify sweet spots where breakdown pressures are minimal, resulting in maximum hydrocarbon accumulations possible. If the perforations clusters are placed in zones with extreme local principal stresses, the near wellbore fracture widths would be too small to admit any proppant, leading to early proppant screenout. The results from the model shows a critical perforation phasing angle that should be avoided, as the local principal stresses maximise, increasing breakdown pressures. The model aims to advance the current understanding of fracture initiation in highly deviated wells in shale reservoirs. It can also assist engineers to better select sweet spots for well and cluster placement to avoid excessive breakdown pressures and/or potential early proppant screenout.

AN OPTIMISED HYDRAULIC FRACTURING TREATMENT ON CHALLENGING RIZQ FIELD

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Hydrocarbon production from unconventional reservoirs is often associated with hydraulic fracturing operations. In many cases however, the high *in situ* stresses and complex natural fracture network hinder an effective stimulation process. Therefore, different strategies are adopted to increase the success chance of stimulation. These strategies are in many cases field dependent and thus cannot be extended to other fields. In this study we demonstrate a new work flow introduced to ensure a successful stimulation process in an unconventional gas field in Pakistan. Well Rizq-01 was drilled as an exploration into challenging PAB formation which is tight sandstone with 0.3 mD permeability but highly fractured. Exploration wells in offset fields were drilled and stimulated in the same formation and resulted in screening-out and inability to place enough proppant due to fracture complexity and high in-situ-stresses. To overcome these challenges, extensive petrophysical and geomechanical analysis were performed to introduce a new workflow for stimulation.

The workflow includes:

- Extracting the intensive well log information for better understanding of stress barriers, stress magnitude and orientation, Young's Modulus, formation fluid information, etc.
- Sensitivity analysis on the hydraulic fracturing Treatment including the proppant size, type and volume, and fluid system. The design was based upon geomechanical and petrophysical interpretations of the openhole log data.
- Redesigning the fracturing treatment process utilising a first-of-its-kind onsite pre-frac test results, providing it helpful in the absence of bottomhole gauge.

The study therefore summarises the challenges, the work flow implemented, and the lesson learnt for successful stimulation job in Rizq Field.

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4D GEOPHYSICS TECHNOLOGY

MATHEMATICAL PROPERTIES AND PHYSICAL MEANING OF THE GRAVITY GRADIENT TENSOR EIGENVALUES

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The eigenvalues of the gravity gradient tensor can be expressed as functions of two parameters: a magnitude and a phase. The decomposition gives physical meaning to the eigenvalues: the magnitude measures the amount of curvature and the phase is related to the type of source. A modified phase eigenvalue offers the interpreter an enhanced version of the vertical gravity gradient which is demonstrated with model data and applied to FALCON airborne gravity gradiometer data from the Perth Basin, Australia.

APPLICATION OF FREQUENCY DOMAIN INDUCTION EM SOUNDINGS WITH CONTROLLED SOURCE (FDEMS METHOD) FOR PRECISE TRACING OF BOUNDARIES IN GEOELECTRICAL SECTIONS

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The FDEMS method was introduced in the former USSR at the turn of the 50s and 60s of the last century as an integral part of the triad of induction EM methods (MT, FDEMS, TDEM), which were actively developed in the 50s after the grand discoveries by A. N. Tikhonov and L. Cagniard. The method was not widely used, primarily due to lack of suitable hardware and software for data processing and interpretation. Nevertheless, FDEMS was actively developed in certain regions of Russia and Ukraine until the present day. Interest in the method is supported by the potentially high accuracy of mapping high-resistivity boundaries, since in the FDEMS method there is a direct relationship between the ratio (R/H) of the sounding spacing (R) to the depth (H) to the high-resistivity reference horizon pronounced by significant points of amplitude and phase frequency characteristics (curves). A number of successful FDEMS surveys were completed on the Ukrainian Shield and its slopes, Dnipro-Donetsk basin (Ukraine) and different parts of Russia and Uzbekistan that achieved positive results (1977–2000). To date, the capabilities of modern multifunction and multichannel equipment and software for processing and interpreting field data allows to realise to a large extent the prospective capabilities of the FDEMS method for high-precision mapping of boundaries in the geoelectric section and mapping of low-contrast objects.

APPLICATION OF PASSIVE SEISMIC IN DETERMINING OVERBURDEN THICKNESS: NORTH WEST ZAMBIA

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There are several ways to estimate the overburden cover thickness. One of the non-invasive and inexpensive ways to rapidly estimate the cover thickness is the Horizontal-to-Vertical Spectral Ratio (HVSR) of the ambient seismic noise method. This approach utilises a broadband three-component sensitive seismometer to record ambient noise (or microtremor) induced by the wind, ocean waves and several anthropogenic activities. These microtremors are mainly composed of Rayleigh Waves propagate in the surface layer.

Tromino, which works on HVSR principle, is a very light and portable instrument that records seismic noise in the frequency range of 0.1 to 1024 Hz and capable of estimating overburden cover greater than 80 meters depending on the ambient noise strength and geological setting of the area.

The average ratio of the horizontal-to-vertical (H/V) component of the shear wave (Vs) spectrum is used to calculate the resonance frequency at a particular station, which is used in inferring the overburden thickness using one or more existing drillholes in the area or local geological knowledge about the overburden. This paper discusses different methods to calculate the overburden thickness, which includes calculation using regression equation or hybrid approach.

This paper shows the results of a Tromino survey in North West Zambia and comparison of estimated overburden thickness using different methods. The results were further compared with those determined from Audio-magnetotellurics and drilling data. Tromino successfully estimated the overburden thickness and mapped the bedrock topography with reasonable accuracy.

SCINTILLATORS FOR SPECTRAL GAMMA-GAMMA AND PGNAA IN MINERAL EXPLORATION

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Current gamma-ray detectors, based upon scintillation, are not likely to perform well in narrow diameter logging-while-drilling (LWD), such as NQ diamond drilling. The normally used scintillators of NaI, CsI and BGO materials, are not sufficiently dense to properly represent the gamma ray spectrum. Also, their resolution is not high enough to compensate for lack of stopping power in PGNAA applications. In the case of BGO it performs so poorly with respect to resolution and temperature sensitivity that the higher density does not compensate fully.

We have evaluated several novel halide and oxide scintillators that might improve the viability of spectral Gamma-Gamma and PGNAA in small diameter LWD. Specifically, we have looked at GAGG, YAP, SrI, CWO and ZWO scintillators and found that GAGG and CWO are good for spectral Gamma-Gamma use and that YAP and SrI may be a useful alternative to LaBr in PGNAA applications. However, we believe that very dense scintillators such as LGSO with moderate resolution capability are even better for measuring line spectra from PGNAA with small, less than 40 mm diameter, scintillator detectors.

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4E STRATEGIC AND INDUSTRIAL

STRATEGIC AND INDUSTRIAL MINERALS LEADING THE NEXT PRODUCTION REVOLUTION

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The last decade of rapid industrialisation and urbanisation particularly in China led to a rapid growth of minerals particularly those required for infrastructure and construction.

The next decade will be equally dramatic but the growth will shift to the minerals required for the next production revolution including renewable energy, energy storage and energy reduction.

Minerals containing materials such as lithium, vanadium, graphite and cobalt are used in batteries and demand is estimated to grow at 14% CAGR. Other minerals such as rare earths, high purity alumina and high purity quartz are also expected to be in high demand.

The expected growth in electric vehicles will encourage changes in the production and demand of traditional materials such as steel and glass as well as changing demand for metals such as copper and aluminium.

Understanding these changing market forces and the changing demand for minerals is essential to determine where future exploration and capital investment will be most effective.

THE PILGANGOORA LITHIUM-TANTALUM DEPOSIT – GEOLOGICAL OVERVIEW AND EVOLUTION OF DISCOVERY

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The Pilgangoora Lithium-tantalum pegmatite deposit with a total resource of 156.3 Mt grading 1.25% Li_2O and 128 ppm Ta_2O_5, is a globally significant hard-rock lithium-tantalum deposit. The deposit is located in the East Pilbara Terrane of the northwest Pilbara Craton in Western Australia. The Northwest Pilbara Craton is one of the world's major lithium-tanatlum provinces with large scale lithium-caesium-tantlum bearing pegmatites located at Mt Francisco, Wodgina, Pilgangoora and Strelley.

Pegmatites bearing columbite-tantalite at Mt. York were first described in government geological surveys in 1906. Subsequent interest in the pegmatites focussed on their tin and tantalum mineral potential, with small scale hardrock, eluvial and alluvial mining, chiefly in the period 1947–1978. Larger scale alluvial and eluvial mining of tin-tantalum was carried out over 1978–1982 and 1992–1996 by a number of junior companies. In May 2014, Pilbara Minerals acquired the Pilgangoora Project for its lithium potential and has since drilled over 1450 holes for approximately 120 000 metres.

The Pilgangoora pegmatite intrusions crop out in a well exposed greenstone belt, with little weathering at surface. Exploration drilling programs along with detailed geological mapping of the Pilgangoora tenement group has provided a better understanding of the geological setting of the fractionated pegmatite intrusions within the East Strelley greenstone belt. This work has led to the recognition of some valuable exploration criteria that may be applied locally to locate additional resources and, longer term, may be used more strategically to review other pegmatite fields across the Pilbara region.

EVALUATING RARE EARTH DEPOSITS

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There has been a significant growth in exploration activity for rare earth element (REE) deposits since the firming of prices began in 2003. Numerous deposits have been subject to detailed evaluation, though during this period only one new operation at Mt Weld, Western Australia is in production. One older operation at Mountain Pass, USA, re-opened in 2012 but, due to low rare earth prices, shut down in 2015. Chinese production dominates the world rare earth industry, accounting for approximately 85% of the world's annual production of ~110 000 tonnes, from numerous deposits in five provinces. It is reported that approximately 45 000 tonnes of Chinese production is illegal.

The talk will discuss a number of types of rare earth deposits including those hosted by carbonatite, alkali- intrusives and supergene material including heavy rare earth enriched examples. One important case-study will be discussed. The Mt Weld deposit, in Western Australia, was put into production after a 30 year exploration history and was only successfully drilled after 1991 once the regolith that hosts the mineralisation had been de-watered. This enabled the recovery of samples that had not suffered from the loss of fines. Its first reported resource estimates in 2002 achieved close reconciliations within a few percent of actual mined material.

In general, cut-off grades used to report resources for many REE deposits are unrealistically low and significantly less than those used by the only two recent Western operations. These cut-offs result from attaching notional values on the basis of available metal prices and unrealistically low costs associated with production and sales.

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4F MAGNETOTELLURICS

PARTICULARITIES OF 5-COMPONENT MAGNETOTELLURIC SOUNDINGS APPLICATION FOR MINERAL EXPLORATION

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In the application of electroprospecting for mineral exploration, there are few clearly observed trends based on the development of electroprospecting technologies. These are hardware, software and computer technologies aimed at: (a) the increase of electroprospecting application in comparison with other EM methods; (b) application of electroprospecting at all stages of the exploration cycle; (c) the increase of application of induction electroprospecting methods. These technologies are based on the study of the natural EM field of the Earth (NEMFE). A special role here is played by the method of Broadband Magnetovariational Profiling (BMVP).

Three stages in the application of electroprospecting are quite clearly distinguished: (a) exploration for new mining provinces according to the distribution of resistivity in the Earth's crust and upper mantle (the AusLAMP project, a revolutionary idea proposed by Australian scientists; deep MT, scale 1 : 5 000 000 – 1 : 1 000 000); (b) exploration for large conductive ore bodies, areas with a prospecting survey square area of more than 100 km^2 by airborne geophysics, for areas with smaller size – 5-component AMT on a scale of 1 : 200 000 – 1 : 50 000; (c) detailisation and support of drilling operations, mapping of veins and dikes – 5-component AMT on the scale 1 : 20 000 – 1 : 5000 in complex areas with induction and geometric soundings using control source if Induced Polarisation is an exploration factor.

SFERIC SIGNALS FOR LIGHTNING SOURCED ELECTROMAGNETIC SURVEYS

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Lightning strikes generate electromagnetic (EM) waves, known as sferics, which are used in passive Audio-Frequency Magnetotelluric (AMT) and Geomagnetic depth soundings (GDS). Global lightning networks detect sferics and catalogue the time and location of up to four million lightning strikes per day. In this research, we use lightning network data to predict time of arrival, azimuth, and amplitude for each known sferic in our time series EM data.

A significant and ill-posed problem in conventional AMT surveys is the identification and removal of galvanic distortion. Since conductors effectively rotate electromagnetic fields, we infer the location and geometry of local and regional structures by calculating the rotation of measured data from their predicted

arrival azimuths. To demonstrate our approach, we carried out a Global Positioning System (GPS) synchronised AMT survey along a profile over a known mineral deposit in Western Australia, using a local AMT reference site to estimate electromagnetic field gradients along the survey profile. Assuming that the roving and reference sensors observe the same primary field, then the gradient operator effectively removes primary fields leaving only secondary fields generated by subsurface conductors. We used lightning network data to correct our reference data for local distortions, and then calculated profiles of the magnetic field gradient over the known conductor. Forward modelling of Fixed Loop Electromagnetic (FLEM) data corroborates our GDS results.

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4G REGIONAL MAPPING

NATIONAL MINERAL EXPLORATION STRATEGY: A VISION FOR UNLOCKING AUSTRALIA'S HIDDEN MINERAL WEALTH

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The National Mineral Exploration Strategy sets out a 5-year program to overcome major challenges to discovery of new mineral deposits in frontier terrains across Australia. The Strategy, as endorsed by the COAG Energy Council, will be driven by the Geoscience Working Group (GWG), comprised of the Commonwealth, State and Territory government geological surveys. The Strategy will be delivered in partnership with the resources industry, the research community, and the services sector. It includes programs to attract increased investment into the Australian exploration sector but does not address the financial or regulatory challenges facing mineral exploration.

The Geoscience Working Group (GWG) will deliver the Strategy by:

(1) Encouraging investment through a renewed commitment to the creation and delivery of government-funded pre-competitive geoscience, and a refreshed approach to the global promotion of Australia.
(2) Harnessing our capability through a cross-institutional research venture focused on delivering the applied geoscience needed for industry to better explore beneath the covered regions of Australia, as well as continued development and promotion of Australia's world-leading METS sector.
(3) Protecting the environment through provision of robust baseline pre-competitive geoscience data for evidence-based decision making and reducing the exploration footprint.
(4) Supporting our people and communities through wider engagement and clear communication of relevant geoscience information, and the economic and social benefits of a vibrant minerals industry to a broad audience.

This paper will outline each of the four themes with examples from across Australia of the actions currently underway.

AN INTEGRATED APPROACH TO MAPPING CRUSTAL GEOLOGY AND STRUCTURES IN THE NE CAPRICORN OROGEN, WESTERN AUSTRALIA: IMPLICATIONS FOR URANIUM EXPLORATION

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Crustal-scale geology and structures in the NE Capricorn Orogen have been mapped using techniques from various disciplines. Several interpretations were generated from the processed gravity and magnetic data. The interpretations were tested by petrophysical constrainted gravity and magnetic forward modelling and ground truthed by field mapping, core logging and structural analysis. The significance of the structures at surface was tested by logging and mapping the Paleoproterozoic Bresnahan Basin for sedimentary facies changes across faults. Additionally, a nearby seismic line was used to further constrain the interpretations.

The integrated approach to mapping indicates more prospective locations for uranium exploration. While uranium occurrences are common across the region, the significant deposits are associated with interpreted major structures. The absence of major crustal-scale structures in the NE of the study area is a likely reason for the lack of major uranium deposits in that region. The work indicates that hanging wall blocks associated with faults bounding a major longitudinal sub-basin of the Paleoproterozoic Ashburton Basin offer better potential for larger uranium deposits. The hanging wall block is unconformably overlain by the Bresnahan Basin where the geology adjacent to the sub-basin bounding faults appear to be 'bleached' with clay replacement of detrital feldspar from the rock. This along with common carbonate veins maybe indicating a distal alteration halo of unconformity type uranium deposits.

ARCHEAN CONTROLS ON BASIN DEVELOPMENT AND MINERALISATION IN THE SOUTHERN CAPRICORN OROGEN

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Basins along the northern margin of the Yilgarn Craton developed in response to extensional and compressional processes in the Paleoproterozoic along the craton margin. Early extension resulted in the formation of the Yerrida Basin as a large single basin over the northern Yilgarn Craton. Subsequent rifting led to voluminous volcanism in the northern part of the 2.2 to 1.9 Ga Yerrida Basin, within two depositional centres – the c. 2.03 to 1.96 Ga Bryah and Mooloogool Sub-basins. Yilgarn Craton crust can be mapped using gravity and magnetic data beneath the Yerrida Basin, and Mooloogool Sub-basin. However, it can't be mapped below the Bryah Basin, implying the formation of an ocean in this region. The degree of rifting of the Yilgarn Craton, and resulting architecture influenced subsequent basin development, and deformation in the region. For example, in areas where Yilgarn Craton crust can't be mapped beneath basin sediments deformation is pronounced with the formation of disharmonic folds, refolded folds, and

anastomosing shear zones. The southern part of the Yerrida Basin and the Earaheedy Basin formed shallow depositional centres over the Yilgarn Craton, and subsequent deformation in these regions is less intense. Base metal mineralisation in the region can, in part, be related to the presence of deep crustal scale structures that initially developed in the Archean, and were re-activated during the Proterozoic. However, the location of c. 1800 Ma orogenic Au mineralisation in the Bryah Sub-basin may not have been influenced by deep crustal-scale faults that initially formed during the Archean.

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4H GROUNDWATER CASE STUDIES

CHARACTERISING THE SPIRITWOOD VALLEY AQUIFER, NORTH DAKOTA, USING HELICOPTER TIME-DOMAIN EM

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Buried valley aquifers, consisting of permeable sand and gravel deposits in eroded bedrock valleys, are important sources of groundwater supply in many regions of the United States and Canada.

Investigations of the Spiritwood aquifer in southern Manitoba by the Geological Survey of Canada and other workers, have demonstrated the value of helicopter time domain electromagnetic (TDEM) surveys in aquifer mapping and characterisation using the contrasts between Quaternary glacio-lacustrine sand-gravels (high resistivity) that are relatively permeable and clay-tills (low resistivity) that are relatively impermeable, as well as the deeper, much less resistive Cretaceous Pierre Formation Shale basement rocks. This success provided the impetus for the North Dakota State Water Commission to fly a VTEM helicopter EM survey in the Jamestown, ND region in October, 2016.

The VTEM data collected over the Spiritwood-JT block allowed for geological mapping from near surface to depth, in spite of relatively weak resistivity contrasts (<10X). These data were inverted with a layered-earth algorithm to produce resistivity-depth models. These models were able to resolve the location and depths to the top and bottom of the Spiritwood aquifer throughout the central portion of the block providing more detailed pictures of the aquifer's geometry. In addition to resolving the main aquifer as well as its deeper channels, the VTEM data and models highlighted several smaller, previously undiscovered aquifers that cross-cut/branch-off from the main Spiritwood channel. These are interpreted as probable transverse low-K barriers that were apparent from the existing test drilling and aquifer testing.

REINTERPRETATION OF WIRELINE LOG DATA IN THE EASTERN GALILEE BASIN, QUEENSLAND: STRATIGRAPHICAL AND HYDROGEOLOGICAL IMPLICATIONS

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In response to the Millennium drought and increased demand for water throughout Australia, the Bureau of Meteorology (BoM) was given the role of compiling and delivering Australia's water information under the conditions set out in the Federal Water Act 2007.

To achieve this the BoM developed the Australian Water Resource Information System (AWRIS) and the National Groundwater Information System (NGIS) to support AWRIS. Functionality of the NGIS relied on compiling state and territory groundwater databases and the completeness of data in these databases was critical in facilitating data migration. Groundwater bores in the Galilee Basin were identified as a priority target for addressing data gaps.

A stratigraphic framework was created using published wireline log interpretations to map structure surfaces for the Galilee Basin. Assessment of these structure surfaces and wireline log interpretations identified numerous inconsistencies with the established basin stratigraphy. This is partially attributed to the large number of interpretation sources, exploration relevance and an incomplete understanding of facies variability.

Systematic reinterpretation of the published wireline log data was undertaken to validate and reassign inconsistent interpretations in the eastern Galilee Basin. Reinterpretation has resulted in shifting formation top picks vertically by up to 300 m in some instances, leading to significant modification of some structure contour surfaces.

Uncertainty over the internal architecture of the Galilee Basin has significant implications for understanding the hydrogeology of aquifer systems and springs in the basin. Reinterpretation by a single operator has assisted in removing some of this uncertainty and provided a consistent dataset of interpretations.

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5A PNG AND NZ

PLIO-PLEISTOCENE RIVER DRAINAGE EVOLUTION IN NEW GUINEA

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The drainage of New Guinea has evolved rapidly since Pliocene time. Relief growth initiated in accreted oceanic terranes in the north and immigrated into the Australian margin interior over time. The present-day drainage retains inherited elements of an ancient fluvial system that routed sediments from these northern terranes through the Central Highlands into foreland flexural basins, epicontinental seas, and deep oceanic basins. The rise of the Highlands and of the Papuan Peninsula spurred drainage reorganisation, such that today little of the oceanic terranes still drains through the mountain range. This evolution has strongly affected the composition of the clastic sediments delivered to the shelves.

The topography retains the memory of some of the most recent changes. Most of the relief of the Papuan Peninsula formed during the past 5 Ma, driven by tectonic removal of the load of the peninsular ophiolites, accompanied by contractional collapse along the Aure-Pocklington trough. In the eastern Central Highlands, rapid drainage reversal results from flexural back-tilting under the load of the colliding Huon-Finisterre Range. Northward reversal is also observed at the western end of the Highlands. In the south, the Fly platform has experienced recent, widespread, non-tectonic and non-flexural uplift of deep origin that will ultimately close the Torres Strait.

The Quaternary drainage evolution will be used to calibrate the *Badlands* software developed by the Basin Genesis Hub, as a first step for simulating the evolution of topography and sediment delivery to the Australian shelf and Gulf of Papua in earlier times.

GEOPHYSICAL AND GEOLOGICAL CHARACTERISATION OF DREDGE LOCATIONS FROM RV SOUTHERN SURVEYOR VOYAGE SS2012_V06 (ECOSATI): HOTSPOT ACTIVITY IN NORTHERN ZEALANDIA

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In October–November 2012, a geophysical mapping and dredging campaign in the eastern Coral Sea was conducted on the *RV Southern Surveyor* during voyage ss2012_v06 (ECOSAT). Part of this campaign was focussed in northernmost Zealandia where volcanic seamounts and uplifted portions of the Lord Howe Rise were targetted to determine the age and extent of the Lord Howe Seamount Chain (LHSC) and to recover continental basement from the Lord Howe Rise. Our geophysical and geological analysis of dredge sites from the South Rennell Trough and Chesterfield Plateau confirm the extension of the LHSC ~300 km northward than previously identified, with an age-progression extending to ~27–28 Ma. These new samples, together with previously published results from the southernmost chain, show consistency with both Indo-Atlantic and Pacific hotspot models and further highlight the change in Australian absolute motion between 27–23 Ma. The recovery of trachytes at the Le Noroit seamounts (northern New Caledonia Trough) and aphyric lava, porphyritic lava and volcaniclastic sandstone along Nerus Reef and Landsdowne Bank provide some of the only indications of continental basement from northern Zealandia. Swath bathymetry analysis of dredge locations reveals consistently large discrepancies (in the order of 1000 m) with global compilations, and together with an analysis of gravity signatures, suggests complex basement structure in the area. The results of our sampling from northern Zealandia will assist in understanding the thermal history of Northern Zealandia and will provide a geological framework for resource exploration in this frontier basin exploration area.

COMPRESSIONAL EVOLUTION OF THE PNG MARGIN FROM AN OROGENIC TRANSECT FROM JUHA TO THE SEPIK

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A crustal-scale, fully restored section across the PNG orogenic belt reveals the Oligocene to Recent compressional deformation of the margin. The northern end of the section comprises the Landslip Metamorphics, an accreted continental terrane, separated from the main part of the fold belt by the Jurassic April Ultramafics and Om Metamorphics, interleaved with Eocene volcanics, which together constitute an accretionary prism. Existing maps show that the suture is overlain by distal Miocene sediments indicating Oligocene docking and probable compression prior to Early Miocene subsidence. The latter is consistent with Early Miocene extension in PNG and the emplacement of metamorphic core complexes in the Sepik area, but is also related to dynamic topography causing subsidence of the whole northern margin of Australia. Neogene compression commenced around 12 Ma with ~70 km shortening in the Om

terrane and ~38 km shortening in the Fold Belt. Existing thermochronology data indicate shortening of ~12 mm/year from 12–4 Ma, but only 2.5 mm/year from 4–0 Ma, consistent with a change in structural style in the Fold Belt from thrust to more ductile, fold-dominated deformation. The model also requires substantial thickening of the continental crust beneath the Muller Ranges, here represented by 'basement' underthrusting. Gravity modelling indicates the presence of sedimentary graben up to 10 km deep beneath the fold belt, which were strongly inverted, such as beneath the Lavani Valley. A key issue is when this inversion occurred, in the Oligocene or Pliocene, as this has a significant influence on the timing of hydrocarbon generation and migration.

TECTONIC AND GEODYNAMIC EVOLUTION OF THE NORTHERN AUSTRALIAN MARGIN AND NEW GUINEA

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Rapid convergence between the Indo-Australian, Southeast Asian, and Pacific plates in the Cenozoic has resulted in a complex tectonic evolution of Australia's northern margin. A lack of available geologic data leads to large uncertainties, such as the timing of the Sepik collision with the New Guinea margin, currently constrained to sometime between 50 and 30 Ma. Previous work suggested a link between the Sepik collision and a voluminous fast seismic anomaly presently in the mantle beneath Lake Eyre. Following from previous work, this study uses coupled plate reconstruction and numerical geodynamic software to test 50 Ma and 30 Ma collision timings of the Sepik terrane, along with an upper extent back-arc basin, to further refine our understanding of the source and trajectory of the slab beneath Lake Eyre and address uncertainties in the plate reconstructions. The results of mantle flow models indicate that the ~50 Ma collision timing is more likely. In addition, dynamic topography results support previous suggestions that dynamic subsidence relating to the down-going Sepik slab has had a significant influence on the evolution of the Eyre Basin, with up to ~100 m of dynamic subsidence since ~20 Ma. However, further work is required to address numerical issues relating to rapid thermal diffusion, and to investigate reasonable trench retreat velocities for intermediate (~3000 km) subduction zone lengths. This work highlights the benefit of numerical modelling of transient plate-mantle processes and their effect on basin evolution on the interiors and margins of continents affected by subduction.

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5B WEST AUSTRALIAN BASINS SYMPOSIUM

CANNING BASIN – PETROLEUM SYSTEMS ANALYSIS

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High resolution geochemical analysis of Canning Basin oils and condensates demonstrated a common and potentially regional source rock. Ungani field oils suggest they were all generated within the peak oil window from a similar high quality marine source rock, which is clastic and contains bacterial and marine algal matter deposited under anoxic to sub-oxic conditions. Low GOR's are likely the consequence of the source rock type with gas removal possibly by water washing.

Liquids from the Yulleroo field were derived from a similar source to the Ungani oils, with the addition of dry gas from a higher maturity and/or more gas prone source. These liquids were generated and expelled at slightly higher maturity than the Ungani oils, with the current lean gas condensate phase the result of the addition of dry gas combined with minimal water washing. The Ungani and Yulleroo liquids resemble the L4 family previously attributed by GA to a probable Carboniferous age source.

Map based burial history and maturity modelling was undertaken incorporating eleven 1D models using a source rock model derived from the liquid geochemistry with Type B from the Pepper and Corvi organofacies. Burial history modelling and maturity modelling at the top of the Laurel Lower Carbonate shows maturity for gas expulsion in the main trough and oil to light oil expulsion on the flanks of the basin. Maximum burial in the basin took place immediately prior to the Fitzroy Uplift, resulting in the main phase of oil generation and expulsion taking place around 200a.

THE UNGANI OIL FIELD, CANNING BASIN – EVALUATION OF A DOLOMITE RESERVOIR

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The Ungani field was discovered in 2011 within the Fitzroy Trough, with oil reservoired in early Carboniferous dolomites of the Lower Laurel Formation, previously only encountered on the basin edges. It has produced 792 000 barrels of oil to December 2017. Production rates, well interference and material balance analysis suggest the reservoir has significant porosity and multi Darcy permeability with initial well rates of 1500 bopd. Recent drilling, the installation of artificial lift, and facilities upgrades in

late 2017 should enable field oil production rates to reach 3000 bopd in 2018.

Seventy metres of continuous core through the reservoir was acquired at the Ungani Far West 1 well in 2015 and this has enabled new insights into the heterogeneous reservoir architecture and support for upgrades to resource estimates. 3D structural analysis of 140 micron resolution helical CT-scans by CSIRO is used to directly measure vuggy connected macro porosity over 30% (pu), interspaced by a tight matrix with non-connected macro porosities not greater than 2.5% (pu). These measurements were up-scaled to calibrate porosity estimates derived from neutron-density and sonic log data and demonstrates that the log data does not adequately resolve the productive zones and confirms a greater net contributing and connected pore space than estimates based on log data.

The heterogeneity and prolific nature of the uppermost part of the reservoir had not been previously recognised and this has been compounded by poor log data coverage around casing shoes. Re-analysis of ditch cuttings samples from Ungani-3 using Chemostrat ICP-OES-MS was instrumental in proposing additional drilling at Ungani 5 (December 2017) to successfully re-target the upper-most part of the reservoir.

Significant oil prospectivity is identified from modern 3D and 2D seismic near Ungani and along an under-explored 200km long depositional belt extending both west and east from the field. Exploration drilling of a number of large high impact prospects along this trend is planned through 2018.

DEPOSITIONAL, DIAGENETIC AND MINERALOGICAL CONTROLS ON POROSITY DEVELOPMENT IN UNGANI FIELD, CANNING BASIN

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In late 2015, a 75 m thick section of Early Carboniferous Laurel Formation was continuously cored in Ungani Far West 1, an appraisal well 3 km away from the main Ungani field on the southern flank of the Fitzroy Tough in the Canning Basin. One of the main objectives of this coring program was to better understand the pore systems, mineralogy, and diagenetic history of the reservoir to allow calibration and extrapolation of the petrophysical evaluation of the field. Petrography, stable isotope, XRF, hyperspectral logging, grain density and CT scan studies were conducted on the core.

The core consists of a 12 m overlying sealing shale and 63 m of vuggy, fractured and dolomitised reservoir. The reservoir is commonly bioclastic-rich but pervasive dolomitisation hindered recognition of earlier depositional features. Upper carbonate facies are interpreted as shallow to moderate depth marine ramp-type deposits. The lower carbonate facies is suggestive of shallow platform top settings with ‘reefal’ constructing organisms. Bio-mouldic, fracture, cavern and inter-crystalline porosity resulting from multistage brecciation, fracturing, dolomitisation and dissoulution events are all critical to reservoir development.

Based on hyperspectral logging and thin section petrography, the reservoir is deemed to predominantly dolomite with late phase cements comprising of quartz, calcite, gypsum, anhydrite, chalcedony and pyrite. Variable grain densities that correspond with porosity have been noted throughout the core. This is likely to be a result of diagenetic alteration or possibly even depositional environment (conclusion to be established).

LAUREL GAS PLAY, CANNING BASIN – RECENT STRATIGRAPHIC LEARNINGS

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Well, core and seismic data from the Lennard Shelf and Fitzroy Trough were integrated to produce a predictive sequence stratigraphic framework of the Laurel Formation consisting of Lower, Middle and Upper depositional sequences.

Significant encouragement for potentially commercial flow rates was achieved by the hydraulic stimulation of the Middle Laurel in the Eastern Gas Province (Valhalla North 1 and Asgard 1 wells) in late 2015 and in the Western Gas Province (Yulleroo) in 2010. The Laurel tight gas play extends over a 20 000 km2 area developed within a 2000 m thick succession of marine clastics and carbonates. Condensate rich wet gas associated with overpressure is encountered regionally within low porosity and permeability sands at depths below 2000 m. This was correlated across the basin from Yulleroo to the Meda Embayment and Northern Gas Province where a number of prospective plays were identified.

Upper Laurel shallow marine sandstones commonly possess good oil and gas shows and have potential for tight gas where overpressured. A prominent Middle Laurel lowstand prograding shelf slope wedge supported by the presence of conglomerates in updip wells suggest better clastic sediment supply and the potential for the development of conventional lowstand topset sandstone reservoirs in the Northern Province.

The Middle Laurel interval in the Northern Gas Province likely consists of a similar and potentially better tight gas reservoir than the interval stimulated in the Eastern Gas Province. Further drilling is required to confirm this and also to prove the viability of the tight gas play in the Northern Gas Province.

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5C NON CONVENTIONAL

NEW METHOD FOR MONITORING STEAM INJECTION FOR EOR AND FINDINGS SOURCES OF GEOTHERMAL HEAT

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A database of over 10 000 wells with open hole logs, of which over 600 wells are dedicated surveillance wells with whole core, time lapse Carbon/Oxygen, Neutron, and Temperature data is being used for evaluating Adrok's deep penetrating radar system.

Kern River (California) is on its way to recovering 90% of its OOIP and surveillance is playing a significant role in achieving such a world class milestone. Future growth for develop of the field and surveillance technologies still exist as well. To that end, we are looking at the possibly of surface only acquisition for Chevron's surveillance needs.

Significant time and effort was spent on dielectric logging in the 1970s–80s by operators and service companies. Adrok's Atomic Dielectric Resonance (ADR) claims to interact with the subsurface in the same region of the electro-magnetic spectrum as di-electric logging, but from surface measurement. First Principles predicts a rise in dielectric constant as temperature rises. Fieldwork was conducted during 2014 to 2016. The surveys were divided up into two groups, one for training (full access to database) and one for blind testing (no access to database). Surprisingly, the blind tests could detect the presence or absence of a single zone steamchest by a rise in dielectric constant at the correct spacetime.

The body of the presentation will describe in greater detail the technology, field experiment and results to date for Chevron. Results from onshore geothermal heat exploration at a number of sites in New Zealand, Cornwall and Northeast England will also be presented.

A NEW SYSTEM FOR EFFICIENTLY ACQUIRING VERTICAL SEISMIC PROFILE SURVEYS

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Vertical seismic profiles (VSPs) utilise seismic sensors placed in a borehole to record vibrations transmitted by a source at surface. These surveys provide data that can be used both to calibrate surface seismic surveys, and provide geomechanical properties. Although undoubtedly valuable, acquiring VSPs can be cost prohibitive, both due to the equipment acquisition cost, and the time required to acquire the survey. VSP acquisition systems fall into two broad categories, those that transmit the analogue data up a cable to be digitised at the surface and those that digitise the data downhole before transmission to the surface. The former have limited maximum depths, typically around 300 m, and require cables with a considerable number of cores (at least six per tool) and are thus usually limited to one or two sondes (the acquisition time of a survey is roughly proportional to the number of tools deployed). Digital tools are usually rated to greater depths and support a greater number of sondes, but are typically much more expensive and require specialised wireline cables. In this paper we describe a new system for acquiring VSP data. Our system digitises the data within each sonde but stores the data in memory for downloading at the surface. The system requires only four-core wireline cable, two of which are used for powering and communicating QC information with the sonde electronics. This system has the additional advantages of having a high depth rating and a theoretically unlimited number of sondes making it highly efficient.

WHAT WE KNOW, WHAT WE DON'T KNOW, AND THINGS WE DO NOT KNOW WE DON'T KNOW ABOUT HYDRAULIC FRACTURING IN HIGH STRESS ENVIRONMENTS

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Hydraulic fracturing in many Australian Basins, particularly the Cooper Basin has been successful in higher permeability, structured conventional plays. However, adaptation of North American strategies to Australia's complex, and highly stressed unconventional areas has resulted in less than adequate performance to progress further investment into widespread development these resources. This presentation will explore the obvious differences between Australian and North American stress settings, and the problems manifested by those differences in hydraulic fracture containment and behaviour. Further, as more unconventional targets are attempted, complementary strategies need to be considered based on fundamental geomechanical principles, relative to these basinal environments. This presentation will explore several problems, emerging potential solutions, and areas of ongoing research with the purpose of aiding Australia to tap into a vast supply of potential unconventional resources, which are currently under-appraised.

THE ROLE OF DIAGNOSTIC FRACTURE INJECTION TESTING TO IMPROVE RESERVOIR EVALUATION AND STRESS CHARACTERISATION IN COMPRESSIVE STRESS REGIMES

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The diagnostic fracture injection test, commonly known as a DFIT, is frequently used in conventional and unconventional reservoirs (e.g. tight gas, shale gas, tight coals) to calibrate the hydraulic fracture treatment. In a normal stress regime, a single test can calibrate the in-situ stress profile and provide parameters such as reservoir pressure and transmissibility. However, in strike-slip regimes a single test cannot adequately derive strain values to develop an accurate stress profile as compared to multiple, precise, well-designed multi-DFIT program. Thus, if more consideration were given to the design process and

stepwise implementation, a more robust stress profile and definitive reservoir characterisation can result from implementation of DFITs in low permeability, unconventional gas reservoirs.

This presentation will define the workflow of a multi-DFIT program and the governing equations for stress profiling to allow practitioners to incorporate DFIT data with other available data to derive accurate geomechanical parameters. Further, a well defined program can provide insight for hydraulic fracturing modelling and key information regarding natural fracturing and transmissibility for reservoir modelling. For unconventional, non-normal, tectonically-stressed reservoirs this includes defining minimum and maximum horizontal strains as well as intermediate stress values acting on known natural fracturing azimuths. Overall, a comprehensive set of recommendations and references are made for the practical application of DFITs to illustrate the overall benefit for the well design processes.

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5D GENERAL GEOLOGY

GEOPHYSICAL DETECTION OF THE HYDROTHERMAL ALTERATION FOOTPRINTS OF ORE DEPOSITS

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Exploring deep or under cover means no expectation of a direct ore deposit signature in exploration data. The deposit, however, is part of a mineralised system with alteration assemblages that may extend kilometres. Where the architecture of such systems is generally understood in terms of alteration domains—the deposit 'footprint'—exploration strategy can focus on the identification of such domains and, in the best cases, use their spatial relationships to vector towards the ore deposit.

Potential fields data with extensive coverage are common, and high-quality airborne magnetic data are nearly ubiquitous in modern mineral exploration. The use of geophysical data is appealing because, although it does not directly respond to rock chemistry, it provides the greatest and most uniform areal data coverage. In the age of deep and undercover exploration, direct recognition of footprint-scale hydrothermal alteration from geophysical data is the holy grail of geophysical interpretation.

The key to geophysical recognition of alteration at the ore system scale is the assumption, typically met in practice, that the primary control on physical property variation across the system is formational and structural, with hydrothermal alteration a contributing secondary effect. Specialised interpretation workflows can take advantage of this assumption to create physical property models composed of primary (formational and structural) and secondary (alteration) physical property signatures that are fully consistent with geophysical data and whatever level of geological data is available. The secondary physical property signatures are in many cases directly interpretable in terms of hydrothermal alteration domains.

CREATING A NEW FRONTIER IN DETECTION AND DATA INTEGRATION FOR EXPLORATION THROUGH COVER

Robert Hough

With the recent declines in greenfields exploration activity and discovery success in Australia, a new wave of technologies and data products are needed. Australia is an old continent with much of its remaining mineral endowment obscured by a thick cover of weathered rock, sediment and soil materials. This presents a critical challenge for mineral exploration now and into the future, as the industry currently lacks the fundamental data, scientific knowledge and technological tools needed to discover new, world-class ore deposits buried beneath this cover. UNCOVER, is a national vision in Australia for the future for mineral exploration geoscience research to tackle the geological barriers to more tier 1 discoveries.

UNCOVER as a national initiative, has the potential to position Australian exploration geoscience research for a shift in collaboration for technology development, one that tackles the exploration through *deep* cover challenge as one of major national importance. As we move into exploring the deeper cover regions of Australia, we need to determine detectable signatures of buried mineral systems and ore systems from a number of varied sample media and with different technologies. Arguably, the challenge posed by the depth of cover to find the mines of the future is going to be in the 100s of m, given current mining practices from the surface combined with the economic realities. Firstly though, we need to know the extent of that thickness of cover, its stratigraphy, lithogeochemistry and physical properties. Comprehensive data that will in turn aid in more effective processing and interpretation of the regional data-sets collected e.g. magnetics, and increase confidence in our geological models of the sub-surface. While the cover is a barrier it also presents an opportunity and detection through cover may lead to new resource discovery within the cover itself.

Our ability to detect an anomaly in exploration rests not in the direct detection itself but in being able to place the data point into a regional geological context. For example, research on the geochemistry of the Fortescue Group volcanics assessing burial metasomatism effects has been undertaken in the Capricorn distal footprints project so that we can position the industry to place perceived geochemical, geophysical and mineralogical anomalism from similar lithologies into a broader geological and indeed regional context.

Australian researchers have long played a globally leading role in developing new approaches and technologies to support the minerals industry in exploration, most often through collaboration involving multiple organisations and with close industry engagement. Co-operative research centres and Centres of Excellence are vehicles that have been very important in the focus and drive for innovation to support the industry to tackle technical challenges involved with mineral exploration in Australia. Recently, the SIEF, MRIWA, GSWA and industry supported Capricorn distal footprints project between CSIRO, UWA and Curtin University teams also reflects a highly collaborative approach to the challenge, including in a highly multi-disciplinary manner with a very strong cohort of early career researcehrs.

Acknowledgements: The presentation will include much content from my CSIRO colleagues and I thank each for their important contributions.

EPISODIC MINERALISING FLUID INJECTION THROUGH CHEMICAL SHEAR ZONES

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A lot of uncertainty remains about the exact nature of the geological mechanisms allowing mineralising fluids to flow from depth and form localised mineral deposits. Traditional assumptions of fluids travelling through highly permeable faults raise interesting questions about the existence of such open faults at depths below the brittle-ductile transition for example. In this contribution, we present the behaviour of impermeable shear zones in such environments, under specific conditions where temperature sensitive endothermal reactions trigger in-situ release of fluids that lubricates the fault and leads to their reactivation. The response of such systems can be of various nature, including slow creep, one-off reactivation events, or episodic reactivation events during which the permeability increases by several orders of magnitudes and allows fluids from depth to flow upwards. Such periodic events can be observed currently as episodic tremor and slip events in subduction zones and can also be inferred from spatial observations from exhumed megathrusts.

Three major driving parameters impact the system response: the Gruntfest, Lewis, and Damköhler numbers. We present the respective impacts of those parameters, along with numerical solutions to investigate the various stability regimes. This includes the open-source REDBACK simulator (https://github.com/pou036/redback), specifically developed to simulate this chemo-mechanical oscillator, as well as a pseudo-arclength continuation method based on REDBACK.

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5E STRATEGIC AND INDUSTRIAL

INDUSTRIAL MINERALS – EVALUATION AND PROFITABILITY

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Industrial minerals are often misunderstood and misrepresented by the general community, education and research organisations, industry professionals and governments. They may best be defined as mineral and mineral concentrate products used in industrial and manufacturing applications. During production, their specific chemical and physical properties may be enhanced, though remain largely unchanged by any chemical processing.

Industrial minerals are commonly misperceived by technocrats and financial types alike as the poor cousin to precious metals, base metals, light metals and energy minerals. To the contrary, many small and large industrial mineral companies are highly profitable at 15–30% EBIT/Sales with strong returns on capital employed, including iron ore, potash and borates.

Effective exploration and evaluation of industrial minerals must recognise the principle of ‘Value in Use’. This involves a dynamic interplay between technical, market and commercial factors, including resource characterisation, geometallurgy, application tests, customer trials and primary market surveys. Products require consistency of physical and chemical properties and performance in the customers’ application.

Key profitability factors include technical understanding (not just JORC numbers), market knowledge, QA/QC discipline and key customer relationships. Success is rarely about having the biggest or the cheapest, it’s more about consistency, rarity, functionality, market structures and barriers to entry.

All the buzz is about minerals and metals for the electronic, battery and sustainable energy industries. Key criteria and methods to evaluate, benchmark and create a highly profitable and sustainable business in lithium, cobalt, graphite, indium, manganese, scandium, beryllium, silicon or high-purity quartz are considered.

MINERAL DEPOSITS IN THE ONTARIO COBALT BELT

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Recent exploration by Battery Mineral Resources Limited has located numerous cobalt-arsenic-(silver, gold, nickel, copper) deposits in eastern Ontario. The deposits are located within a 250 km zone located north of Sudbury and trending east across the Quebec border. Deposit types include sulphide-carbonate vein systems, skarn, massive sulphide and sulphide breccia. This talk provides an update on the geology and exploration of several high-grade cobalt deposits within this belt.

THE SINCLAIR ZONE CAESIUM DEPOSIT, PIONEER DOME, WA

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During 2017 Pioneer intersected Australia’s first significant intersection of pollucite in RC drilling, resulting in the definition of the Sinclair Zone caesium deposit, within 1 of 7 identified pegmatite suites with LCT mineral affinities that occur along the Eastern margin of the Pioneer Dome, Western Australia.

At the start of 2017, the Pioneer Dome was a clean slate in respect of LCT pegmatite knowledge. Using first principals, soil sampling and mapping, successive LCT pegmatites were identified and are now drill-ready.

The Company has been at the forefront of using modern techniques such as pXRF, SWIR and RAMAN to assist in its exploration advances.

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5F EM INVERSION MODELLING

TRANS-DIMENSIONAL MONTE CARLO INVERSION OF SHORT PERIOD MAGNETOTELLURIC DATA FOR COVER THICKNESS ESTIMATION

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We have developed an algorithm and released open-source code for the 1D inversion of magnetotelluric data. The algorithm uses trans-dimensional Markov chain Monte Carlo techniques to solve for a probabilistic conductivity-depth model.

The inversion of each station employs multiple Markov Chains in parallel to generate an ensemble of millions of conductivity models that adequately fit the data given the assigned noise levels. The trans-dimensional aspect of the inversion means that the number of layers in the conductivity model is solved for rather than being predetermined and kept fixed. Each Markov chain increases and decrease the number of layers in the model and the depths of the interfaces as it samples.

Once the ensemble of models is generated, its statistics are analysed to assess the posterior probability distribution of the conductivity at any particular depth, as well as the number of layers and the depths of the interfaces. This stochastic approach gives a thorough exploration of model space and a more robust estimation of uncertainty than deterministic methods allow.

The method's application to cover thickness estimation is discussed with synthetic and real examples. Inversion of complex impedance tensor and also derived apparent resistivity/phase data are both demonstrated. It is found that the more pronounced layer boundaries allow more straightforward interpretation of cover thickness than that from deterministic smooth model inversions. It is concluded that thickness estimates compare favorably with borehole lithologic logs in most cases, and that the method is a useful addition to a range of cover thickness estimate tools.

COMPARATIVE ANALYSIS AND JOINT INVERSION OF MT AND ZTEM DATA

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Magnetotelluric (MT) data are typically broadband, covering 0.001 to >1000 Hz, but inter-site spacing is coarse. Airborne Z-axis tipper data (ZTEM) are denser but usually limited to frequencies >30 Hz. We analyse a pair of overlapping 3D surveys to examine lateral and vertical spatial sensitivity.

The MT data include a 2D line and a 3D survey. The line data also has magnetic tipper data that allows for a direct comparison with ZTEM; in the overlapping frequency range the agreement between the two magnetic data sets is good, with ZTEM showing higher lateral smoothness.

CGG's 3D MT-CSEM non-linear conjugate gradient inversion engine was extended to accurately model the ZTEM data, using measured sensor altimetry data and detailed 3D topography. Both single domain and joint inversions of the ZTEM and MT data were carried out. A suite of inversions were run to test the influence of starting resistivity and regularisation parameters on output models, carried out in exactly the same way for MT, ZTEM, and joint MT+ZTEM inversions to allow for direct comparison.

ZTEM single domain inversion results depend strongly on the starting resistivity value, confirming that the method maps relative variations rather than absolute resistivity values. Shallow lateral structure qualitatively agrees with the MT, while deep resistivity from ZTEM inversion is driven by model regularisation only. Joint inversion improved the relatively shallow section, calibrating the ZTEM resistivities and adding continuity between the MT sites. Below around 1,500 m, the 3D resistivity model is controlled by the MT data alone.

1, 2.5 AND/OR 3D INVERSION OF AIRBORNE EM DATA – OPTIONS IN THE SEARCH FOR SEDIMENT-HOSTED BASE METAL MINERALISATION IN THE MCARTHUR BASIN, NORTHERN TERRITORY

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The southern McArthur Basin in Australia's Northern Territory is host to some Tier-1 sediment-hosted base metal mineral deposits including the McArthur River Zn–Pb–Ag mine. Airborne electromagnetic (AEM) data sets have been employed as a key exploration technology in the search for these mineral systems. A geological interpretation of results arising from the use of different inversion techniques, including 1, 2.5 and 3D methods, was undertaken on a helicopter EM data set acquired over a structurally complex sediment package in the Batten Fault Zone north of the McArthur River Mine. The exploration targets were conductive, mineralised units (HYC pyritic shale member) associated with the Barney Creek Formation. Results from this study suggested that although the model fits were generally good, the derived conductivity models for the 2.5D and 3D inversions appeared to be smooth representations of geological reality, particularly when compared with data from drilling and surface geological mapping. Superficially, the 1D smooth model layered Earth inversions appear to map geological variability and structural complexity in greater detail even though the structures are more 3D in nature. IP effects are observed in the data and influence the modelled structure, but can be accounted for. The outcome of this study also indicates that when employing higher order inversion methods in the interpretation of AEM data sets, there may be significant benefit in asking a contractor/consultant for 1D inversion results as well. In the resulting interpretations if conductors appear in one but not the other, it is worth asking the question why?

SPATIALLY AND CONDUCTIVITY LOG CONSTRAINED AEM INVERSION

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We have developed an algorithm and released open-source code for 1D inversion of airborne electromagnetic data incorporating spatial and conductivity log constraints. The deterministic gradient based inversion algorithm uses an all-at-once approach, in which whole datasets or flight lines are inverted simultaneously. This allows spatial constraints to be imposed while also ensuring the inversion model closely matches any downhole conductivity logs that are near to the flight lines. The intent of the algorithm is to improve consistency along and across flight lines by taking advantage of the assumed coherency of the geology.

Instead of roughness constraints, 'sameness' constraints are used. To implement these the regularisation penalises differences between the conductivity of 1D model/layer pairs and the weighted average conductivity of every other neighboring 1D model within a user selected radius of their position. The neighbor averages are computed with inverse distance to a power weighting. The comparisons can be made over equivalent elevations or equivalent depths. Downhole conductivity log constraints are imposed in a similar fashion, by penalizing the differences between conductivity logs, averaged over selected intervals, with their respective neighboring 1D models. Overall the regularisation encourages the final 1D conductivity models to be as similar as possible to their neighbors and to conductivity logs.

It is demonstrated with real and synthetic data examples that the method enhances geological interpretation by improving the model's continuity along and between flight lines, and its match to conductivity logs.

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5G REGIONAL MAPPING AND THOMSON OROGEN

AUSAEM; ACQUISITION OF AEM AT AN UNPRECEDENTED SCALE

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Exploring for the Future is a four-year program of the Commonwealth Government in which a significant component of the data acquisition phase of the project is the AusAEM Airborne Electromagnetic (AEM) Survey. This survey will focus on wide line-spaced acquisition as a regional mapping tool to gather new pre-competitive data and information, on an unprecedented scale. The objectives are to map, at a reconnaissance scale:

- Trends in regolith thickness, character, and variability.
- Variations in bedrock conductivity.
- The continuity of key conductive bedrock (lithology-related) conductive units under cover.
- The groundwater resource potential of the region.

The first AEM survey of this program will cover an area of over one million square kilometers, at a nominal line spacing of 20 km with infill lines spaced at 200 or 1400 m in selected areas.

In order to have the greatest impact the survey targets greenfield areas where the resource potential is unknown. The AEM data will contribute to estimating the thickness and variability of the cover material. To maximise industry collaboration on the project GA sought, and received, expressions of interest from explorers for infill flying on the regional survey.

Regional AEM surveys improve geological understanding in areas with little or no outcrop. The data enable informed interpolations between sparse drill-holes and estimates on the location of the model basement-cover interface information which reduces exploration risk. The new data will be released to the public domain at regular intervals to promote future activity by the exploration and research sectors.

APPLICATION OF AEM FOR COVER THICKNESS MAPPING IN THE SOUTHERN THOMSON OROGEN

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The southern Thomson Orogen is a poorly understood crustal element of northwestern New South Wales and Queensland. The Southern Thomson Project, a joint research project between Geoscience Australia, the Geological Survey of New South Wales and the Geological Survey of Queensland, is improving mineral systems understanding of this under-explored orogen to encourage mineral exploration investment. The Project includes new pre-competitive geological and geophysical data collection and interpretation to inform stratigraphic drilling of strategic crustal elements within the southern Thomson Orogen.

Two AEM surveys were flown in 2014 and 2016, respectively. Results from these were interpreted using available stratigraphic borehole data and surface geological mapping to produce a new cover thickness model of the area that is used to interpret target depths for the stratigraphic drilling, and to inform on the validity of other pre-drilling geophysical methods.

This presentation presents highlights of the AEM data and discusses its implications for mineral exploration as well as long-term landscape evolution, neotectonism within the Eromanga and Lake Eyre basins and hydrostratigraphic unit mapping within the region. Results of the modelling will demonstrate that large portions of covered ground are within reach of exploration drilling.

ESTIMATING COVER THICKNESS IN THE SOUTHERN THOMSON OROGEN – A COMPARISON OF APPLIED GEOPHYSICS ESTIMATES WITH BOREHOLE RESULTS

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The geology of the southern Thomson Orogen in northern New South Wales and southern Queensland is poorly understood. Basement geology is rarely exposed and there are generally many tens to a few hundreds of metres of overlying

unconsolidated or indurated Cenozoic and Mesozoic cover, largely consisting of Eromanga Basin rocks. These cover sequences are a significant impediment to mineral discovery and highlight the need for precompetitive data to be collected in this area to increase our understanding of the geological character and mineral potential of the covered basement geology.

Potential sites for up to sixteen stratigraphic boreholes designed to intersect the basement geology were selected using potential fields, solid geology interpretation, airborne electromagnetic data and local water-bore cover thickness information. Once these sites were selected, high resolution estimates of cover thickness (i.e. the thickness of regolith and/or sedimentary rocks overlying crystalline or metamorphic basement) were derived by applying refraction seismic, passive seismic and audio-magnetotelluric techniques, to more accurately determine cover thickness for accurate budgeting and drilling technical risk reduction.

A comparison of the estimates derived from the applied geophysical techniques with the actual cover thicknesses determined from borehole logs, together with an analysis of the uncertainties for each method, has highlighted the effectiveness of each geophysical technique. These new data and interpretations contribute to an Explorers' Toolkit of techniques to help reduce the risk to the exploration industry in searching for new mineral deposits in covered terrains in general, and in particular the underexplored terrain of the southern Thomson Orogen.

INCREASING PROSPECTIVITY IN A COVERED TERRAIN – THE SOUTHERN THOMSON OROGEN, NORTHWEST NSW

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Palaeozoic rocks of the southern Thomson Orogen form basement throughout northwest NSW and southwest Queensland, and potentially have similar mineral endowment to adjoining regions of the Tasmanides, including the base metal and gold mineralisation of the Lachlan Orogen to the south. The basement rocks are covered almost completely by Mesozoic sedimentary rocks of the Eromanga Basin within NSW, masking any prospective structural corridors and mineral systems. Several mineral exploration programs have penetrated cover in recent years, with a variety of targets sought, techniques applied, and some indications of mineralisation identified within the Thomson Orogen. However, overall the terrane is underexplored.

The collaborative Southern Thomson Project between Geoscience Australia, the Geological Survey of New South Wales and the Geological Survey of Queensland is advancing the understanding of tectonic history and mineral prospectivity beneath cover in the southern Thomson Orogen by acquiring and interpreting new geoscience data, including geophysical, geochemical, and isotopic investigations.

Regional Broadband MT traverses have been modelled across significant basement domains, showing deep crustal conductivity contrasts along major faults such as the Olepoloko and Mount Oxley faults. The timing of significant structures within the southern Thomson Orogen has similarities to those of adjoining orogens.

Age constraints are developing for key stratigraphic units identified from geophysical mapping. In the Cuttaburra area, a detailed study of geochronology and paragenesis has focussed on mineral system analysis and event timing. A drilling program to obtain core samples from a range of geophysical features is scheduled for completion in 2017.

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5H GROUNDWATER CASE STUDIES

RATE OF SUCCESS FOR A GROUNDWATER DRILLING PROGRAM PLANNED FROM AEM, GASCOYNE RIVER, WA

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In a collaboration between Department of Agriculture and Food, Western Australia (DAFWA) and CSIRO, funded by the Western Australia Government's Royalties for Regions Program and the Gascoyne Foodbowl Project, the Gascoyne River AEM Aquifer and Groundwater Characterisation Project was established with the aim of determining whether airborne electromagnetic (AEM) data can be employed to better map attributes of the unconfined alluvial aquifer beneath and adjacent to the ephemeral Gascoyne River.

One major aspect of the project was to produce drilling targets, based on interpretation of AEM data, for groundwater production. In a previous presentation delivered at SAGEEP (2015), we explained our method of selecting 71 drill targets. In this presentation, we briefly recapitulate our method and discuss the result of the drilling campaign that ensued. We show that our exploration targets have resulted in overwhelming success in the conversion of exploration wells to production bores; and that the production wells produce greater yields of better quality groundwater than previous campaigns that were conducted through step-out drilling.

We also show that the interpretation of the AEM inversions allowed us to map the aquitard layers that define the bottom of the Gascoyne River Old Alluvium aquifer system, determine the extent of the saltwater intrusion from the nearby Indian Ocean, and to calculate the overall volume of the aquifer system. These calculations allow us to provide estimates of total groundwater volume contained in the aquifer for sustainable production.

GEOPHYSICAL INVESTIGATION TO SUPPORT CHARACTERISATION OF STRUCTURALLY CONTROLLED GROUNDWATER FLOW INTO AN OPEN PIT MINE

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Efficient dewatering operations rely on reliable predictions of expected inflow and likely water level behaviour. These predictions stem from the conceptual understanding of the hydrogeology of the area, which itself is derived from studies into the aquifer extents, hydraulic parameterisation and connectivity

with adjacent aquifer units. Due to their isolated and discrete nature, structural controls on these inputs to the conceptual understanding are amongst the most challenging to determine.

We present the findings of an investigation into structurally controlled flow into an open pit iron ore mine in the Pilbara region of Western Australia. Bore yields, groundwater salinity and water level behaviour of in-pit bores unmistakably indicated flows in excess of normal aquifer throughflow. Airborne magnetic data allowed regional identification of a potential lineament which was confirmed with high density grade control drilling results. These indicated the presence of a trough-like mineralised feature likely to enhance connection to a regional aquifer system down dip of the iron ore body or with a fractured rock aquifer beneath the ore body. A detailed ground magnetic survey was conducted along strike from the interpreted lineament, drastically improving on the aeromagnetic data, further validating the conceptualisation of the structure and providing greater spatial accuracy with which to target future hydrogeological works around the current pit. Subsequent modelling and reconciliation with closely spaced drilling information, including downhole magnetic susceptibility logging, increased the understanding of the basement magnetic response, and supports the use of the magnetic method for local hydrogeological studies.

UNCOVERING THE MUSGRAVE PROVINCE IN SOUTH AUSTRALIA USING AIRBORNE EM

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The presence of a thick and complex cover across many parts of Australia represents an impediment to effective and efficient minerals exploration. This is exemplified in the Musgrave Province of South Australia, a terrain highly prospective for magmatic Ni–Cu–PGE and IOCG deposits, where a transported regolith imposes a significant risk and challenge to explorers. Effective exploration through this region requires an understanding of that cover, its character and its spatial variability. This cover is also a source of groundwater that supports community and environment but our understanding of this resource is compromised by the limited information we have about it. To address these issues, two regional AEM surveys were undertaken across the Province involving the TEMPEST High Moment fixed-wing time-domain EM system (western part) and the SkyTEM^{304fast}, a helicopter time-domain EM system (eastern part). In excess of 16 000 line km were acquired, with a nominal line spacing of 2 km, orientated N–S. The inversion of these data and analysis of the results reveals a highly variable cover and a complex series of palaeodrainage systems with a notable litho-structural control on their orientation and distribution. These palaeovalleys are obscured by a valley-fill of Pliocene to Pleistocene sediments and overlying Quaternary sand dunes, and in the eastern region the observed conductivity structure suggests that this fill comprises a stratified aquifer system, which is supported by drilling. The study has generated a regional scale cover map which will aid the future exploration of the region, whist helping secure community and environmental water supplies.

A MULTIDISCIPLINARY STUDY OF GROUNDWATER CONDITIONS IN SEDIMENTARY STRATA AT THIRLMERE LAKES (NSW)

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The Thirlmere Lakes include five natural wetlands within a world heritage listed national park, where a decline in water levels has been observed over many years. Lake levels correlate with rainfall variability and are historically known to have dried several times during prolonged droughts. However, the cumulative effects of long term hydrological changes on the lakes are unclear, as are uncertainties associated with extraction of water for local uses and dewatering for longwall mining.

This study is part of a large multi-disciplinary research program, of which this part focuses on groundwater conditions in structured rock masses, and the possibilities of interactions with sediments below the lakes. Surface geophysical techniques and mapping of geological structures have been combined with deep drilling, wireline logging and investigations of sediment geology. Characterisation of sedimentary strata included permeability, bulk density, moisture content, porewater stable isotopes and XRD mineral identification. Two new deep drillholes were used to obtain information on hydraulic properties of formations. A staged geophysical survey program was designed to complement geological investigation, particularly to target sediment probing: resistivity imaging and ground penetrating radar to define heterogeneity within unconsolidated alluvium (clay and peat layers) and an indicative depth estimate to the underlying rock. A combination of these geophysical methods and contextural geological information, with magnetics/electro-magnetics attempted to determine the nature of structural anomalies, including infill materials and the extent of penetration of lineaments through rock formations. The results of this work provide a thorough evaluation of groundwater conditions in structured rock that underlie the sediments of Thirlmere Lakes.

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6A PNG AND NZ

A METHOD FOR ASSESSING EARTH MODEL UNCERTAINTY IN THE TARANAKI BASIN, NEW ZEALAND

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Reservoir evaluation is often based on the interpretation of one seismic image. The amount of uncertainty associated with this image is unquantified.

When building an earth model tomographically there is inherent uncertainty as a number of models can all realise the same

measure of common image gather flatness. We present an analysis tool that quantifies that inherent image uncertainty.

Firstly, the maximum spatial resolution and recoverable velocity error of the tomographic velocity update is established using a classic checker-board test. Once the intrinsic resolution of the inversion process is established, a large population of perturbated models is generated from a given velocity model.

Secondly, migrations are performed for all perturbation models and residual moveout metrics generated. Finally, tomographic inversions are performed for all perturbations and are compared to the starting model to establish an inversion error.

Statistical analysis across all inverted models is performed for each grid location to reveal the mean, variance and standard deviation velocity. Additionally, a spatial reliability indicator is created to give a positional error envelope for the data. These model variance cubes and error envelope analysis are generated with the new workflow in the Taranaki Basin, offshore New Zealand.

The metrics can be directly used by interpreters to improve the reliability of their reservoir interpretation and can be used in conjunction with traditional seismic deliverables in mitigating risk associated with target positioning and volume. Additional information about the local illumination strength, for example, can be added to highlight any possible correlations between poor illumination and high model uncertainty.

MODELLING AND VISUALISING DISTRIBUTED LITHOSPHERIC DEFORMATION OF AUSTRALIA AND ZEALANDIA USING GPLATES2.0

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The recently released GPlates2.0 software (www.gplates.org) provides a framework for building plate models including distributed extension and compression, driven by the motions of the surrounding, rigid plate interiors, assimilating information from well and seismic data. Here we present a regional deforming plate model for Australia and Zealandia. It captures the progressive extension of all Australian continental margins, starting with the Jurassic extension of the Northwest Shelf, and including the extension of the southern and eastern Australian margins. The model also includes the extension of the Lord Howe Rise and southern Zealandia starting in the mid-Cretaceous, the subsequent complex compressional deformation of New Zealand since the early Miocene, and the orogeny along Papua New Guinea. The model allows a computation of lithospheric stretching factors for passive margins, as well as compression factors for orogenies. This allows the computation of crustal thinning/thickening through time of any point within a deforming mesh, either by starting with an assumed initial crustal thickness, or by using present-day crustal thickness as a constraint. The latter is suitable for basins, while the former is more applicable for orogens, where today's crustal thickness is not a good indicator for total crustal thickening due to erosion. The model can be combined with estimates of mantle-driven dynamic topography through time to generate basement subsidence or uplift models including isostatic and dynamic components, serving as boundary conditions for basin models as well as source-to-sink sediment transport models to provide improved constraints for resource exploration.

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6B INTERNATIONAL

ON THE GEOTHERMAL POTENTIAL OF THE HEYUAN FAULT, SOUTH CHINA

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Geothermal energy potential in China is high, and although they currently lead the way in direct heat production, geothermal power generation is still low. Hot spring analysis and surface heat flux data indicate significant potential resources for the major industrial province of Guangdong, South China. This pilot study investigates the Heyuan Fault, Guangdong, as a potential site for a geothermal power plant. The study focuses on two principal hypotheses: (1) that there are preferred locations of hot spots at fault intersections and (2) that a combination of processes may be acting to contribute to the elevated surface heat flow.

We find that hot springs occur along the NE trending Heyuan Fault, clustering where NNW striking faults crosscut the Heyuan. The increased heat flow can be explained partly by radioactive decay of a large granite pluton beneath the fault, however, additional heat sources may need to be considered to explain the heat flow maxima of above 85 mWm^{-2}. We postulate that advective (topographically driven) and convective (deep fluids ponding at the brittle-ductile transition) processes may be operating to generate these heat anomalies.

Expansive quartz reef systems exposed on the Heyuan Fault are proposed here to represent uplifted sections of these deep fluid circulation patterns. A detailed systematical analysis of reef structures will reveal (1) the fluid provenance, (2) precipitation conditions and (3) deformation mechanisms, which will ultimately help us understand how fault intersection relations control fluid flow; which is of key significance if it can be utilised for targeting geothermal energy.

THE DISCOVERY AND DEVELOPMENT OF OIL RIM FIELDS IN THE BEIBU GULF, CHINA

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The Beibu Gulf is a prolific hydrocarbon province on the western coastline of China. The Miocene Jiaowei Formation contains thick sandstone sequences with excellent reservoir quality, a low degree of internal heterogeneity and excellent aquifer support. Structures are low relief causing many discoveries to be classified as thin oil rim fields (<15 m oil columns with bottom-water drive). These discoveries have moderate to heavy oils with low gas-oil ratios and moderate to high oil viscosities. The combination of these rock and fluid

properties are ideal conditions for rapid water coning, hence early well water breakthrough and low oil recovery factors. However, multiple fields in the Beibu Gulf significantly exceed pre-development production expectations. Closer inspection of core and log data indicates there is often a dolomitic alteration zone at the oil-water contacts with permeabilities typically 2 to 3 order of magnitudes lower than the hydrocarbon-bearing reservoir which act as effective aquitards to slow the onset of water coning. The diagenesis is theorised to be due to microbial decomposition of hydrocarbons at the oil-water interface which accrete dolomitic cements as a byproduct. Seismic inversion and amplitude mapping reinforce the view that the alteration zones are pervasive and flat-lying. Case studies are presented covering the discovery, development and production performance of three oil rim fields in the Beibu Gulf.

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6C NON CONVENTIONAL

THE USE OF CORING INDUCED PETAL FRACTURES IN COAL TO SUPPLEMENT AND GROUND TRUTH THE INTERPRETATION OF ACOUSTIC AND RESISTIVITY IMAGE LOGS

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Resistivity and acoustic scanner image logs, in both the CSG and coal-mining industries, are the predominant means of determining azimuths of joints/cleat in coal. Resistivity images of the bore wall reveal large fractures that intersect the entirety of the bore wall (represented by a sinusoidal traces), and those have low height and intersect one side of the bore wall (represented by lineations). Acoustic image logs often only record the larger-scale features.

The strike of fractures that appear on an image log as a lineation are mostly apparent rather than true. In some instances all lineations are presented on rose diagrams as true azimuths, and lineations are erroneously treated as poles to a fracture. Both produce misleading results. A statistical method that extracts the true azimuths from a weighted mean of apparent azimuths, as well as the mean azimuths of highest apparent dips is presented. This is of value to interpreting local tectonic history and gas production.

Petal fractures (PF) in coal, when combined with breakout information, can also be used to determine joint/cleat azimuths of both large and small scale fractures. The PF core-based method can be limited by the presence and abundance of PF, and is dependent on restoring segments of core to their correct relative orientation. Bedding-plane observations of core provides cleat/fracture information not obtainable from an image log. The PF core-based method, in combination with bedding-plane observations of cleat and joints, provides a means to ground truth the results of both acoustic and resistivity image log analysis.

AUTOMATIC FRACTURE IDENTIFICATION USING X-RAY IMAGES

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Unconventional energy (shale gas, shale oil, tight gas, coalbed methane) are trapped in low porosity/permeability environments and are difficult to produce. While the US economy booms due to the shale gas production, rest of the world with nearly 7000 trillion cubic feet of shale gas reserves hasn't been able to unlock the potential of shale gas, yet. Given the technological advancements, the big question is – Are we missing the science? We address this unconventional resource challenge by combining a recent multiphysics, multiscale geomechanics theory with laboratory and modern computational assisted petrophysics and material science concepts. This solid science base will build the platform for enabling a data intensive paradigm for the resource industry. To this end we use of a finite element, Multiphysics Object-Oriented Simulation Environment (MOOSE, http://mooseframework.org) open source software originally designed for multiscale simulations of a nuclear reactor. Using MOOSE, we aim to incorporate multiphase flow in the presence of viscous and plastic processes within the reservoir. Our new simulation platform for the petroleum industry is also available as an open-source parallel simulator for Rock mEchanics with Dissipative feedBACKs (REDBACK, https://github.com/pou036/redback). Early attempts of modelling sand production in a geo-pressured reservoir in Papua New Guinea using REDBACK has been successful. In our current work, we aim to build a tightly-coupled benchmarked reservoir simulator which will highlight the impact of geomechanics on reservoir modelling. This novel approach to incorporate time-dependent geomechanical evolution of the reservoir and its effect on multiphase flow simulations is dubbed, 'Next Generation Reservoir Engineering'.

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6D GEOCHEMISTRY

21ST CENTURY EXPLORATION GEOCHEMISTRY – THE GOOD, THE BAD AND THE UGLY

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'The Good, the Bad and the Ugly' film of 1966 revolves around gunslingers competing to find fortune of gold amid the chaos of the American Civil War. This scenario is not dissimilar to current exploration geochemists' objectives in the turbulence of an extended economic down turn. The film is also distinct in the use of long shots and close-up cinematography, as well as violence, tension, and stylistic gunfights. Again, not dissimilar to the multiple exploration scales we work with, the pressure to get results and the various technical tools one employs to achieve these results. The 21st century has seen some major developments that have shaped the manner in which exploration

geochemistry is conducted. Some of these are good, some are negative and some are downright ugly. More recent advances and future developments can be categorised in four key areas: (1) understanding metal mobility and mechanisms, (2) rapid geochemical analyses, (3) data access, integration and interoperability, and (4) innovation in laboratory-based methods. This presentation will highlight examples in these key areas with the related comparison to the good, bad and ugly aspects of each. Finally, we will look to avoid the hangman's noose by recognising the challenges and identify the frontiers that the exploration geochemistry community needs to traverse to find the next deposit (or buried cache of Confederate gold).

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6E INDUSTRIAL – SANDS

FRAC SAND SUPPLY AND DEMAND AUSTRALIA

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Natural gas is an essential commodity for modern Australia. It's needed for power generation and is an indispensable feedstock for manufactured products such as fertilisers, plastics and chemicals. The distinction between 'unconventional' gas and 'conventional' gas is simply based on the type of rock the gas is found in. Both 'conventional' and 'unconventional' natural gas is methane. CSG and shale gas is almost pure methane whereas conventional gas may also contain ethane, propane, butane, and other hydrocarbons. Gas demand in eastern Australia continues and will increasingly need to be supplied from unconventional sources such as coal seam and tight shale gas formations which generally need the use of hydraulic fracturing techniques to allow the economic extraction of gas. Frac sand competes with ceramic proppants that are all imported. Frac sand must meet the tight specifications outlined by API RP-56. Key factors include: crush resistance, sphericity/roundness, acid solubility and sising. The demand will rise as more production holes are commenced to stimulate gas production in the years ahead. Only ~4% of coal seam gas holes in the Surat Basin have needed frac sand in recent years, but this is expected to rise to 40% within three years. The frac sand grade used is primarily 20/40# with smaller quantities of 16/30#, 40/70# and 70/100# making up the balance. There are few producers of frac sand in Australia. Logistics is a key component of the delivered price. There is a trend towards the end users preferring delivery in pneumatic tankers.

HIGH-GRADE SILICA SANDS IN THE EASTERN MURRAY BASIN NSW

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Investigations in 1979 defined a sand resource at Wah Wah of suitable colourless glassmaking sand. In December 2016 further drilling infilled some of the previously drilled area and extended to new areas.

From this drilling coloured and white sand resources have been defined, under a clay unit. The recent work suggests that the white sands may be of beach origin rather than fluvial.

White sand, defined by the 0.050% Fe_2O_3 contour, coincides generally with higher yield, mostly underlying 6 m to 8 m of clay – the thinner overburden.

Estimated resources are shown in Table 1.

Table 1. Resources summary

	All sand	White sand				
	In situ	*In situ*	Yield <0.710 >0.075mm	Product	$\%Fe_2O_3$	$\%Al_2O_3$
Area (m^2)	1 242 000	669 000				
Overburden clay (m^3)	11 000 000	6 360 000				
Sand quantity (t)	25 000 000	15 000 000	58%	8 700 000	0.035	0.20

These resources are Indicated Resources for JORC 2012 reporting, are defined by drilling and testing, and are suited for glass and other uses.

From the investigations a number of processing techniques can be employed dependant on user requirements. After the 2016 work an attrition-gravity process will be suitable, and cheaper than other options.

Based on results, the sand appears to be suitable for other products, including filter media, various construction uses, and other applications depending on markets.

Compared to the resource defined in 1979 the deposit is expected to be suited to:
- Selective extraction,
- Reduced focus on one market,
- By-products increasing overall yield,
- Lower cost treatment for the higher value products,
- Certainty that sufficient resource will meet longer term needs for a range of products.

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6F EM INVERSION MODELLING

LARGE SCALE 3D AIRBORNE ELECTROMAGNETIC INVERSION – RECENT TECHNICAL IMPROVEMENTS

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The level of sophistication of 3D airborne electromagnetic (AEM) inversion software continues to advance in modern times. Coupled with data acquisition improvements and the rise in parallel computing, the capability of large scale 3D AEM inversion modelling for both time and frequency domain data is

reaching new heights. This work will highlight specific technical improvements that have facilitated this movement. It will also provide the necessary background information for the accompanying abstract that presents a field example showcasing 3D inversion results from an orogenic gold setting.

Key factors that have advanced 3D AEM inversion in recent years are the separation of forward meshes from the inverse mesh, the use of direct solvers on adaptive octree meshes and the strategic optimisation for massive parallel implementation. This work will address how each of these have contributed to 3D AEM inversion improvements and a synthetic model will highlight the benefit of 3D inversion for such targets as dipping plates. The abstract will also discuss how selectively down-sampling based on data gradients can reduce the number of observations without greatly affecting the overall model result. Finally, we demonstrate the effect of increased signal to noise ratios from modern acquisition systems and how this results in improved inversion models.

3D TIME-DOMAIN AIRBORNE EM INVERSION WITH FINITE-VOLUME METHOD

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Imaging and stitched 1D inversion algorithms for airborne EM data interpretation have been very effective in quasi-layered earth environments, but fail in steeply dipping geology and for compact 3D targets. Conventional time-domain 3D inversions consume lots of computer time, even when the discretisation is very coarse. Most of this time is taken for forward modeling and calculation of the sensitivity matrix. We present here an effective 3D time-domain airborne EM inversion based on the Gauss-Newton method.

We directly calculate the time-domain secondary field with the finite-volume method, which method is compact and thus greatly decreases calculation time. We apply several methods and techniques to speed up inversion: (1) we use a local mesh where fine cells are located near the center and coarse ones towards the edges; (2) the multi-frontal massively parallel sparse direct solver is employed to solve equations with multi-channels; (3) we use the adjoint forward method to obtain elements of the sensitivity matrix, and (4) we calculate the local sensitivity for each individual transmitter before re-combining them to form a complete sensitivity matrix. Finally, (5), for each iteration, we update the model using the preconditioned conjugate gradient method.

Using forward models and survey data, we show that our 3D time-domain airborne EM method achieves computational efficiency and obtains good inversion results.

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6G REGIONAL COBAR

METAMORPHISM AND MINERALISATION IN THE COBAR BASIN: IMPLICATIONS FOR EXPLORATION

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The c.420 Ma Cobar Basin is a major mining province in central New South Wales with an estimated metal endowment exceeding 134.9 t Au, 1.91 Mt Cu, 3.46 Mt Zn, 1.8 Mt Pb and 3832 t Ag. Sedimentary sequences of the Cobar Basin preserve diagenetic to burial-related metamorphic grade. Inversion of the basin c.380 Ma resulted in localised penetrative cleavage development and epizone hydrothermal metamorphic grades developed around high-strain reactivated faults and shear zones. Mineralisation in the main Cobar mineral field is associated with these high-strain zones and is linked with hot structurally controlled fluids. South of the main Cobar mineral field, hydrothermal metamorphic highs are associated with correlative mineral deposits in areas of comparatively lower strain (Nymagee and Hera). These deposits are proximal to similar fault systems as those within high-strain zones. New data show that these southern deposits are in part stratigraphically controlled skarns, with early high-temperature (T) mineralogy preserved due to limited syn-inversion retrogression. Carbonate clasts are preserved in the lowest-T skarn and, combined with the regional distribution of ore bodies at a similar stratigraphic level, is suggestive of a regional slump horizon that has focused high-T mineralising fluids. High thermal contrast between anchizone 250°C basin sedimentary rocks and 500°C skarn alteration likely reflects a proximal magmatic heat source, and isotopic data are consistent with a mixed magmatic/basin fluid/metal source. A skarn origin for mineralisation in the southeastern Cobar Basin has implications for exploration, combining elements of both stratigraphic and structural control on the Cobar mineral system.

COBAR DEPOSITS – STRUCTURAL CONTROL

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The Cobar Superbasin is a highly mineralised Palaeozoic basin located in the Central sub-province of the Lachlan Orogen in Eastern Australia. The term Cobar Superbasin is introduced to refer to a series of deep-water troughs/basins, inferred to have formed as half graben and shallow water shelfs. Its northern portion is dominated with siliciclastic sedimentary sequences whilst the southern portion comprisesofsediments, volcaniclastics, volcanic rocks, granites and minor limestone.

The basin formed in the Early Devonian by NE-SW transtension and closed by NW transpression in Late and Middle Carboniferous Period. The overall inversion structural style is NW–SE folding overprinted by NE–SW trending and NNW-

trending eastwards oblique left-lateral reverse faulting in a combined thick- and thin-skinned tectonic environment.

The Cobar Style mineralisation is a common name for mineral deposits hosted in Cobar Superbasin and includes; massive sulphides (VMS), clastic hosted Pb–Zn mineralisation and epithermal gold.

Primary deposit location is controlled within the basement architecture including:
- basin marginal faults (growth faults);
- intersection of growth and transform/transfer faults; and
- intersection transform/transfer faults;

Secondary control of the deposit related to its geometry is caused by inversion tectonic:
- intersection of reactivated growth and transfer/transform faults;
- termination and deflection of strike-slip faults;
- overlap of en-echelon strike-slip; and
- junction of major faults.

Cobar Style mineralisation occurs in in an en-echelon array of sheeted veins characterised by a narrow width (5 m – 10 m), short strike (50 m – 10 m) and a significant depth extension (>2000 m).

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6H INNOVATION

SOURCE ASSISTED MARINE REFRACTION MICRO-TREMOR (REMI) FOR MARINE MATERIAL STRENGTH ASSESSMENTS – NEW IRELAND PROVENCE, PAPUA NEW GUINEA

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Refraction Micro tremor (ReMi) is a relatively new technique which utilises ambient noise generated from urban infrastructure in addition to the natural seismic events to generate shear wave models of the subsurface. Work has been undertaken using ambient seismic data on land, however only very minor work has been undertaken to gain similar information within a shallow marine environments. This paper presents the field acquisition parameters, problems and limitations of data collection and results of a survey conducted in a shallow marine harbour in PNG. The primary objective was to undertake an assessment of the viability of marine ReMi to obtain subsurface parameters to assist in an overarching geotechnical study taking place onsite. The subsurface parameters that the investigation was aiming to define included shear strength and stratigraphy. The environment in which this trial was undertaken was a shallow marine environment containing paleochannels, coral, marine sediments and landslide material.

Material properties are extremely important during design of all engineering projects including seawalls and land reclaiming projects. Until recently there have been limited techniques that could provide S-Wave velocities within a shallow marine environment, with those available being limited to borehole techniques. The application of ReMi has the potential to allow for continuous S-Wave velocities and liquefaction calculations in a shallow marine environment.

The aim of the paper was to undertake research and development into the collection parameters of marine ReMi and attempt to optimise them for use in shallow marine engineering projects.

BOOTSTRAPPING RELIABLE NOISE MEASURE IN TIME-GATED NUCLEAR MAGNETIC RESONANCE DATA

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Time gating is a commonly used approach in the preprocessing of nuclear magnetic resonance (NMR) data before Laplace inversion. Gating suppresses spurious signals that can degrade recovered decay time distributions and therefore often stabilises inversion. However, care must be taken in applying this technique to real world data where both non-Gaussian and correlated noise decrease the efficacy of noise reduction through stacking. If not properly accounted for, unreliable noise estimates introduce inversion artefacts. Fortunately, noise realisation proxies obtained through data phasing can be used to bootstrap reliable confidence intervals for the windowed data. Benefits of the approach are demonstrated through inversion of synthetics as well as borehole data from a deep carbon capture and sequestration application as well as surface NMR data applied to near surface groundwater characterisation. We also introduce an open source cross platorm data processing utility with these capabilities which interested persons can use to explore the impacts of various processing workflows.

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7A PNG AND NZ

INVESTIGATION OF POSSIBLE SHALLOW GAS ACCUMULATIONS ASSOCIATED WITH POCKMARKS ON THE OTAGO SLOPE SOUTHEAST OF NEW ZEALAND

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High-resolution 'boomer' seismic data, together with an industrial 3D seismic dataset indicate the possible presence of shallow gas in the vicinity of the Waitaki Canyon, SE of New Zealand's South Island. Crescent-shaped seafloor depressions are abundant on the marginal extent of the Otago canyon system in water depths between 500 and 1100 m. Fluids seeping through the seabed, potentially forming pockmarks, play a crucial role in seabed ecological systems and can be used to investigate the distribution of hydrocarbons in underlying geological units. Recently acquired 3D seismic data, which characterise the Barque prospect in the Canterbury frontier basin, exhibit the first

indications of shallow gas in the region. Two areas with shallow high-amplitude reversed phase reflections were identified and targeted for a high-resolution 2D seismic survey. The 2D data, acquired by the University of Otago in 2017, show reduced amplitudes beneath the bright spots (as also observed in the 3D data). Above the bright spots, bathymetry data show crescent-shaped seafloor depressions, which were most likely modified by northward flowing currents. Both recent and buried seafloor depressions along the shelf exhibit the same northward facing crescent form that we associate with water current modification. Water column imaging data reveal no evidence for present-day seepage of gas through the seabed. An ongoing program of 2D seismic and bathymetry data collection is underway. High-density velocity analysis and amplitude variations with offset (AVO) will be assessed around the bright spots using several in- and crosslines from the 3D data.

CHARACTERISATIONS OF FOCUSED GAS HYDRATE ACCUMULATIONS FROM THE PEGASUS BASIN, NEW ZEALAND, USING HIGH-RESOLUTION AND CONVENTIONAL SEISMIC DATA

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Gas hydrates are reported widely in seismic data from New Zealand's Hikurangi Margin (east coast of the North Island). Over the last decade, conventional petroleum exploration interests in this region have led to the collection of several regional seismic datasets. These data have greatly improved our understanding of hydrate accumulations in the area; however, the resolution of industry multichannel seismic surveys is limited by the bandwidth of the airgun sources used. We present results from an academic high-resolution generator-injector (GI) airgun seismic survey, undertaken in mid-2015, that targeted focused gas hydrate accumulations lying within thrusted accretionary units in the Pegasus Basin, at the south end of the Hikurangi Margin. Each feature was surveyed with 5 to 10 closely spaced seismic lines that provide an opportunity to examine the three dimensional structure and stratigraphy with better resolution than the original lines.

Two main processes of natural gas migration and resulting accumulation as hydrate are examined more fully: (1) vertical transport into the shallow seafloor driven by overpressure and (2) inclined transport upward along dipping permeable beds. In both of these cases, our data show significant three-dimensional variability is needed to focus fluid migration from below into hydrate trapping configurations within the hydrate stability field nearer to the seafloor. Due to the absence of well data in this basin, the high-resolution seismic data also help to constrain interpretations of basin stratigraphy which plays a significant role in hosting and trapping hydrate accumulations.

COMPARING SHALE GOUGE RATIO AND JUXTAPOSITION ANALYSIS USING STOCHASTIC TRAP ANALYSIS: EXAMPLES FROM GIPPSLAND, TARANAKI, OTWAY AND SOUTHERN NORTH SEA BASINS

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Exploration fault seal analysis of prospects is often focused on generating a probability of success. This risking considers sealing hydrocarbons against faults over geological periods of time, rather than production time. Typically the risking is based on cross-fault juxtaposition and/or sealing shale development on the faults, on a single 'best' technical model, commonly referred to as a deterministic model. Considerable work has been done by a number of workers to calibrate the sealing shale development, for example, the Shale Gouge Ratio (SGR) algorithm, to predict free water contacts. These calibrations involve back-calculating the seal potential as SGR and determining a resulting across fault pressure difference (AFPD), to trap an observed free water level. Importantly, this back-fitting of SGR and AFPD has been conducted on single 'best' technical models. In general, application of SGR methods on sealing across faults in prospects increases predicted column heights and enhances pre-drill chance of success. Prospects with large columns are typically generated and then discounted through geologic risk factors. If wells do not find the predicted columns, this is often 'explained' by lack of charge or trap breach. It is proposed that the fault and stratigraphic uncertainties are significant and need to be included in the modelling of fault seal risk and inferred column heights. A process of model validation will be presented in which observed free water levels are compared with the results of single 'best' technical versus probabilistic models for both juxtaposition and SGR. Case studies from the Gippsland, Taranaki, Otway and Southern North Sea Basins show that probabilistic models can accurately predict free water levels (sub 10m accuracy) and identify leaking faults. Probabilistic models better predict free water levels and are thus better define prospect fault seal risk than models such as SGR based on back-calculating from single 'best' technical models. Incorporating uncertainties in a stochastic analysis typically yields smaller but much lower risk traps, rather than high risk traps based on overly optimistic calculations. Applying these models and methods to fault seal analysis will allow explorers to better define risks and rewards on prospects.

NEW REGIONAL DATA AND ADVANCES IN UNDERSTANDING OF THE STRATIGRAPHY, TECTONICS, STRUCTURE AND PROSPECTIVITY OF THE GULF OF PAPUA (PAPUA NEW GUINEA)

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Between 2015 and 2017, Searcher Seismic acquired 32 478 km of long offset PSDM 2D seismic data and reprocessed an additional 12 972 km of previously acquired 2D data in the Gulf of Papua, Papua New Guinea (PNG). The new data has resulted in a significant improvement in subsurface imaging and areal coverage, providing the foundation for a new integrated analysis of the region. In addition, a regional drop core geochemistry and heat flow survey provides important clues regarding the existence of working petroleum systems in the Gulf of Papua. The evaluation of these new datasets has improved the current understanding of the stratigraphy, plate tectonics, local structure petroleum prospectivity of the Gulf of Papua.

New seismic allowed identification of several depositional packages that are often bounded by regional unconformities related to the tectonic development of the area. Seismic and shipborne gravity/magnetics analyses allowed a confident identification of the following events/packages:

- Moho event allowing estimation of the crustal thickness and differentiation between oceanic and crust and calibration of the heat flow measurements;
- Paleozoic severely folded succession analogous to eastern Australia accretionary terrains;
- Permian analogous to the Bowen Basin in Queensland, Australia;
- Triassic to Jurassic succession supported by the existence of the Jurassic seep identified by the Davaria geochemical survey;
- Presence of previously unidentified block faulted highs with Miocene reefs and carbonate platform build-ups;
- Pliocene and younger basin sandstone floor fans; and
- Extension of the compressional front into deep water Gulf of Papua.

These observations have been integrated into an updated plate tectonic model that predicts widespread deposition of the Permian and Triassic to Tertiary source rocks estimated to be often within the hydrocarbon generative window.

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7B INTERNATIONAL

SHELF-MARGIN ARCHITECTURE AND SHORELINE PROCESSES AT THE SHELF-EDGE: CONTROLS ON SEDIMENT PARTITIONING AND PREDICTION OF DEEP-WATER DEPOSITION STYLE

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The Lower Barrow Group (LBG; Latest Tithonian – Early Valanginian) is a shelf-margin that prograded during a late phase of rifting under various subsidence regimes and supply-dominated conditions. A 3D semi-automatic, full-volume seismic interpretation method allow identifying high-order clinothems presenting an estimated cyclicity of ~40 000 years, in which a quantitative analysis of the shelf-margin architecture and shorelines processes was conducted. Overall, three and four main types of hydrodynamic regimes and deep-water systems were identified, respectively.

Falling to flat shelf-edge trajectories are associated with sediment bypass, whereas rising shelf-edge trajectories are linked with increasing sediment storage on the shelf. While fluvial to wave processes can be dominant in all A/S conditions, results show that fluvial-dominated coastlines are associated with steep high-angle slope clinoforms and short to longer run-out turbidites. Conversely, wave-dominated coastlines are linked to low-angle slope clinoforms and poor turbidite system development (occasional sheet sand and MTDs).

The short and longer run-out turbidite systems present a tripartite architecture (canyon/slope valley; channel; lobes), which mostly appear as short-lived, vertically/laterally stacked elements fed by multiple small rivers forming linear ramp systems. Due to the shallow configuration of the margin (<500 m), the presence of short slopes and overall high sand-to-mud ratio, the turbidite systems are smaller scale (<50 km) and probably shorter lived than most modern turbidite systems (100–1000 km).

This study sheds new lights on the significant role of shelf-margin architecture (slope gradient, hydrodynamic regime) in predicting the deep-water sediment delivery behavior (sediment partitioning, type of deep-water system).

SEDIMENTARY CHARACTERISTICS AND LITHOLOGICAL TRAP IDENTIFICATION OF DISTANT BRAIDED RIVER DELTA DEPOSITS: A CASE ON UPPER CRETACEOUS YOGOU FORMATION OF TERMIT BASIN, NIGER

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Lithological trap identification in thin sand and thick shale layers is still a challenge for hydrocarbon exploration. Based on the high-resolution sequence stratigraphy theory and the establishment of high resolution sequence stratigraphy framework with seismic-well tie, the dynamic deposition process of braided river delta sands on late Cretaceous Yogou formation has been analysed on 62 wells in passive rift Termit basin with multi-stages depressions and reversals. (1) Six kinds of sedimentary microfacies and three major reservoir sands are in Yogou formation; (2) Based on accommodation space/sediment supply change and the deposition progress, sedimentary facies distribution in each member of YS3 sub-formation has been done according to sands thickness statistics of sedimentary micro-facies, narrow-time seismic attributes and slices analysis, the multi-sources and distant braided river delta depositional model has been concluded; (3) Based on source rock and caprock evaluation, with reservoir sands distribution and faults impact on Yogou formation of Termit basin, structure-lithology traps, structure-stratigraphic traps, stratigraphic traps and lithology traps are concluded. Traps influencing factors, i.e., structure geometry, sands distribution, paleotopography, stratigraphy cycling, sand/shale lateral connection, reservoir quality and so on, have different impacts on these traps, and different lithologic-stratigraphy traps have different exploration risks.

AIRBORNE GRAVITY GRADIOMETER SURVEY OVER THE PELARANG ANTICLINE, ONSHORE KUTAI BASIN, INDONESIA

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The Pelarang Anticline is part of the NNE-SSW oriented Samarinda Anticlinorium, a detached thrust-and-fold belt in the Tertiary Kutai Basin. Results from an airborne gravity gradiometer survey over the Pelarang Anticline are presented herein.

The Pelarang Anticline is interpreted as a detachment fold ~30 km long with steeply dipping (70°–80°) flanks. However, seismic imaging on existing 2D data is poor.

In October 2016 Cue Energy acquired airborne gravity gradiometer survey data over the anticline. The survey revealed a large (~10 mGal) gravity signal range, and that the anticline is associated with a strong, positive gravity anomaly. Subsequent application of potential field enhancement filters clearly delineated the crest and the flanks of the feature.

2D modelling of selected profiles across the anticline suggests that it can be modelled as a 1500 m – 2000 m wide, by ~2000 m high shale body that is close to breaching the surface in places. This is in alignment with an interpretation that the feature is cored by a shale diapir, resulting in un-prospective areas.

However, 3D modelling has revealed significant along-strike variations in the depths to the crest of the anticline, suggesting the presence of several anomalous structural lows. Further investigation suggests these features are pull-apart mini-grabens, formed in response to localised shear movements. At least two commercial hydrocarbon accumulations, Sambutan and Mutiara, appear to be genetically related to the newly recognised structural anomalies.

This survey has led to the recognition of a new exploration play in the region, and provided a tool to pursue it.

THE EFFECT OF DEEP BURIAL AND FOLDING ON SANDSTONE RESERVOIRS IN GIANT GAS FIELDS, SOUTH AMERICA

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The underthrust fold belt of the Andes contains some very large gas fields in which the Lower Palaeozoic Sandstone reservoirs are buried to depths of over 4-6 km. The foreland depositional environment received high amounts of metamorphic and igneous rock fragments and deep burial was accompanied by substantial tectonic folding and fracturing. The combined effects of temperature, pressure and time on these labile sediments have reduced typical porosities <5% and matrix permeabilities <1 mD so that these reservoirs are ultra-tight and effectively unconventional. Nevertheless, the fields contain very large recoverable amounts of gas with minor liquids per well and they provide an intriguing case study that contrasts with the typical concept of a petroleum prospect and pose the question how many more large gas fields fit this model?

These complex structural fields required modelling by 3D-Geo using fractured and folded simulation models. The micro-porosity and micro-permeability has been investigated by Curtin University specialists using nano-scale special core analysis in an attempt to identify where the hydrocarbons reside in these rocks, how do they migrate out on production, and how best to estimate and optimise ultimate recovery?

High technology characterisation included TIMA-SEM to map mineralogy and texture at the nano-scale; X-ray Micro-CT analysis of 3D microstructure; NMR, ultra-low Helium porosity and permeability, Hg injection for capillary pressure; elastic and electrical properties to tie the seismic and log data for the modelling. Tri-axial tests helped understand the structural and tectonic history and its relation to the burial history of the reservoirs.

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7C NON CONVENTIONAL

FRACCING ONSHORE AUSTRALIA

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Recent history has seen major inquiries in the Senate and under the control of several States and Territory Governments where one aspect involved the oil and gas exploration technique of fraccing.

Each and every inquiry has concluded that the technique is safe for the purposes of petroleum extraction, subject to appropriate scientific and technical regulation over the activity.

The paper covers the more significant negative submissions made to those inquiries by a range of providers and then explains why those submissions lack scientific and technical support. Such conclusion can only be that it is time for political intervention with science to be abandoned for the long term benefit of Australia and its energy requirements, not only on the east coast.

Each of these inquiries has focused its attention to onshore petroleum activities, but the technique is also commonly used offshore in tight sands and shales.

The paper will include a brief section to define what is fraccing and how the activity has been applied onshore Australia, rather than as applied to the massive fraccs in the major shale basins in the USA.

Submissions have been made by groups such as Lock the Gate, elements of the green movement in Australia, doctors and farmers. Few of these submissions have been founded on sound scientific principles, but that does not make them any less interesting to us or politically less powerful.

IMPACT OF ARTIFICIALLY MATURED ORGANIC MATTER ON THE DIELECTRIC AND ELASTIC PROPERTIES OF COMPACTED SHALES

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Organic material in shale formations contrasts greatly with the mineral matrix. It has a lower density, hydrophobic properties, higher compressibility than any mineral and by comparison with neighbouring minerals is an electrical insulant. With these characteristics organic matter (OM), even when present as only a small weight fraction, influences greatly the overall physical properties of a formation.

We developed a methodology in an attempt to reproduce OM found in shale source rocks with different maturity levels, kerogen types and particle sizes. The process notably comprises a heating phase in anoxic conditions with water and swelling clays. The resulting material is tested elastically and dielectrically by itself and then incorporated in a mineral matrix. It allows us to assess both the intrinsic properties of the OM and its influence in a natural-like scenario with comparison to control samples.

To create our artificial samples we develop a novel apparatus that includes a compaction cell that keeps track of porosity, density, expelled pore fluid and is equipped with P- and S-wave ultrasonic transducers to compute elastic moduli continuously. It also presents the possibility to produce several CT-scan images at different compaction levels to follow the evolution of fabric, homogeneity and organic particles distribution.

Our study aims to analyse the relationship between OM distribution and the anisotropy of elastic and dielectric properties. The effect of maturity level on the OM intrinsic properties and its influence on dielectric permittivity and P-wave velocity is also investigated.

THE STRATIGRAPHIC ARCHITECTURE, DISTRIBUTION AND HYDROCARBON POTENTIAL OF THE ORGANIC RICH KYALLA AND VELKERRI SHALES OF THE UPPER ROPER GROUP (MCARTHUR BASIN)

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The laterally extensive Mesoproterozoic Velkerri and Kyalla organic rich shales of the Roper Group in the McArthur Basin have been identified as possibly one of the most prospective shale gas plays in Australia. The Velkerri and Kyalla shales occur within a thick, predominantly marine, clastic succession within the upper Roper Group of the McArthur Basin in the Northern Territory. Santos has implemented regional studies across the McArthur Basin focussing on the tectonic setting, depositional models and sedimentological/stratigraphic relationships of the Roper Group to better understand the prospectively of the Velkerri and Kyalla shale gas plays. The review involves the study of open file drill core, well log analysis, seismic interpretation as well as the integration of available potential field data. The studies have provided an insight into the facies relationships across the full spectrum of shallow water to deeper marine deposits and the regional distribution of the main stratal units of the upper Roper Group. The Roper Group succession consists of approximately six major regressive–transgressive (R–T) sequences, each ca 500–1000 m thick, deposited in a clastic-dominated marine deltaic setting. This analysis focusses on the three youngest R–T sequences. The regional seismic interpretation reveals an overall southeast thickening of the upper Roper Group succession in the Beetaloo and OT Downs sub-basins, supporting a northward prograding delta depositional model. Well and seismic data indicate that the organic rich shales of the Velkerri and Kyalla formations are laterally continuous, relatively undeformed and thermally mature, classifying them as unconventional reservoirs hosting potentially large volumes of retained hydrocarbon.

GEOMECHANICAL PRESTACK DEPTH MIGRATION OF THE KRAKEN 3D (BROWSE BASIN, AUSTRALIA)

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Conventional pre-stack depth migration applied to the broadband Kraken 3D Marine Seismic Survey was unable to fully resolve short-wavelength velocity anomalies below the sea floor causing obvious imaging problems and limiting depth conversion and amplitude interpretation. Improved imaging was achieved by initiating tomography using a velocity model built by combining geomechanics with rock physics appropriate for shallow carbonates and mudrocks.

3D gravity modelling using high-resolution bathymetry and compaction trends constitutes a new approach for iteratively building a 3D geomechanical model. Effective stress (as a function of x, y and depth) is derived by applying Terzaghi's principle within an integration (along depth) involving the model bulk and fluid densities and the vertical component of gravity (all of which may vary with x, y and depth, using more refined models).

Carbonate and mudrock rock physics models, believed to be appropriate for Neogene sediments along much of the NW Shelf of Australia were derived from abundant core and wireline data acquired during the recent IODP Expedition 356. These models provide the necessary link between effective stress and P-wave velocity with Backus averaging handling the 'seismic scale' mixing of different lithologies expected in the Kraken 3D area.

Kirchhoff prestack depth migration was revisited from archived preprocessed gathers using the geomechanical model to initiate tomography. Heavy smoothing of velocities was imposed where sequence stratigraphic interpretation suggests only distal mudstone facies. Tomography in shallower layers was then revisited to restore geologically plausible depth structures and deliver a clear improvement in imaging relative to previous processing efforts.

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7D GEOCHEMISTRY

A NEW BLASTHOLE XRF PROBE FOR MINING GRADE CONTROL

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Mining grade control is often based on geochemical sampling of blast cones. Limitations of this method include; a single assay result representing the entire length of the hole, the requirement of an on-site lab to meet turn-around times, bias generated by sampling of the blast cones and the risk of physical injury during sampling.

A new 125 mm diameter XRF logging probe has been designed specifically for providing chemical assays by wireline logging. This tool will provide a continuous assay log down the length of the blasthole, providing a more representative sampling of the entire hole as well as providing the opportunity for composite sampling over different section of the hole, e.g. to provide more detailed grade control to support selective mining as several flitches within an open-pit bench. Once the system is calibrated, results can be delivered as soon as logging is complete.

This paper presents the results of a series of bench tests demonstrating the accuracy and precision of the prototype BHXRF probe as a grade control tool for different types of bulk commodity or base metal deposits.

CASSITERITE AND RUTILE AS INDICATOR MINERALS FOR EXPLORING THE VMS SYSTEM, GOLDEN GROVE, WESTERN AUSTRALIA

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Cassiterite and rutile strongly resist physical and chemical weathering. These minerals are abundant in a near-surface silcrete duricrust capping a deeply weathered profile over the Scuddles Cu–Zn–Pb VMS deposit, Golden Grove, Western Australia. Silcrete consists mainly of massive microcrystalline quartz at depth grading upward into silicified, collapse breccia. Silcrete changes laterally into kaolinitic saprolite and both form a shallow leached zone (<40 m) over supergene Cu–Zn sulphide and oxides zones at depth.

Strongly acidic and highly saline fluids, generated by oxidation of massive sulphides, caused weathering of labile minerals, removal of clays and leaching of alkali, alkaline earth and transition (e.g. Fe, Mn, V, Ni, Co, Cu, Zn) elements, followed by collapse and residual concentration of resistate minerals. Pyrite, chalcopyrite, sphalerite, galena and argentite in the VMS are preserved as inclusions in cassiterite, rutile and quartz in silcrete. Supergene nanocrystalline Au (up to 35 ppm) and Ag (up to 1100 ppm) halides occur as a cavity-filling cement and postdates silica cementation.

After residual concentration in silcrete, cassiterite, rutile and quartz are intensely corroded releasing Sn, Ti, Pb, Sb, Bi, W, Mo and Te. Subsequently, these elements form a cement of complex mineral paragenesis and variable chemical compositions corroding Ag halides. These elements together with Au and Ag are enriched in silcrete forming a narrow halo delineating the underlying Scuddles VMS system.

Discovering mineralised silcrete over the Scuddles VHMS deposit has significant implications for exploration, not only in Australia, but also in regolith-dominated terrains with similar weathering histories elsewhere in the world.

CAN GEOPHYSICS AND GEOCHEMISTRY COMBINE TO DETECT MINERALISATION UNDER TRANSPORTED COVER?

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The oxidation of Fe-containing sulfide mineralisation leads to the development of natural galvanic cells that are characterised by a reduced acid chimney above the mineralisation itself and pH-redox controlled chemical haloes surrounding the chimney and may extend through overlying transported regolith cover of varying thicknesses and composition. Acid reduced chimneys also alter regolith mineralogy (changes to clays, loss of carbonates), which may alter geophysical characteristics such as electrical conductivity (EC). This paper reviews trace element geochemical and EC geophysical mapping over porphyry style Au–Mo–Cu mineralisation at Mandamah (NSW) and MVT Pb–Zn mineralisation at Tappeh Sorkh (Iran). At Mandamah, mineralisation is buried under 50 m of alluvium and a further 30 m of *in situ* regolith. The main mineralised zones are characterised by low EC in the upper 6 m of the regolith profile that can be related to changes in clay mineralogy and the destruction of carbonates caused by the acid chimney. These patterns are variably reflected in pH and the distribution of selectively-extracted Ca, Mg, S, Ba and REE in the upper part of the transported regolith profile, but generally not in the elements of economic interest (Au, Cu or Mo). At Tappeh Sorkh mineralisation is covered by 80 m of dolomitic sedimentary rocks and thin alluvium. There is an increase in EC above mineralisation and adjacent low EC values. The combined geochemical and geophysical approach provides a new approach to exploration in large areas with economically prospective geology but where mineralisation is buried by rock or transported regolith cover.

FIELD ANALYSIS OF LOW PPB GOLD USING PXRF AND NEW DETECTORE TECHNOLOGY

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The ability to analyse gold in the field at meaningful concentration levels for mineral exploration, and in a practical manner, has not been achievable. Portable X-Ray Fluorescence (pXRF) was a game changer for explorers when it became available about a decade ago. However, whereas pXRF can analyse for metals such as Cu, Zn, As and Fe at concentration levels relevant to mineral exploration, it can only reasonably analyse for gold above 10 ppm and only then when interfering elements are absent. Here we present new patented detectORE technology, developed by CSIRO, that can analyse gold using a pXRF at four orders of magnitude lower, at 1–10 ppb concentrations, which will revolutionise world gold exploration. The method has been tested against certified reference materials and whilst not a 'total' gold method like fire assay or neutron activation analysis, it provides the mineral explorer with crucial information in the field. Having data available during the execution of a soil sampling or drilling program allows the geologist to make decisions on where to sample next 'on-the-fly'. For example, adjusting drilling strategy and quickly defining the extent of the mineralisation. Currently, mineral explorers may have to wait weeks or months before the results of the gold analysis are returned from the analytical laboratory, and by this time the drill campaign is over, possibly for another year. Medium to small exploration companies can ill afford to wait that long in the current financial climate.

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7E BRINE DEPOSITS

LITHIUM: FUNDAMENTAL SUPPLY/DEMAND, THE LITHIUM BRINES OF SOUTH AMERICA AND EXPLORATION/DEVELOPMENT METHODOLOGIES

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Demand for electric vehicles has surprised to the upside in the past year with a widening realisation of a significant shortfall in supply of lithium for lithium ion batteries from both hard rock and brine sources. South American lithium brines contribute approximately 50% of global lithium supply but new supply developments are choked in the short to medium time due to development timelines and regulatory restrictions. Current exploration and development methodologies of lithium brines are reviewed with the latest extraction techniques summarised.

EVALUATING BRINE DEPOSITS USING BOREHOLE MAGNETIC RESONANCE.

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Brine mining is an important source of elements such as potassium, iodine, lithium, and bromine that occur in solution in groundwater, typically in shallow brines occurring beneath saline or dry lakes or in deep brines in sedimentary basins. Where feasible, brine mining is an attractive alternative to conventional mining due to lower surface and environmental impact and lower OPEX than conventional mining operations.

As with any resource, evaluating brine deposits requires developing an understanding of how much resource is present and how it can be most economically produced. How much resource is present is a function of the bulk aquifer volume, the specific yield, and the brine composition, while the primary subsurface control on economic production is hydraulic conductivity, which dictates the rate at which the brine can be produced to surface. Specific yield and hydraulic conductivity are analogous to the free fluid volume and permeability quantities that are of interest in oil and gas resource assessment.

Borehole magnetic resonance has been applied in the oil and gas industry for the evaluation of bound and free fluid volumes and

permeability for over 20 years. These same methodologies are equally applicable in the evaluation of brine deposits, however the hypersaline brines that are targets for commercial development cause highly conductive borehole environments that can be extremely challenging for magnetic resonance measurements. Nevertheless, use of borehole magnetic resonance measurements to help evaluate a sulphate of potash brine deposit currently under assessment shows that such measurements can be employed successfully in these environments.

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7F NEW AIRBORNE EM TECHNIQUES

SUB-AUDIO MAGNETICS (SAM) – GROUND-BASED AND UAV-BORNE FLEM TRIALS AT THE FORRESTANIA EM TEST RANGE

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Sub-Audio Magnetics (SAM) is a rapid sampling survey technique capable of simultaneous acquisition of data related to the magnetic and electrical properties of the earth. Based on Total B-field Cs vapour sensors, SAM surveys have historically focused on the acquisition of high-resolution Magnetometric Resistivity (MMR) and Total Magnetic Intensity (TMI) data.

Recent developments in SAM receiver instrumentation, data processing and high power transmitter technology have now made SAM Fixed Loop EM (FLEM) surveys possible due to the exceptionally high data quality now being achieved.

SAM data are acquired from a moving platform which makes the technique amenable to applications ranging from ultra-detailed, man-carried or vehicle-towed ground surveys to large-scale Helicopter-borne acquisition. Because the instrumentation is light-weight, it may also be deployed from a remote-controlled or autonomous, unmanned aerial vehicle (UAV) or drone.

This paper describes ground-based and UAV-borne SAM FLEM trials conducted over the Forrestania EM Test Range in Western Australia and compares the results with conventionally-acquired (stationary) SAMSON surveys. The trials have demonstrated that SAM FLEM surveys are able to detect high conductance ore bodies at significant depth from a moving survey platform.

In either ground or UAV mode of operation, the SAM technique is shown to be a significant advance towards reducing the cost of deep exploration for high conductance orebodies.

CGG'S NEW HELITEM C SYSTEMS

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Recent development and re-design of the Helitem helicopter time domain system have resulted in the release of the Helitem$_{30C}$ and Helitem$_{35C}$ systems. This paper describes the design path of these two systems and provides field examples highlighting the major design features.

The Helitem$_{30C}$ is an all-around system designed to be applicable to the majority of TEM surveys. The system utilises a 30 m diameter transmitter loop with a concentric receiver geometry.

The Helitem$_{35C}$ is a high specification system designed to provide the highest Tx power, the lowest base frequency and the lowest noise performance. A 35 m diameter transmitter loop is used, with transmitter moment up to 1.3 MAm^2. Pulse width is configurable, from 4 ms (for resistive/small features) to 10 ms (exploring under conductive cover). Helitem$_{35C}$ employs concentric receiver geometry with a re-designed suspension system which significantly reduces coil motion, allowing it to operate at base frequencies as low as 12.5/15 Hz with no increase in motion noise. 12.5 Hz base frequency provides a measuring time of over 30 ms, which is an important factor for exploring under conductive cover.

To illustrate the design changes, we provide data examples from 25 Hz surveys in Tasmania, 12.5 Hz operation in Western Australia, and geologic mapping for gold exploration from a resistive area.

PASSIVE EM PROCESSING OF MEGATEM AND HELITEM DATA

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The recording of raw or streaming data, as done by CGG during MEGATEM and HELITEM surveys, allows for the extraction of passive EM responses, inadvertently recorded during AEM surveys. These include powerline responses in data sets acquired in the vicinity of strong powerlines, VLF responses in data sets recorded with sufficiently high sampling frequencies and potentially AFMAG responses in the frequency range 25–600 Hz.

The recording of the three-component AEM data allows for the vector processing of these passive EM responses, including the derivation and modeling of the tipper data. Conductivity information can be derived from the tipper data with an apparent conductivity transformation and, more rigorously, with 2D and 3D inversions that take into account the terrain's topography.

The extraction of passive EM responses is demonstrated on a number of data sets. A powerline apparent-conductivity grid, derived from a MEGATEM survey near Timmins, Canada, indicates conductivity structures not evident in the corresponding active-source EM data. VLF responses derived from various HELITEM and MEGATEM data sets, show a strong correlation to topography, but were successfully modeled with 2D and 3D inversions. The derived shallow conductivity structures confirm

and complement the information extracted from the active-source EM data.

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7G REGIONAL MAPPING METHODS

CHARACTERISING THE SUBSURFACE ARCHITECTURE AND STRATIGRAPHY OF THE MCARTHUR GROUP THROUGH INTEGRATED AIRBORNE EM AND GRAVITY INVERSION

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The Caranbirini sediment-hosted Zn-Pb-Ag prospect is located to west of the Emu Fault, ~20 km north of McArthur River Mine (formally HYC), within the Batten Fault Zone of the McArthur Basin (Northern Territory). The Caranbirini area exposes stratigraphy from McArthur Group and shows some structural complexity with post-depositional folding and faulting. In order to better characterise the subsurface basin architecture we combine structural, sedimentological, and stratigraphic interpretations with 3D gravity inversion, and a 1D airborne electromagnetic inversion. Results are integrated to build a 3D model of the subsurface basin architecture, and identify prospective stratigraphy such as the Barney Creek Formation. 3D gravity inversions were performed using a preliminary 3D geological model of the project area as a reference model for a constrained property inversion. The gravity inversion identified an anomalous density zone immediately west of the Emu Fault. Interpretation of the inverted AEM data provided stratigraphic constraint for the geological model by defining the depth and geometry of the Barney Creek Formation. They also indicated the presence of several N–S trending faults to the west of the Emu Fault coincident with the western boundary of the anomalous density zone. The interpretation suggests that the depth to the Barney Creek Formation increases westwards of the Emu Fault. We interpret the increase in depth to the Barney Creek Formation, in combination with the zone of increased density as a fault-bounded sub-basin, bounded in the west by a paleo-high. Recognition of the sub-basin and controlling faults has implications for targeting Zn–Pb–Ag mineralisation.

SELF ORGANISING MAPS - A CASE STUDY OF BROKEN HILL

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'Self-organising maps' is a type of unsupervised learning technique for multivariate data. It runs through as many layers of data as you can provide it with and finds correlations between them. This means the end users sole responsibility is to evaluate the cause of the correlations. Broken Hill, thanks to the Broken Hill Exploration Initiative, has a data density which is relatively unparalleled. However, thanks to the rising quality of remote sensing, we can expect increasingly high density data sites within Australia and globally. SOM is used to effectively evaluate this very rich data set.

The goals of the project were to develop a workflow that simplified and assisted with data integration and interpretation and then to integrate this software with commercially available packages and become part of a standard workflow. The SOM toolbox creates a SOM domain representation of how component clusters correlate. It DOES NOT give any spatial information. Our work takes the SOM result and translates it back into the spatial domain. It is important to note that none of the results we developed use geological unit maps. Stratigraphic maps were only utilised for remapping individual units, and regolith data was intentionally left out to demonstrate the effectiveness of SOM. Spatial Structures and other regions arise naturally out of the data provided to the SOM.

We present the workflow and MATLAB program we developed to create these spatial maps of correlations indicated by a standard SOM map. Some features such as the Granitic intrusives, unmapped features in the Adelaidean and the high contrasting Silver King Formation (mineralisation zone), are discussed. An emphasis is placed on how SOM works and finds correlations.

This work was submitted for consideration to the Frank Arnott Award.

THE UTILITY OF MACHINE LEARNING IN IDENTIFICATION OF KEY GEOPHYSICAL AND GEOCHEMICAL DATASETS: A CASE STUDY IN LITHOLOGICAL MAPPING IN THE CENTRAL AFRICAN COPPER BELT

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Random Forests, a supervised machine learning algorithm, provides a robust, data driven means of predicting lithology from geophysical, geochemical and remote sensing data. As an essential part of input selection, datasets are ranked in order of importance to the classification outcome. Those ranked most important provide, on average, the most decisive split between lithological classes. These rankings provide explorers with an additional line of reasoning to complement conventional, geophysical and geochemical interpretation workflows. The approach shows potential to directly aid in identifying important criteria for distinguishing geological map units during early stage exploration. Subsequently, this can assist in directing expenditure towards the acquisition and advancements datasets which will be the most productive for mapping.

In this case study, we use Random Forests to classify the lithology of a project in the Central African Copper-Belt, Zambia. The project area boasts extensive magnetic, radiometric, electromagnetic and multi-element geochemical coverage but only sparse geological observations. Under various training data paradigms, Random Forests produced a series of varying but closely related lithological maps. In each case, variable ranking

highlighted those datasets which were of greatest importance to the result. Both geophysical and geochemical datasets were well represented in the highest ranking variables, re-enforcing the importance of access to both data types. Further analysis showed that in many cases, the importance of high ranking datasets had a plausible geological explanation, often consistent with conventional interpretation. In other cases, attention was drawn to datasets that may not have previously been considered to be of interest.

TERRAIN CORRECTION CORRECTION TASMANIA – RESULTS AND IMPLICATIONS

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As Tasmania has the greatest topographic variation of any Australian continental jurisdiction, the terrain correction (TC) is a major component of complete Bouguer anomaly reduction for the State gravity database. TC values >1 mGal are not uncommon, and may exceed 30 mGal, readily swamping anomalies of exploration interest. Accurate determination of the terrain effect is therefore critical.

Most corrections in the Tasmanian database were calculated manually, to 22 km radius. Availability of high resolution elevation models, coupled with high computing capacity, allows revision of these. An earlier pilot project on portions of western Tasmania indicated that the older TC values may be substantial underestimates. In some areas, automatic corrections (to 167 km radius) exceed the former by >5 mGal. The pilot also demonstrated that 25-m. DEMs, currently the best resolution available for the entire State, deliver acceptably low loss of TC accuracy in comparison to 1-m. DTMs from LiDAR.

This paper presents results from the complete statewide TC revision. To enable this, an improved, 'bare earth' version of the State 25-m. DEM was produced. This was achieved by incorporation of a high quality subset of the State survey control points, combination with bathymetry from Tasmania's extensive larger lakes and hydroelectric impoundments, and extension via near-shore marine research data to merge with national bathymetric data. The DTM was also improved in coastal areas by inclusion of low-water-mark mapping together with tidal range information.

Areas of the most substantial TC changes are highlighted, and possible geological and exploration implications examined.

1530–1710
TUESDAY 20 FEBRUARY 2018

7H INNOVATION

LOW NOISE, MULTICHANNEL SURFACE NMR RECEIVER SYSTEM WITH WIRELESS CONNECTIONS TO RECEIVER COILS

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Surface NMR is often considered a promising tool in groundwater measurements due to its unique direct sensitivity to subsurface water and its ability to provide information on the pore space in which the water is situated. The surface NMR method currently suffers from a number of drawbacks limiting its widespread applicability. Among these drawbacks are a low signal to noise ratio limiting the use of the method in many places of interest and a low production rate, which makes the method costly in field campaigns. There is thus a need for new research on instrumentation further advancing the technology. We report on the development of a new multichannel, low noise surface NMR receiver system with wireless connections to noise reference receiver coils. Due to the wireless operation, noise reference receiver coils can be located near particular noise sources and remain there as the NMR transmitter and receiver coil is moved between different measurement sites improving both noise reduction and field methodology. The receiver system works as a completely independent add-on to existing transmitter systems and consists of a number of independently operated data acquisition boxes connected with WiFi and synchronised by GPS. The internal electronic noise level of the system is 1.2 nV/sqrt(Hz). The timing jitter between data acquired in different boxes is less than 100 ns.

ECLOUD – MAGNETOTELLURIC WEBAPP

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Geophysical web applications are highly underrated. There are many potential benefits for transitioning to a cloud based web applications, including compatibility improvement, low on-going operating costs and better access to existing third-party code and tools for facilitating rapid development. For users, time spent on installation, general IT maintenance such license management and upgrading is minimised.

While web applications for business style applications are deeply established, scientific applications on the web are only just emerging. This research builds upon our previous feasibility study (Pethick and Harris, 2015), which was the development of a 1D MT web application. This is to be redeveloped into a commercial grade cloud hosted geophysical inversion web app that can cooperatively invert seismic and magnetotelluric (MT) data. Our software, ECloud, is designed to be user friendly where geoscientists and drillers can upload MT field data

directly from their laptop, tablet or mobile to obtain subsurface geo-electrical distributions quickly with minimal input. This application is designed to be scalable, suiting cloud environments and is currently hosted on an Amazon EC2 instance. The preconceived notion that web applications are slow will be challenged. The purposefully designed MT algorithm and software structure will hopefully result in lower computation times while minimising restrictions based on hardware requirements (i.e., primary memory).

GROUNDWATER ASSESSMENT IN A COAL MEASURES SEQUENCE USING BOREHOLE MAGNETIC RESONANCE

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Hydraulic behaviour of an aquifer is defined in terms of the volumes of water present, both producible and not (specific yield and specific retention), and the productivity of the water (hydraulic conductivity). These parameters are typically evaluated using pumping tests, which provide zonal average properties, or more rarely on core samples, which provide discrete point measurements. Both methods can be costly and time-consuming, potentially limiting the amount of characterisation that can be conducted on a given project, and a significant measurement scale difference exists between the two.

Borehole magnetic resonance has been applied in the oil and gas industry for the evaluation of bound and free fluid volumes, analogous to specific retention and specific yield, and permeability, analogous to hydraulic conductivity, for over twenty years. These quantities are evaluated continuously, allowing for cost-effective characterisation, and at a measurement scale that is intermediate between that of core and pumping tests, providing a convenient framework for the integration of all measurements.

The role of borehole magnetic resonance measurements in hydrogeological characterisation is illustrated as part of a larger hydrogeological study of a coal measures unit and associated overburden. Borehole magnetic resonance has been used for aquifer and aquitard identification, and to provide continuous estimates of hydraulic properties. These results have been compared and reconciled with pumping test and core data, considering the scale differences between measurements. Finally, an integrated hydrogeological description of the target rock units has been developed.

GEOLOGICALLY-CONSTRAINED INTERPRETATION OF AIRBORNE ELECTROMAGNETIC DATA FOR DEFINITION OF PROSPECTIVE GROUNDWATER RESOURCES, ALBANY HINTERLAND, WESTERN AUSTRALIA

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A TEMPEST airborne electromagnetic survey was flown in the Albany Hinterland with the objective of determining likely palaeochannel locations for future groundwater exploration. The basement in the survey area is the Proterozoic Nornalup Complex, which is overlain by Tertiary-Eocene sediments, including the Werillup Formation and Pallinup Siltstone. These units are overlain by Quaternary sediments of thickness 10–70 m. The maximum thickness of cover materials overlying basement is ~100 m. The main aquifers in the area are Werillup Formation sands within palaeochannels incised into the basement.

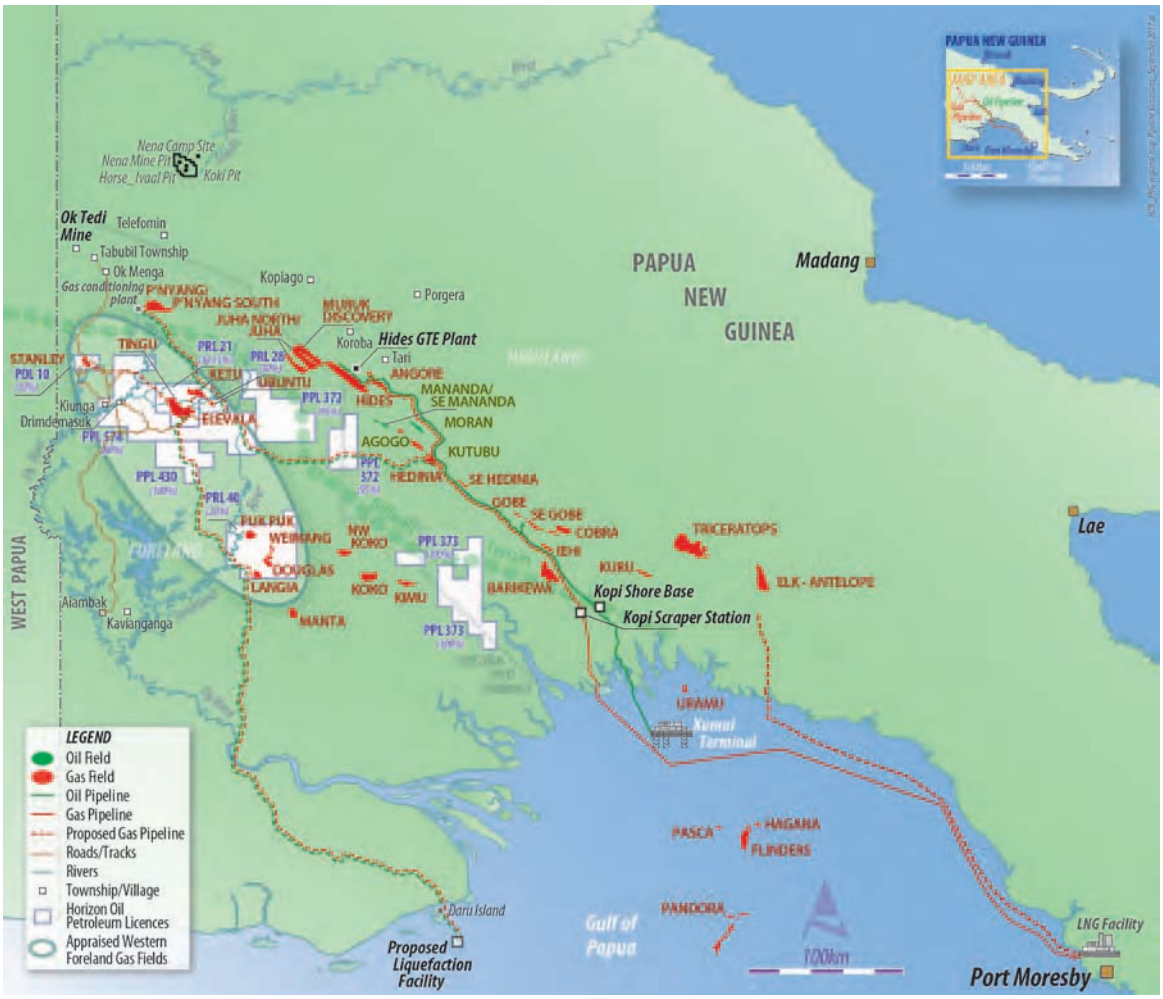
The conductivity derived from the TEMPEST data shows a layer of moderate electrical conductivity (50–150+ mS/m), which correlates well with clayey units within the Werillup Formation, and possibly also the weathered upper part of the Proterozoic bedrock. Bedrock conductivities are typically low (average ~1.2 mS/m). The strong electrical contrast between the Werillup Formation and the bedrock allowed depth to Proterozoic basement to be interpreted from the TEMPEST data. This was done by conventional unconstrained layered-earth inversion followed by manual interpretation of the depth to bedrock on each survey line. The interpreted bedrock depths were used to construct a triangulated surface representing base of cover. Geologically-constrained inversion of the TEMPEST data was then undertaken to refine the preliminary depth to basement model. Geological constraints on the model were provided by drillhole basement pierce points and outcrop. A large number of drillholes which did not reach bedrock were also used. The inversion was constrained to place the final bedrock surface below the ends of these drillholes.

The geologically-constrained inversion and subsequent synthesised interpretation identified a number of bedrock lows which have been confirmed by drilling to correspond to palaeochannels, and has defined four main groundwater resource areas. The results of the interpretation have formed the framework for the Albany Hinterland Prospective Groundwater map (Ryan *et al*., 2016).

Horizon Oil - focused on the future

The sharp and sustained fall in prices experienced since 2014 has been the defining feature of the oil and gas industry in recent times. Globally, many projects have been deferred or cancelled, the workforce has been in decline and there have been substantial reductions in exploration expenditure around the world. While Horizon Oil is not immune to the challenges facing the industry generally, the Australian based, ASX-listed upstream oil and gas company continues to see attractive opportunities in Papua New Guinea and is pushing ahead with plans to commercialise its gas-condensate resources in PNG's remote, but highly prospective, Western Province.

It is noteworthy that despite the difficult market conditions, Papua New Guinea continues to attract strong competitive interest from major investors. This interest has been demonstrated by the entry of Total S.A. into Elk/Antelope and more recently, by ExxonMobil's US$2.5 billion purchase of InterOil Corporation. Furthermore, substantial expenditure on exploration and appraisal drilling continues to be incurred by large companies (including Oil Search and Santos) in close proximity to Horizon Oil's Licence areas. This investment activity highlights the stability and attractiveness of PNG as an oil and gas investment destination. It also underlines the value of Horizon Oil's material PNG asset portfolio; a commanding acreage position in the northern forelands of Western Province which includes a Petroleum Development Licence over the Stanley Field (PDL 10), and Petroleum Retention Licences over the Elevala and Ketu Fields (PRL 21), the Puk Puk and Douglas Fields (PRL 40) and the Ubuntu Field (PRL 28).



Gas commercialisation pathways emerging

Horizon Oil's primary focus is to develop its Western Province resources and work completed to date has identified a number of promising gas commercialisation pathways. PRL 21, which contains the Elevala and Ketu fields, is of particular importance in this context. The Elevala and Ketu gas-condensate fields contain a combined independently certified gross contingent resource (2C) of 1.4 trillion cubic feet of gas and 56 million barrels of condensate, forming the cornerstone volume needed for Horizon Oil's gas commercialisation efforts. These gas-condensate fields were originally discovered in the early 1990s and are located some 60 km east of the Western Province port town of Kiunga. A comprehensive appraisal program, consisting of 3 appraisal wells and 205 km of 2D seismic, was completed between 2011 and 2013 with the results of that appraisal program and subsequent analysis confirming the commerciality of the Elevala and Ketu fields.

The high ratio of condensate to gas found in both the Elevala and Ketu fields initially supported a two phase development plan aimed initially at gas recycling and condensate recovery in the first phase, with gas commercialisation options to be evaluated and matured in a subsequent second phase of the development. A Petroleum Development Licence application was submitted to the PNG Government on that basis in March 2014, targeting initial condensate production of 10,000 to 12,000 barrels per day. Pleasingly, there has been significant progress made with the regulatory approval process, including receipt of formal approval by the PNG Conservation and Environment Protection Authority of the Elevala development Environmental Impact Statement.

In response to the recent commodity price market, when oil prices were sitting below US$50/barrel, the attention of Horizon Oil and its PRL 21 joint venture partners turned to combining both phases by accelerating the gas commercialisation phase of the overall development plan. Horizon Oil's proposed Western LNG project seeks to aggregate these gas fields to develop 2.0 to 2.5 trillion cubic feet of gas and 60 to 70 million barrels of condensate. The aim is to export the gas and condensate via pipeline and an offshore LNG facility which will have a capacity of around 1.5 million tonnes per annum.

Crucially, the resources in Western LNG are held by only 6 participants, with almost 70% concentrated in the hands of Horizon Oil and the Spanish major Repsol. This consolidation of ownership is important as it will make the process of development planning and aggregation simpler than with a widely dispersed ownership group.

The LNG market is becoming rapidly aware of the potential of smaller LNG developments, with strong demand growth for LNG in emerging South East Asian economies, particularly in relation to dispersed power generation, and this is largely being driven by new entrants who want greater flexibility of supply. PNG is somewhere of a sweet spot from which to meet those needs.

Western LNG is targeting start up in the early 2020s when it is anticipated that the South East Asian markets will be undersupplied with LNG. While focusing on export markets a key component of the development criteria is making sure that the development plan maximises the potential for domestic PNG market access for gas and LPG. The design concept provides multiple gas offtake points for local industrial consumers and power generation.

Preliminary economics are attractive and Western LNG, if successful, will be expected to generate around US$1 billion a year for 20 years or more. The project is in pre-Front End Engineering and Design now, Horizon Oil anticipates proceeding into Front End Engineering and Design in 2018, with a Final Investment Decision scheduled for 2019.

Although focusing on export opportunities, Horizon Oil is a strong supporter of proposals aimed at developing PNG's resources for domestic consumption and the Company is actively pursuing domestic market opportunities. PNG's mineral resource industry provides substantial opportunities to substitute clean natural gas for diesel or heavy fuel oil-fired power, adding value not only to mining operations but also to power intensive mineral processing and refining within PNG. Horizon Oil's gas resources, along with the significant upside potential provided by nearby exploration prospects continue to represent a significant commercial opportunity for PNG and the Western Province to establish and develop infrastructure, industrial activity, employment and export revenue based on a secure and long-term gas and fuel supply resource.

Stakeholder engagement - an ongoing priority

While focused on the technical task of planning and designing a major gas project, Horizon Oil remains cognisant of the broader social context in which it operates in PNG. Community expectations do not change with a rise or fall in the price of oil or gas and like many resource developers, Horizon Oil expends considerable effort on stakeholder engagement. Many of Horizon Oil's project area communities are located in remote, difficult to reach areas. A core tenet of Horizon Oil's stakeholder engagement activity is the maintenance of 'face to face' contact, essential for building positive relationships. This work is primarily led by the Community Affairs team who make

regular visits to project area villages, often staying overnight, to conduct formal and informal information sessions. These village visits are fundamental and provide community members with an important opportunity to ask questions, share their views or offer insights into Horizon Oil's activities.

Although the current commodity price environment has caused Horizon Oil, like all petroleum companies, to cut costs, this does not extend to our commitment to community support and in this regard the Company has maintained our partnerships with Australian Doctors International and Mercy Works. ADI is a not-for-profit, non-government development aid organisation which has been focused on strengthening primary health care services in rural and remote communities in PNG since 2002, and Mercy Works provide maternal health focused training services to regional health centres and rural aid posts, training programs for women and low cost child care for working mums along with workshops in rural communities aimed at minimising violence in families and communities. The partnerships see Horizon Oil allocate A$100,000 (PGK200,000) annually to support the deployment of voluntary medical practitioners in the Western Province of PNG. Two ADI doctors have been deployed since 2016 and the partnership is on track to deliver a broad program of clinical consultation with structured and unstructured in-service training to health workers in remote Western Province communities.

There is no doubt that the last few years have been challenging ones for the oil and gas industry. Nevertheless, Horizon Oil continues to see robust opportunities in PNG and remains firmly focused on pursuing those opportunities with the intention of bringing its Western Province resources to production.

Wednesday 21 February 2018

0830–1010
WEDNESDAY 21 FEBRUARY 2018

8A NEW TECHNOLOGY – SEISMIC

BROADBAND LEAST-SQUARES WAVE-EQUATION MIGRATION

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We introduce an efficient iterative Least-Squares Wave–Equation Migration (LS–WEM) solution for broadband imaging. Least-Squares Migration (LSM) solutions are designed to produce images of the subsurface corrected for wavefield distortions caused by acquisition and propagation effects. They implicitly solve for the earth reflectivity by means of data residual reduction in an iterative fashion, which usually demands intensive computation. The LS–WEM is implemented using an acoustic anisotropic one-way wave-equation wavefield propagator that is able to fully utilise both the broader seismic bandwidth and the high-resolution velocity information from Full Waveform Inversion (FWI). Our implementation combines the one-way extrapolator with fast linear inversion solvers into an efficient migration inversion system. Application to the 2D Sigsbee2b synthetic model improves the sub-salt illumination by balancing the image amplitudes and reducing the effects of the shadow zones, enhances temporal resolution by broadening the frequency spectrum, balances the wavenumber content and improves images of faults and dipping salt flanks. In addition, LS–WEM converges rapidly to the true solution, reducing the data residuals by 90% in only four iterations. Application to real 3D datasets from the Gulf of Mexico and the North Sea demonstrates high-resolution imaging with reduced acquisition footprint effects, improved spatial frequency content, and better structural imaging at all depths.

METHODS FOR REDUCING UNWANTED NOISE (AND INCREASING SIGNAL) IN PASSIVE SEISMIC SURVEYS

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Passive seismic surveys are becoming of increasing interest for characterising the near surface, in particular the depth of cover. For passive seismic acquisition ambient noise is both signal and noise. The 'signal' component is generally considered to be energy resulting from distant sources (storms, tides etc.) while the 'noise' component is a result of near sources (vehicles, vegetation movement etc.). For surveys to be successful we clearly need to maximise the former while minimising the latter. We cannot directly increase the amount of source energy so instead we need to ensure that we enhance the recording of the signal while minimising unwanted noise. In this paper we describe how the positioning and coupling of seismic sensors can be optimised to maximise the signal-to-noise ratio of passive seismic data.

QUANTITATIVE INTERPRETATION: USE OF SEISMIC INVERSION DATA TO DIRECTLY ESTIMATE HYDROCARBON RESERVES AND RESOURCES

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A quantitative interpretation workflow utilising AVO inversion based lithology prediction data was developed to directly assess reserves and resources for an LNG development project in the Carnarvon Basin. The study area is covered by modern MAZ PSDM 3D seismic data using broadband acquisition and processing techniques, calibrated by numerous well intersections of the Triassic Mungaroo Formation reservoirs.

Interpretation of the fluvio-deltaic reservoir bodies can be somewhat interpretive using 'traditional' workflows. By interpreting chrono-stratigraphic events tied to well-based biostratigraphy and then using the lithology prediction volumes, the interpretation of reservoir bodies becomes more objective.

Seismic inversion data are typically used to qualitatively guide resource assessments, through amplitude mapping or use in static and dynamic modelling. In this case study, the inversion based prediction volumes are used to extract P90, P50 and P10 sand geobodies which are directly input into probabilistic reserve and resource assessments. The workflow is applied to discovered, developed, undeveloped and prospective reservoirs.

Geobody extraction required the PSDM depth data to be accurately calibrated to wells. A calibrated velocity model was built by perturbing the imaging velocities in a 3D model to tie the chronostratigraphic events associated with all the reservoir intervals. Fluid contacts derived from wells were used to provide a depth cut-off to the geobody extractions.

The resulting reserve and resource assessments from this workflow show an excellent match with previous assessments including static and dynamic modelling methods. The geobodies also identified previously unrecognised channel sands not easily interpreted on full and angle stack data.

SOLID SUBSTITUTION: THEORY VERSUS EXPERIMENT

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Gassmann fluid substitution is widely used in geophysical practice. In the last few years a topic of fluid/solid substitution has emerged, where the substances filling the pore space can be solids, fluids, or visco-elastic materials such as heavy oils. Solid substitution cannot be accomplished with the Gassmann theory because the finite rigidity of the pore fill (either solid or viscoelastic) prevents pressure communication throughout the pore space, which is a key assumption of the Gassmann theory. In this paper we explore applicability of solid substation techniques by using a sandstone saturated with a solid substance, Octadecane, a hydrocarbon with a melting point of 28°C, making it convenient to use in the lab in both solid and fluid

form. Our approach is to measure a dry sandstone sample, then saturate it with liquid Octadecane at 35°C, measure, cool it to 20–25°C and measure again. The dry properties can be used to obtain parameters necessary for fluid and solid substitution. The results show that moduli of the dry sandstone exhibit significant pressure dependency, which is reduced for the solid filled rock. Also the prediction of the Gasmann theory and Ciz and Shapiro theory underestimate the velocities. This suggests that stiffening occurs due to substantial reduction of compliance of grain contacts by the solid infill. This effect is accounted for by the solid squirt theory. The results give direct evidence of the solid squirt effect and can be used to verify and calibrate theoretical solutions for rocks saturated with solid or viscoelastic substances.

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8B NEW TECHNOLOGY – CO_2

ROCK-PHYSICS BASED TIME-LAPSE INVERSION IN DELIVERY4D: SYNTHETIC FEASIBILITY STUDY FOR CO2CRC OTWAY PROJECT

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Conventional approach to 4D seismic inversion consists of parallel inversions applied to seismic vintages. Only then, the inverted changes of seismic attributes are converted into petrophysical properties using rock physics. This paper develops a robust approach to 4D seismic inversion based on a Bayesian approach along with rock physics constraints. This means that observed time-lapse seismic response along with the baseline amplitudes are inverted directly into rock properties via pre-defined relations to the seismic properties. To this end, we extend the functional of Delivery - an open-source stochastic inversion software.

We illustrate efficiency of Delivery4D using synthetic 4D dataset generated for Stage 2C of CO2CRC Otway project, Victoria. Complexity of the synthetic wavefield resembles field data acquired for the Otway project while all unknown sources of noise/uncertainty are excluded and we have 'ground-truth' subsurface properties.

Despite the relatively thin CO_2 plume, the 4D inversion reduced detected time-lapse anomaly to the location that closely corresponds to the actual CO_2 plume. Estimated distributions of the plume characteristics (thickness, saturation and CO_2 mass) are overall similar to the static and dynamic geomodels. However, the values inverted at a particular trace may differ significantly. We attribute these discrepancies to the limited seismic resolution and imperfections of the amplitude-preserved seismic processing.

APPLICATION OF TIME-LAPSE FULL WAVEFORM INVERSION OF VERTICAL SEISMIC PROFILE DATA FOR THE IDENTIFICATION OF CHANGES INTRODUCED BY CO_2 SEQUESTRATION

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Seismic methods are frequently used for the purpose of monitoring of time-lapse changes introduced by CO_2 sequestration. Surface seismic is often considered as the main tool for monitoring. Vertical Seismic Profile (VSP) is occasionally applied as an auxiliary method. Standard VSP data processing workflow does not provide a quantitative estimate of the time-lapse changes in the physical properties. However, full waveform inversion (FWI) may be used for the purpose of quantitative interpretation. Its ability to employ the whole seismic wavefield (including transmitted, reflected and converted waves) for the purpose of building the models of physical properties can be considered one of its main advantages.

We show that time-lapse elastic FWI of single- or multi- offset VSP data is capable of providing quantitative estimates of time-lapse changes in the medium. A feasibility study is carried out on 2D and 3D synthetic datasets created using full-earth models of the CO2CRC Otway CO_2 sequestration site. The inversion workflow obtained from the feasibility study is successfully applied to a field single-offset time-lapse VSP dataset. As a result, FWI provides an image of the time-lapse changes introduced by the injection of supercritical CO_2.

3D VERTICAL SEISMIC PROFILING ACQUIRED USING FIBRE-OPTIC SENSING DAS – RESULTS FROM THE CO2CRC OTWAY PROJECT

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Distributed Acoustic Sensing (DAS) is an optical interferometric method for acquisition of acoustic and seismic signals. It uses laser pulses that travel along the length of the fibre-optic cable and backscatter as they encounter small inconsistencies in the fibre. Impinging seismic waves cause strain on the cable, resulting in differences in phase of the backscattered light. Interest in DAS has increased significantly in the past decade as it is particularly suited for VSP acquisitions, including for permanent reservoir monitoring. Fibre-optic cables can be installed permanently in the well, cemented behind the casing or in the tubing; they offer a relatively cheaper and efficient solution when compared to conventional borehole sensors.

This study is part of the CO2CRC Otway Project. The Otway Project site is located approximately 240 km south-west of Melbourne, Australia. The Stage 2C of the project aims to monitor a small injection (15 kt) of CO2/CH4 gas mixture at a depth of approximately 1500 m (Paaratte Formation). Here, we

show the results of a 3D VSP survey acquired using DAS, as part of the fourth monitoring survey for Stage 2C. We aim to analyse the quality of DAS 3D VSP by establishing levels of signal and noise, as well as investigating directivity patterns of the data. Also, we analyse the feasibility of using DAS for detection of the gas plume.

GEOCHEMISTRY OF STORING CO_2 AND NO_X IN THE DEEP PRECIPICE SANDSTONE

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The Precipice Sandstone in the Surat Basin is being appraised for CO_2 geological storage owing to its high porosity and permeability and expected high injectivity. Generally it is quartz rich with variable kaolinite, however detailed characterisation of core shows that it contains minor to trace amounts of potentially reactive minerals including carbonates, plagioclase, chlorite, and muscovite, increasing towards the overlying Evergreen Formation top seal. The Evergreen Formation is mineralogically more variable with interbedded low porosity and permeability mudstones, fine-grained sandstones, and calcite cemented zones. Recent data from capture technologies has reported that CO_2 from coal combustion will retain NOx impurities in the form of NO. Experiments performed in our laboratory at reservoir conditions show CO_2-NO lowers pH and is more reactive to minerals in the core than pure CO_2. Geochemical modelling will investigate the optimum amount of NO that can enhance long term mineral trapping compared to pure CO_2 injection in the Precipice Sandstone. The optimal CO_2 quality (purity) with respect to groundwater TDS will also be discussed. Our previous work with CO_2 +/– SO_2 and O_2 impurities has shown a mineralogical control on the reactive geochemistry especially in the overlying Evergreen Formation, where calcite cemented zones below the sealing mudstone sections can favourably buffer the acidity generated by the dissolved impure CO_2 stream.

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8C CENTRAL AUSTRALIAN BASINS SYMPOSIUM

EVOLVING EXPLORATION METHODS IN THE HYDROCARBON PLAY WITHIN THE PATCHAWARRA FORMATION ON THE WESTERN FLANK, COOPER BASIN

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The hydrocarbon play in the Patchawarra Formation lies within a Permian age, high latitude, fluvial sand and coal measure system that is some 300 m thick and deposited in the Cooper Basin of Central Australia. Fluvial sand channels, ranging from 1 to 20 m thick, form a conventional reservoir. Seal and source play components are in the inter-bedded overbank, silts, clays and coal seams. The low seismic reflectivity sands combined with the numerous, high seismic reflectivity coals makes standard seismic interpretation difficult. These factors combined with the thin, irregular geometry of the reservoir, make exploring for hydrocarbon traps challenging.

The largest fields in the Western Flank, discovered to date, are considered to have a stratigraphic trap component that is combined with a structural influence. Each field has a single main pay zone located in different clastic package compared to the other fields in the play.

An evolving exploration method is reviewed that uses the coals as local timelines with trap limits defined using structural and stratigraphic indications from the seismic. This method combined with ideas of source and trap has recently proved successful in extending the play.

Examples of some of the hydrocarbon traps and concepts are shown that may help with evolving ideas and future exploration methods in this basin and other basins with similar fluvial plays.

STROMATOLITE CONSTRUCTION, BIOFACIES AND BIOMARKERS IN THE LOWER CAMBRIAN HAWKER GROUP, ARROWIE BASIN, SOUTH AUSTRALIA

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Stromatolites are laminated microbial deposits, normally composed of accretionary layers of cyanobacteria and other (often anoxic) bacteria which form on the sediment-water interface. Stromatolites represent one of the earliest records of life on Earth, dating back at least 3.7 billion years. Stromatolites became extremely diverse and very abundant throughout the Archaean era 4–2.5 billion years ago, eventually causing increasing levels of atmospheric oxygen on Earth, as part of the Great Oxidation Event. The emergence and radiation of bilaterian animals and the development of new and more complex food webs during the early Cambrian coincided with a sharp decline of the abundance of stromatolites – yet they continued to exist in a range of Cambrian carbonate environments. The appearance, environment, and possibly the biogeochemistry, of Cambrian stromatolites appears to have been altered after the evolutionary development of epifaunal grazing bilaterians. We sampled stromatolites from a wide spectrum of carbonate facies in the lower Cambrian Hawker Group in the Ikara-Flinders Ranges, South Australia. The appearance, construction, distribution, and biogeochemistry of stromatolites from different depositional environments, including phosphatic hardgrounds, intertidal shoals and shelf/ramp settings is being described as part of an investigation into their morphological variation and ecological association, aiding in the clarification of specific stromatolitic biofacies, and taxonomic associations. There has been little research on the morphology, architecture, growth, and biogeochemistry of stromatolites of stromatolites in the Arrowie Basin; this study is designed to provide novel data about stromatolite evolution and ecology during a period dominated by the radiation of complex animals.

RESERVOIR MODELLING, STRUCTURAL HISTORY AND VOLUMETRICS OF THE JERBOA AREA, EYRE SUB-BASIN

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The Eyre Sub-basin occurs towards the western end of the Southern Australian rift system that has developed since the Jurassic. Jerboa-1, the only well in the sub-basin, was drilled by Esso in 1980 on a mid-basin high using sparse 2D seismic. Though 'dry', subsequent studies estimate a 15 m palaeo-oil column indicating a working petroleum system with Jurassic source rocks. The Jerboa-1 trap was breached in the Early Cretaceous, however, there is the potential of non-breached traps elsewhere in the sub-basin. Regional interest has led several companies to restart exploration including Santos, Murphy Oil, Chevron, BP and JX Nippon.

The Curtin University petroleum group has an active program of seismic, reservoir characterisation and organic geochemical research. The Jerboa area has been remapped with the latest seismic, well logs and core data to produce 3D models of the basin structure, burial and thermal histories. More detailed 3D reservoir models investigate the facies and trap integrity around the well through time and the results reveal new insights into the petroleum potential of the region.

The 3D modelling allows estimation of volumes in the palaeo-trap and associated traps. The Jerboa structure possibly held >20 million barrels of oil with potential for much larger accumulations. Other potential traps exist down-dip in the sub-basin where trap breaching may be less than on the inter-basin highs. These plays are comparable with East African Rift Systems, where spectacular exploration successes have occurred recently drilling down-dip, after 50 years of unsuccessful drilling on the obvious highs.

TERTIARY DEEP-WATER CORAL SUPPORTS COLD SEEPS IN THE CEDUNA SUB-BASIN

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The analysis of new 3D seismic and the acquisition of unique core data enables an in-depth interpretation of outboard Eocene mounds in the central Ceduna Sub-basin and a more accurate model of their origin.

Seismic attributes and spectral decomposition clearly image the 3D morphology and internal architecture of the mounds and enable building episodes to be defined. Mounds have length of 5-35 km, width of 1–4 km and heights of 50–110 m and developed at water depth 300–600 m. Gravity core of the top of one mound indicates that it consists, at least partly, of corals typical of a deep-water reef. This initial interpretation is based on comparison with modern reef-forming biota, the presence of suspected brachiopods and lack of gastropods.

The underlying faults control the initial localisation of the mounds. These faults were active in the Cretaceous and reactivated in the Tertiary and intersect sequences modelled as oil- and gas-mature.

One main control for deep-water coral is the need for suitable hard substrates for initial attachment. The distribution of the mounds supports a development mechanism that relies on carbonate hardgrounds produced by chemosynthetic communities metabolising nutrients from natural hydrocarbon cold seeps along reactivated faults and segments intersections. A hydrothermal feedstock for these communities is possible but less likely due to the distance to the nearest volcanic bodies. Once the substrates are in place the mounds growth is not directly dependant on ongoing cold seeps and could be as well related to the specifics of hydrodynamics in the areas.

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8D HISTORY

OCEAN AND ATMOSPHERE CHEMISTRY DRIVE CYCLES OF BASIN-HOSTED ORE DEPOSITS THROUGH TIME

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Trace element concentrations in marine pyrite, measured by laser ablation ICP-MS, have opened a new window into deep time ocean chemistry, atmosphere oxygenation and genesis of basin-hosted ore deposits (Large et al., 2014, 2015, 2017). A database of over 5000 marine pyrite trace element analyses has enabled the development of deep time proxies for nutrient supply, productivity, ocean pH and atmosphere oxygenation. These proxies suggest that the Archean ocean was enriched in Fe, Ni, Co, As, Au and Hg compared with modern oceans, probably related to composition of erosive flux from the continents and active seafloor hydrothermal activity. This was also a time for major iron, gold and nickel ore formation in sedimentary and greenstone settings. In the Palaeoproterozoic there was a decrease in Ni, Co, As and Au replaced by increasing Cu, Zn and SO_4^{2-} in the oceans and O_2 in the atmosphere. The first appearance of red beds and evaporates is a response to the rise in O_2 and SO_4, and provided the conditions necessary for sediment-hosted Cu and Pb–Zn–Ag deposits. Through 1700 to 1500 Ma, phosphorous, gold and most other nutrient TE dropped to a minimum in the ocean, possibly related to tectonic stasis and changes in atmosphere O_2 and/or ocean pH. Sediment-hosted Au, orogenic Au and VHMS deposits are virtually absent from this period, whereas mineral systems that required relatively oxidised ore fluids, such as SEDEX Zn-Pb and IOCG became more abundant, due to these changed conditions. All redox sensitive and nutrient TE rose dramatically in concentration at the Proterozoic–Phanerozoic boundary and peaked in the mid to late Cambrian, accompanied by black shale deposition enriched in Mo, Se, Ni, Ag ± Au and PGE. Cyclic variation in nutrient TE increased in frequency through the Phanerozoic on a wavelength of 50 to 100 Ma, compared with 500 to 1000 Ma in the Proterozoic. The more frequent Phanerozoic cycles relate to repeated episodes of continent collision, mountain building and increased erosive flux of TE into the oceans. Ore deposit cycles in the Phanerozoic of SEDEX Zn-Pb, orogenic sediment hosted Au and VHMS have a similar time frame to the tectonic and seawater chemistry cycles.

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QUEST FOR THE HOLY GRAIL; BHP'S GEOPHYSICAL RESEARCH PROGRAM 1985–2005

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Over the period from 1985 to 2005, BHP Minerals carried out three major geophysical research projects that were intended to significantly enhance the ability to find new ore deposits. This involved major activities internally as well as external components that involved complex multi-year programs involving the large expenditure of funds. In all cases, major efforts were made to deploy the outcomes in BHP's exploration programs. While the technologies developed could be considered as successful in having met or exceeded the original development goals, in no case did the outcomes of these efforts contribute materially to the discovery of significant new mineral resources. This suggests that the technical objectives for a new technology were comparatively straight forward to define but the subsequent implementation path, once the technological goals are achieved, were poorly conceived.

BHP's experience is much like the exploration industry as a whole over the same period. While much appears to have been developed that has added significantly to the technical capabilities of the industry, it has been less apparent that these developments have been able to contribute significantly to an improved discovery record.

Considerable effort is now being directed towards bringing new geophysical technologies on in programs such as *Uncover* in Australia and CMIC's *Footprint* in Canada. Past experience suggests, however, that better technology alone can't be expected to achieve the sought after goal of improved discovery success.

TEN YEARS IN THE WILD: THE P223 EXPERIMENT

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The use of open-source codes has become pervasive over the past 20 years but such codes are uncommon in minerals exploration. The P223 series of programs researching forward and inverse modelling of electromagnetic data was supported by CSIRO and six AMIRA consortia over 27 years and produced, amongst others, the codes, Airbeo, LeroiAir and Marco. This project concluded in 2008 and, after a two-year embargo, the code base, consisting of computer programs modelling different approximations of the earth for ground and airborne prospecting systems, was released to the public. Our study examines highlights of the research program and the evolution of some programs of the suite in the 10 years since the program concluded. We ask why codes have not been more widely adopted, and examine the evolution of some of the codes in research, academia and in industry as a guide to parties who would embark on a similar route.

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8E GEOPHYSICAL CASE STUDY

CONSTRAINED 3D MODELLING AND GEOCHEMICAL ANALYSES OF THE HORSESHOE RANGE BIF: TOOLS FOR EVALUATING MAGNETIC SIGNATURES UNDER COVER

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The Horseshoe Range is a banded iron formation (BIF) in the Southern Capricorn Orogen, WA, and is associated with a large linear positive magnetic anomaly. Electron microscope mineralogy identified ubiquitous goethite and magnetite/hematite. This study focussed on measuring the magnetic properties of the rocks at Horseshoe Range in order to accurately predict their geophysical responses when buried beneath cover.

The BIF can be modelled using a single homogenous layer with a susceptibility of 0.8 SI. However, this is not geologically consistent with BIFs which typically display variable iron-oxide mineralogy and associated petrophysical properties.

One way to more accurately model BIFs is to use the first vertical derivative as the model input. Using this approach, a 4 layer model was generated which matched the anomaly to an RMS of ~1%. Modelled susceptibilities ranged from 0.01–0.55 SI which is consistent with the measured properties. However, this model did not take into account the measured high intensity downward magnetisation vectors.

Remanent magnetisation intensities of the rocks were high (up to 1300 A/m) and vectors measured in the rocks were oriented predominately downward which typically result in negative anomalies which is inconsistent with the observed anomaly.

Due to the positive nature of the magnetic anomaly, and the ability to accurately model the response without remanent magnetisation, it appears that the high intensity remanent magnetisations may be volumetrically insignificant and likely limited to the near surface. The remanence may be caused by near surface formation of maghaemite during bushfires and/or induced by lightning strikes.

COMPARING RESPONSES FROM DIFFERENT AEM SYSTEMS AND DERIVED MODELS AT THE SUNNYSIDE NICKEL PROJECT, BOTSWANA

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The Sunnyside nickel deposit in SE Botswana is a shallow Selebi-Phikwe type deposit composed of disseminated, blebby and massive nickel sulphides. It was discovered by Anglo American in the 70s but considered uneconomic to mine. It is associated with pyroxenite and gabbro, and is an extremely complex orebody. Since that time several nickel companies have explored the body further, trying to improve on the size and grade and confirm whether the body extends to depth.

The deposit has been surveyed to date by four different AEM systems, being VTEM, Spectrem, SkyTEM and Xcite. In addition, detailed ground geophysics in the form of moving loop TDEM and AMT has been done. In this paper we present a detailed comparison of the EM data measured by the four systems, and of the models derived through quasi-3D spatially constrained inversions of the AEM data. The resulting models are also compared to drilling information and the resistivity models obtained from inversion of the AMT data. The AEM systems all display different signal and noise levels, and various types of preprocessing. The inversion results are, in general, in good agreement with each other and with the ancillary drilling and AMT information. Some systems however produce inversion outputs with higher accuracy or depth of investigation than others. IP effects, present in portions of the AEM datasets, add another degree of complexity but can also provide an extra layer of information.

WHAT IS ZTEM SEEING OVER THIS TROPICAL PORPHYRY?

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A ZTEM survey over the Cobre Panama mine lease, which highlights most of the known porphyry copper deposits in the cluster, is credited with the discovery of a sixth deposit that will be included in the mine plan. The source of the ZTEM response is within the fresh rock below weathered saprolite and extends to a depth of many hundreds of metres, as does the orebody. The response is at least partly due to the sulphide content of the orebody, both pyrite and chalcopyrite. However, the sulphide percentage of all the deposits is quite low, to a maximum of 3%. A shallow airborne TEM survey also detects a near-surface, fresh rock signature associated with the ZTEM response of each deposit. Thus the TEM response should probably be attributed in part to the associated alteration, mainly sericite, and this will contribute to the intensity of the ZTEM signature as well. Inversion modelling in 2D and 3D indicates the ZTEM is detecting deeper parts of the orebodies, with the correct gross geometries, including the main chalcopyrite mineralisation. These conclusions are supported by analysis of multiple deposits in the cluster.

AIRBORNE GEOPHYSICS OVER THE DOLLY VARDEN VMS AND LOW SULPHIDATION EPITHERMAL SILVER DEPOSITS, NORTHWESTERN BC, CANADA

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Results from helicopter VTEM time-domain electromagnetics that include aeromagnetics and gamma ray spectrometrics and later ZTEM natural field helicopter electromagnetics are compared over the Dolly Varden Mine region that hosts both potential VMS Pb–Zn base metal and low sulphidation epithermal silver mineralisation, beyond the known vein-type Ag deposits and showings.

There are few well-defined discrete targets within the VTEM data set. The magnetic data have defined a network of older fault structures trending NNE, ENE, WNW, and NW. These structures are interpreted to be related to extensional basin formation. Prominent in the radiometrics is a potassium anomaly over the Red Point area, consistent with a quartz-K-feldspar–chlorite–pyrite zone, interpreted as a VMS feeder. ZTEM resistivity and magnetic geophysical anomalies suggest the presence of broad, generally flat lying resistive and magnetic units at depth. At Red Point and along the Tiger-Evindsen Corridor, ZTEM displays moderate to high resistivity and low magnetics, which suggest the presence of strong potassic-silicic alteration, related to low sulphidation epithermal systems.

The airborne geophysical results over the Dolly Varden mine region provide valuable insights on the detectability of similar Ag rich Eskay Creek type HS VMS and Brucejack style LS epithermal deposits. The principal VMS deposits seem immune to clear or discrete identification as EM conductors using VTEM, likely due to their Pb–Zn rich/Cu poor mineralogy; whereas, unlike VTEM, the ZTEM seems to clearly define high resistivity regions surrounding the known deposits that would seem to be consistent with their K-Si-altered low sulphidation epithermal origin.

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8F HARDROCK SEISMIC

POTENTIAL OF FULL WAVEFORM INVERSION OF VERTICAL SEISMIC PROFILE DATA IN HARD ROCK ENVIRONMENT

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Complex structure of the subsurface in hard rock environment often complicates traditional processing and interpretation of seismic datasets based on the analysis of reflected waves. Full-waveform inversion (FWI), in turn, utilises the whole

wavefield, including the transmitted waves and reflections, to build the models of physical properties (such as P wave velocity and density), which is one of its main advantages over traditional methods of seismic imaging. We conduct a feasibility study of 2D full-waveform inversion (FWI) applied to vertical seismic profile (VSP) synthetic data computed in a model that is based on a real hard-rock survey site for the purpose of identification of heterogeneities.

Using this complex model of the subsurface that contains steep interfaces, high seismic wave velocities and densities, we generate a synthetic VSP dataset with a finite-difference code. Multi-offset VSP geometry is considered due to the abundance of transmitted waves. We then apply FWI to this dataset. We use finite-difference modelling for the forward problem in FWI, optimisation is conducted using the limited-memory BFGS method. FWI is applied in a multiscale manner, from 10 Hz to 170 Hz. Inversion results suggest that FWI of VSP data is a suitable tool for building the models of physical properties of the subsurface that are crucial for mineral exploration and mine planning.

THE RISE OF 3D SEISMIC IN HARDROCK MINERAL EXPLORATION

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3D seismic has been a cornerstone of the coal and petroleum industries for decades. And yet, its adoption by the hardrock minerals industry has been much slower. This delay has many causes, with the most obvious being the sheer complexity of acquiring and processing seismic data in a hardrock setting. Fortunately, this topic is the subject of much ongoing research.

A less obvious cause is the limitations of the available software for visualising and interpreting the processed data. Hardrock miners have long enjoyed the flexibility of general mining packages (GMPs) for displaying, analysing, and modelling everything from first-pass geochemical sampling to optimised long-term production scheduling. But these applications are optimised towards massive numbers of drillholes, block (voxel) models, and triangulations, and they perform poorly when asked to display 3D seismic. The result is a massive file, with a long loading time and slow graphics interaction. On the other hand, petroleum software is optimised towards seismic data, but can't handle massive numbers of drillholes.

These limitations can be overcome by incorporating modern gaming graphics technology and efficient file storage platforms within an application, and this presentation concludes by illustrating the results of applied research and development carried out at MICROMINE towards producing a fluid real-time seismic visualisation environment.

FAST-TRACKING GOLD EXPLORATION BELOW 300M – 3D SEISMIC CASE HISTORY FROM DARLOT GOLD MINE

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The Darlot-Centenary gold deposit is one of the larger known mineralised systems in the southern end of the West Australian Yandal Greenstone Belt, with an estimated 3 Moz having been extracted from the Darlot Centenary Mine since 1988. The area is well explored near surface but, given the proven endowment, there is potential for significant additional mineralisation at depth. With current proven reserves dwindling, Gold Fields recognised the need to identify a technology to fast-track target generation in order to more rapidly evaluate the nearby rock volume.

In August 2016 Gold Fields began investigating the potential for 3D reflection seismic to accelerate evaluation of the rock volume accessible via existing workings. In November 2016 a seismic crew was on ground acquiring approximately 150 km^3 of 3D seismic data (25 km^2 surface area $\times$ 6 km depth). The survey coverage was designed to image the local steeply dipping geology and structures. Processing of the seismic dataset was completed in Q1 2017 and Gold Fields has completed preliminary interpretation of the 3D cube.

The seismic data has provided a rich 3D picture of the Darlot structural framework to depth, which could not be obtained by any other geophysical method. It has highlighted a number of features with similar characteristics to known mineralisation and has provided a better defined structural framework that has greatly assisted the fundamental geological understanding and further aided ranking of these targets in terms of prospectivity.

DISTRIBUTED ACOUSTIC SENSING FOR MINERAL EXPLORATIOIN: CASE STUDY

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Vertical seismic profiling (VSP) is commonly used in the oil and gas industry for better subsurface imaging and characterisation, as well as for providing depth calibration for surface seismic. The use of VSP in mineral exploration and mine planning is not common at all, mostly due to the small diameter and stability of the boreholes, as well as relatively high cost of such surveys. These issues can be mitigated by using cheap and potentially disposable borehole sensors, such as fibre-optic cables utilised in distributed acoustic sensing (DAS).

The questions we want to answer in this work are how the quality of DAS data compares to other types of borehole measurements, and what are the operational benefits and constraints for the use of this technology in mineral exploration settings. To this end, we have tested performance of DAS measurements in one of the boreholes of The Mineral Systems Drilling Program in South Australia and compared them to hydrophone measurements. The DAS measurements provide data quality that is much better than a hydrophone string, in particular it has consistent amplitudes at different depths, shows less cable and tube waves, and the reflections are much clearer. The acquisition of DAS data is taking a much shorter time than any other borehole measurements

that require multiple pulls of the receivers. The reduction of the acquisition time increases with the depth of the borehole. This case study proves that DAS measurements show big potential for the mineral exploration and exploitation.

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8G GROUNDWATER

IMPACT OF AIRBORNE ELECTROMAGNETIC (AEM) SURVEYS IN GROUNDWATER MANAGEMENT IN THE LOWER PLATTE SOUTH NATURAL RESOURCES DISTRICT, NEBRASKA, USA

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The Lower Platte South Natural Resources District has collected several thousand line kilometers of Airborne Electromagnetic (AEM) data during five surveys beginning in 2007 and continuing through 2016 to develop a hydrogeologic framework for priority groundwater management areas. Frequency domain systems were originally used in 2007 and 2008. A shift to time domain electromagnetics was required to increase the depth of investigation in areas of conductive glacial till beginning in 2013. The AEM surveys were collected as reconnaissance and block flight lines. Careful calibration and diligent inversions were required to maximise resolution of the AEM data. The AEM improved hydrogeologic framework was the basis for changes to the management area boundaries and the type of management controls for many of the areas. The revised Dwight-Valparaiso-Brainard management area has experienced improvements in ground water levels and recent regulation changes have allowed an increase in groundwater pumping in the eastern region. Based on the AEM a new recharge area was identified, and management controls were implemented to reduce non-point source pollution over the recharge area. The AEM derived hydrogeological framework information has been used for the following: to vary management techniques based on degree of aquifer confinement and in-season water declines; to determine the amount of groundwater in storage; to locate potential recharge areas; to guide the installation of monitoring wells; to locate and install surface water gages to understand groundwater-surface water relationships; to locate areas for vadose zone characterisation; and assist local public water suppliers with the management of limited aquifers.

RESOLVING CHANGES TO FRESHWATER LENS SYSTEMS IN A 'SEA OF SALINITY' USING MULTI-DATE AIRBORNE EM

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Saline aquifers in the Murray River or SE Australia are traversed by freshwater rivers, with adjoining riparian and floodplain regions containing freshwater lenses. Bore data and more recent AEM surveys have determined that these lenses are spatially extensive, but have having widely varying geometries. The maintenance of these lense systems is important as they support ecologically significant riparian vegetation communities such as Red Gum and Black Box. A more complete understanding of their hydrogeology is required to ascertain how they develop and degrade. Limited ground investigations including ^{14}C geochemistry have determined that the lens systems contain recent water, indicating that they are dynamic systems with their development defined by the relative rates of recharge from the river and mixing with groundwater. Changes in groundwater gradients and depth, floodplain extent, and topography are believed to control their initial location. The same controls also govern their stability. The potential of airborne EM systems for defining the geometry of these lens systems in 3D is considered along with an assessment of their value for monitoring variations associated with these ecosystems. The advent of 'calibrated' AEM systems and robust inversion tools have given added impetus to their use for monitoring. Spatio-temporal variations are observed in the near surface (top 20 m) from a multi-temporal assessment of Clark's Floodplain, in co-incident airborne EM surveys acquired between 2008 and 2015. Spatial changes in ground conductivity, attributed to changing groundwater quality have been observed. The freshwater lense systems appear to have contracted significantly over the past decade.

STRETCHING AEM NEAR-SURFACE RESOLUTION LIMITS RELATED TO LOW- AND VERY HIGH RESISTIVITY CONTRASTS

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Data from AEM surveys carried out in Norway, to support ground investigations for infrastructure projects, was used in this study. In large infrastructure projects knowledge of sediment thickness is vital, as is information about possible occurrence of highly sensitive clay.

In an area with conductive shales over resistive bedrock, the recently introduced system response method was tested. It's applied in the inversion of SkyTEM data and makes it possible to utilise the very earliest gates. The models showed more pronounced structures in the near-surface, reflecting true structures observed in resistivity borehole measurements. The same outcome was observed when conducting synthetic modelling.

In another setting AEM, measurements were carried out along a planned road project to provide information about the extent of very conductive, possible alum shale. A volume estimate of excavated masses was sought, as alum shale is decomposed to sulfuric acid by weathering. Preliminary AEM models had a tendency to overestimate the thickness of the resistive overburden. Experimenting with the inversion settings resulted in models better fitting other prior information from the area. Limited LM data was available due to a noisy environment. This affected the reliability of the models, illustrated by modelling and resulting real models.

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8H GROUNDWATER

THE 'EXPLORING FOR THE FUTURE' GROUNDWATER PROGRAM: A MULTI-PHYSICS, INTER-DISCIPLINARY SYSTEMS APPROACH FOR DE-RISKING INVESTMENT IN AGRICULTURE IN NORTHERN AUSTRALIA

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The Australian Government has recently provided AU$100.5M to Geoscience Australia over 4 years (2016–2020) to manage the Exploring for the Future (EFTF) program designed to increase investment in minerals, energy and groundwater resources, primarily in Northern Australia. The program includes AU$30.8M for groundwater-specific investigations, recognising that there are major gaps in our knowledge of Northern Australia's groundwater systems and resources. The groundwater component of the EFTF program is focused on addressing these knowledge gaps, with the aim of underpinning future opportunities for irrigated agriculture, mineral and energy development, and community water supply. The groundwater program will include identification and assessment of potential groundwater resources and water banking options in priority regional areas, while also analysing the salinity risk (including seawater intrusion).

To rapidly map, characterise and assess regional groundwater systems and resources in the data-poor 'frontier' areas of Northern Australia, a multi-physics, inter-disciplinary approach has been developed. The program involves the initial use of temporal remote sensing 'data cube' technologies for surface hydrology and landscape mapping, and acquisition of airborne electromagnetic (AEM) and Ground Magnetic Resonance (GMR) datasets. This provides a framework for targeted investigations including passive seismic, microgravity and GPR; borehole geophysics (Induction, gamma and Nuclear Magnetic Resonance (NMR)); drilling and pump testing; hydrochemistry and geochronology (water, landscapes and geology); as well as soils, regolith and basin/bedrock geological, hydrogeological and structural mapping and modelling.

This methodology has enabled rapid identification and assessment of potential groundwater resources, salinity and seawater intrusion hazards, and groundwater dependent ecosystems in several priority regions.

AN INTEGRATED HYDROGEOPHYSICAL APPROACH TO EXPLORING FOR GROUNDWATER RESOURCES IN SOUTHERN NORTHERN TERRITORY

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In Australia's semi-arid and arid interior, groundwater resources provide water supply security for agriculture and community consumptive use and are critical for underpinning economic development. The Southern Stuart Corridor Project in central Australia, is an inter-disciplinary study which aims to better characterise regional groundwater systems and identify the location, quantity and quality of new groundwater resources. The main aims of the project are (1) to de-risk investment in development of a potential agricultural precinct in the Western Davenport Basin, and expansion of horticulture in Ti-Tree Basin, (2) to identify future water supplies for Alice Springs and Tennant Creek, and (3) for regional water supplies for mineral resource development.

The project is funded by Geoscience Australia (GA) as part of the Exploring for the Future (EFTF) Program. The project integrates airborne electromagnetic (AEM), ground geophysics (ground magnetic resonance (GMR) and borehole geophysics (Induction, gamma and nuclear Magnetic Resonance (NMR)) with drilling and pump testing; hydrochemistry and geochronology; and geomorphic, geological, hydrogeological and structural mapping and modelling. Advancements in temporal remote sensing technologies for surface hydrology, vegetation and landscape mapping are also used to facilitate the identification of recharge and discharge zones and groundwater-dependent vegetation.

This paper reports on initial AEM inversion results for the Alice Springs, Ti-Tree Basin, Western Davenport and Tennant Creek areas and the use of a machine learning approach for rapid geological and hydrogeological interpretation of the AEM data. These machine learning approaches have the potential to significantly reduce interpretation time and facilitate the rapid delivery of project results.

USING AEM AND GMR METHODS FOR NON-INVASIVE, RAPID RECONNAISSANCE MAPPING AND CHARACTERISATION OF GROUNDWATER SYSTEMS IN THE KIMBERLEY REGION, NORTHERN AUSTRALIA

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In northern Australia, groundwater investigations in remote areas face challenges including the cost and difficulty in obtaining drilling permit due to lengthy heritage and environmental approvals processes. Non-invasive geophysical techniques, including airborne electromagnetics (AEM), Ground Magnetic Resonance (GMR) and borehole Nuclear Magnetic Resonance

(NMR), are particularly attractive in these circumstances, as key hydrogeological parameters including depth to water table, porosity and transmissivity can be obtained with limited clearance approvals required.

In the Fitzroy Basin of Western Australia, both surface and borehole MR have been applied to groundwater prospectivity assessment of the Cenozoic sediments, and the Palaeozoic and Mesozoic sandstone aquifers. Eight GMR sites were acquired across the basin, which include Mowanjum, Willare – lower Fitzroy, Mount Anderson, and May – Lennard River areas. These sites were selected based on interpretation of the AEM data.

The GMR results with good resolution to 100 m depth were compared against borehole NMR and lithostratigraphic information, and found to be consistent. Both sets of MR data support that the Palaeozoic (Grant Group and Poole Sandstone) are excellent aquifers. At other sites, the lack of water content in some of the water profiles indicates the presence of aquitards such as Blina Shale and Jarlemai Siltstone.

GMR data indicates that the floodplain alluvium of the intermittent Fitzroy River contains little 'mobile', or free-draining, water (~3 vol %) at the end of the dry season. The water table at the site was ~30 m depth, most likely beneath the alluvium in the Mesozoic sedimentary rock.

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9A NEW TECHNOLOGY – SEISMIC

MULTI-COMPONENT SEISMIC: APPLICATIONS AND NEW DEVELOPMENTS

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Multi-component seismic data capture both the vertical and horizontal components of ground motion at the receiver location. The resultant seismic record is a vector entity that enables discrimination between compressional (P) and shear (S) wave arrivals. In practice, conventional P-wave seismic sources are typically used for seismic acquisition. Thus multi-component seismic data refers to the recording of P wave and converted wave (or PS wave) arrivals.

The integrated use of P and PS waves has supported enhanced imaging of the subsurface over the past three decades. This includes 'seeing' through gas-bearing sediments, delineating very shallow reflectors and delivering enhanced near-surface resolution, mapping lithologies and fluids (e.g. sand / shale discrimination, fluid description), and characterising anisotropy (e.g. fracture densities and orientation). When used in a time lapse sense, multi-component seismic data are useful for reservoir monitoring. These applications still remain very relevant to the resource industry today, and a number of more recent examples will be summarised.

However, despite many periods of enthusiasm, use of multi-component seismic data remains challenging. Interestingly, the focus of technical developments today is largely unchanged from the turn of the century. This presentation will provide an overview of current developments. Perhaps most demanding is the requirement to address the very slow propagation of S waves in the near surface. Further, S waves are extremely sensitive to anisotropy and absorption effects. All of these phenomena require careful attention during data processing. What has evolved in more recent times is the ability to work directly with the vector wavefield through full elastic imaging, and joint P / PS seismic inversion combined with more sophisticated P and PS image registration methodologies.

MARINE VIBRATOR CONCEPTS FOR MODERN SEISMIC CHALLENGES

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Aside from fundamental issues of mechanical durability and efficiency, the design of marine vibrators for towed streamer operations are confronted by several very different possible applications: (1) High power alternatives to conventional air gun arrays for flexible and creative acquisition geometries, (2) Low power alternatives to air gun arrays for environmentally sensitive applications, and (3) High power, ultra-low frequency sources specific to Full Waveform Inversion (FWI) optimisation.

One relevant consideration is the volume of water that must be displaced per cycle to achieve a desired Sound Pressure Level (SPL); increasing exponentially as the frequency of interest decreases, and becoming significant at frequencies less than about 5 Hz. This becomes particularly relevant for FWI optimisation as the frequencies of interest are in the range of 1–6 Hz. Another consideration is that ultra-low frequency output theoretically benefits from deeper towing, enhanced by the well-known free-surface ghost effect, but in practice deeper towing is confronted by an air spring effect that increases the force required per cycle to generate a desired SPL, and is due to the surrounding hydrostatic pressure at depth. Other authors have published the design of an extremely large volume vibrator unit that is towed at about 60–120 m as a solution to the air spring effect. However, completely alternative vibrator concepts can be described that either use an array of units with high power drivers or that distribute the water displacement over a large surface area in a creatively efficient manner.

Environmental motivations to develop low power vibrator concepts are driven by regulatory restrictions upon received SPL, Sound Exposure Level (SEL), and cumulative SEL (SEL_{cum}). We describe the design and application of several very different marine vibrator concepts for the three defined applications, and present results from both controlled testing and real data acquisition that illustrate various challenges and their industrial solutions.

FIBRE-OPTIC VSPS: BOREHOLE SEISMIC REVOLUTION IN AUSTRALIA

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The borehole seismic industry is undergoing a quantum leap in the acquisition technology. The standard borehole seismic imaging tools such as accelerometers and geophones are now being replaced by the fibre-optic (FO) acquisition for basic surveys such as zero-offset vertical seismic profiles (ZVSPs) and checkshots. This saves significant time, and associated rig cost, whilst providing sufficient data quality for basic interpretation. Schlumberger's heterodyne distributed vibration sensing (hDVS) technology, deployed within a wireline heptacable, was recently used in Australia to acquire a zero-offset VSP dataset, whilst simultaneously taking downhole core measurements. The hDVS technology is based on the distributed acoustic sensing (DAS). This presentation shows the acquired dataset and the basic processing results. A comparison between the FO and conventional dataset, in the nearby wellbore, as well as surface seismic and synthetics is made showing remarkable similarity between all datasets, validating the FO data.

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9B NEW TECHNOLOGY – CO_2

FEASIBILITY OF SEISMIC MONITORING OF CCS IN PERTH BASIN

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This work studies the seismic response of injection of super-critical CO_2 in Perth Basin, WA, for the purpose of CO_2 sequestration. We aim to propose the most suitable way of monitoring and verification of such storage. To this end, we generated synthetic seismic datasets based on static geological models reflecting various hypothesis about the subsurface properties and fluid flow simulations for different injection scenarios. We investigated in detail two cases:

1. Reference case – the injected CO_2 remains confined in the injection interval, which we aim to characterise quantitatively;
2. Relatively small leakage (~10 kt) into the shaley overburden through a major fault, which we merely aim to detect.

Existing theories of fluid substitution predict small seismic contrasts caused by the injection. Effectively, we cannot rely on the time-lapse changes of the reflection strength, which makes conventional surface-based time-lapse seismic inefficient. However, the fluid flow simulations predict that the buoyancy-driven plumes have significant thickness to allow for the robust detection of the time shifts, which makes seismic pull-down effect more efficient for the time-lapse seismic monitoring of the injection. Furthermore, this feasibility study proves high efficiency of a surface-to-borehole monitoring systems. In particular, results of the full-waveform inversion of the synthetic borehole seismic datasets shows that such a system will allow for the quantitative characterisation of the injected plume.

A DOUBLE DOUBLE-POROSITY MODEL FOR WAVE PROPAGATION IN PATCHY-SATURATED TIGHT SANDSTONE WITH FABRIC HETEROGENEITY

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In natural reservoir rocks, fabric heterogeneity can further induce heterogeneous geometrical distribution of immiscible multi-phase fluid mixture, since fluid migration may be affected by lithological variation (mainly permeability) in geological time scales, causing patchy saturation of fluids. Both structure heterogeneity and patchy-saturation can lead to strong seismic wave dispersion and attenuation. In this work, a double double-porosity model is presented to describe the overlapping effect of the two heterogeneities on wave dispersion and attenuation. The wave propagation equations are derived from the Hamilton's principle, and the numerical results for a tight sandstone are compared with corresponding low-frequency experimental data, which shows good agreements. This new model allows for a comprehensive description of wave propagation process in highly complex reservoirs.

THE INFLUENCE OF REVERSE-REACTIVATED NORMAL FAULTS ON POROSITY AND PERMEABILITY IN SANDSTONES: A CASE STUDY AT CASTLE COVE, OTWAY BASIN

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An understanding of fault zone structure and transmissibility can have significant implications for reservoir appraisal and development within petroleum systems. Previous studies have demonstrated that porosity and permeability is significantly reduced adjacent to fault zones due to pore collapse, grain crushing, and cement precipitation during deformation. We present results from a detailed mineralogical and geomechanical investigation of the Castle Cove Fault within the Otway Basin at Castle Cove, southeast Australia. Castle Cove provides excellent exposures of the Lower Cretaceous Eumeralla Formation, which is a fine-grained volcanogenic sandstone with moderate to highly porosity (up to 27%), but with generally low permeability (mostly <1 mD). The Castle Cove Fault originated as a normal fault during the late Cretaceous and was reverse-reactivated during NW–SE mid-Eocene to Recent compression. Core plugs were sampled at distances between 0.5 to 225 m from the fault and were orientated with respect to the fault plane. We show that closer to the fault (within 75 m), porosity increases by nearly 10% (i.e. from approximately 17% to 24%) and permeability increases by two orders of magnitude (from

0.02 mD to 3.74 mD). Microstructural investigations from thin sections show an increase in microfracture intensities closer to the fault. This study highlights the importance of detailed mineralogical and geomechanical analyses when attempting to understand fault seal generation and reservoir properties in high porosity and low permeability sandstones.

PORTABLE XRD FOR UNCONVENTIONAL AND CONVENTIONAL PETROLEUM EXPLORATION

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Mudlogging traditionally utilised qualitative data, but it recent years has benefited enormously from quantitative mineralogy, in near real time. Conventional petroleum exploration typically utilises a range of quantitative measurements, but quantitative mineralogy onsite is rarely available. Powdered X-ray diffraction (XRD) is a popular method for determining the bulk mineralogy of geological samples. However, due to the capital cost, environmental requirements and significant sample preparation, XRD instruments are rarely deployed to site.

Recent advances in XRD sample holders and X-ray sources have allowed for the development of portable XRD (pXRD) devices where the sample preparation is simpler and does not require regular calibrations by a technical expert. This technology was initially developed by NASA for the Mars Science Laboratory rover Curiosity, to perform mineralogical analysis of the Martian surface.

Due to its portability, minimal sample preparation, fast collection times, and excellent correlation with laboratory-based XRD devices, pXRD has been shown to be of great use to petroleum geologists and engineers by providing rapid, quantitative mineralogical data. For mudlogging quantitative mineralogy is being used to guide directional drilling towards the target formations and to ensure lateral drilling stays within the target formations. Quantitative mineralogy from the target formation and overburden rock also provides important information regarding the engineering properties of these rocks (e.g. fracturability), and can help determine the most appropriate acid for acid-fracturing stimulation. For conventional petroleum exploration quantitative mineralogy onsite, can be used to understand geophysical responses, and as a screening tool for selecting samples for more detailed analysis.

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9C CENTRAL AUSTRALIAN BASINS SYMPOSIUM

REGIONAL MIGRATION AND TRAPPING FRAMEWORKS IN THE FRONTIER CEDUNA SUB-BASIN: NEW INSIGHTS FROM STRATIGRAPHIC FORWARD MODELLING AND 'TRIANGLE JUXTAPOSITION' DIAGRAMS

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In the Ceduna Sub-basin oil-prone source rocks, reservoirs and seals are predicted in Late Cretaceous marine and deltaic sequences. Despite a recent renewal in exploration the sub-basin is underexplored with only one well drilled in the central >10 km thick sequence. Resulting uncertainty regarding lithofacies distribution is high, leading to limited understanding of reservoir and top seal coupling, trends for fluid migration and structural trapping. In the centre of the sub-basin these uncertainties were reduced by using data from a stratigraphic forward model that recreates the development and preservation of stratigraphic successions.

The area of interest covers three distinct structural provinces with basement related faulting and hard-linkage reactivation to the north, listric faulting and soft-linkage reactivation in the centre and listric faulting with upper decollement and local compression to the south.

Pseudo-wells were extracted from the forward model over an area of 9600 km^2 to sample modelled lithofacies, net-to-gross and shale volume distributions and feed 'triangle juxtaposition' diagrams that allow membrane fault seal analysis and oil column height quantification.

This analysis allowed the definition of regional and local net-to-gross distributional trends and the mapping of prospective areas. For both the marine and the deltaic sequences higher prospectivity for reservoirs and structural traps is located toward the north-west of the study area with thicker sandstone packages and reasonable potential of membrane fault seal. A thick Campanian nearshore sandstone units is predicted to act as hydrocarbon migration fairways or potentially form.

COULD THE MESOPROTEROZOIC KYALLA FORMATION EMERGE AS A VIABLE GAS CONDENSATE SOURCE ROCK RESERVOR PLAY IN THE BEETALOO SUB-BASIN?

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The Mesoproterozoic Kyalla Formation (Kyalla) in the Beetaloo Sub-Basin has historically yielded consistent high mud gas shows, and exhibited evidence of oil and gas in cores from exploration wells. Despite positive hydrocarbon indicators, the Kyalla is often overlooked as a potential regional unconventional resource play due to the apparent high clay content (50–70 wt%) thought to affect the potential for effective hydraulic fracture stimulation.

Preliminary petrophysical, core and gas analysis from exploration wells drilled by Origin Energy in 2015–16 revealed positive reservoir quality indicators including high total porosity (8–10% BV), moderate hydrocarbon saturations (40–60% PV), geochemical indicators consistent with an adequate indigenous hydrocarbon source (2–3 wt% TOC, Type I/II Kerogen, VR_{eq} 1.3–1.5) and moderate to high qualitative gas condensate potential as indicated by gas chromatographic analysis on mud gas and drill cuttings headspace gas. Furthermore, geomechanical testing on recovered core indicates properties conducive to hydraulic fracture stimulation.

Fourier transform infrared spectroscopy (FTIR) analysis indicates bulk clay content is primarily comprised of mica species, in particular muscovite. The relative abundance of muscovite over other clay types may play a key role in explaining the observed geomechanical properties of the Kyalla despite its overall high bulk clay content.

If the Kyalla is technically viable, it will add an alternative or additional play in a basin that has the potential to be key to long term supply stability to domestic and export gas markets.

ISOTOPE CONSTRAINTS ON INTRA-BASIN CORRELATION AND DEPOSITIONAL SETTINGS OF THE MID-PROTEROZOIC CARBONATES AND ORGANIC-RICH SHALES IN THE GREATER MCARTHUR BASIN, NORTHERN TERRITORY, AUSTRALIA

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The greater McArthur Basin in northern Australia forms the world's oldest potential unconventional gas play. It comprises Paleo- to Mid-Proterozoic sedimentary successions of the McArthur and Birrindudu Basins, which are likely linked in the subsurface. The Mid-Proterozoic sedimentary record in these basins is dominated by carbonate rocks (i.e. dolostones) deposited in various shallow marine to more restricted lagoonal and sabkha/playa evaporitic environments, while the associated organic-rich shales (i.e. the Barney Creek and Fraynes Formations) likely formed in relatively deeper and/or redox stratified depositional settings.

Here we use a multi-proxy approach based on the isotope tracers of strontium ($^{87}Sr/^{86}Sr$), carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) to further constrain the plausible paleo-depositional environments, and to test the applicability of these proxies for intra-basin correlations in the greater McArthur Basin. Specifically, we will present the first continuous high-resolution Sr, C and O isotope records acquired from two drill cores, Lv09001 and Manbulloo-S1, intersecting the above Mid-Proterozoic (~1640 ± 5 Ma) organic-rich sedimentary sequences in the McArthur and Birrindudu Basins, respectively.

Importantly, our preliminary data from a drill core Lv09001 in the central McArthur Basin, which comprises dolomites and organic-rich shales (Barney Creek Fm.), show systematic variations in carbonate-based $^{87}Sr/^{86}Sr$ and $\delta^{13}C$ proxy records that are tightly coupled to changes in a local depositional environment, the latter interpreted as oscillations between relatively open-marine (oxic?) to more restricted (anoxic) conditions. We will further test whether the above isotope changes recorded in Lv09001 can be traced across the greater McArthur Basin, by comparing these data with presumably coeval sedimentary sequence from Manbulloo-S1 core (i.e. Lymbunia Group, with organic-rich Fraynes Fm., dated at ~1640 Ma), sampled in the adjacent Birrindudu Basin. Conclusions will be made regarding the purported connectivity of the McArthur and Birrindudu Basins, and the suitability of our multi-proxy isotope approach for the intra-basin correlations.

RANKING DHI ATTRIBUTES FOR EFFECTIVE PROSPECT RISK ASSESSMENT APPLIED TO THE OTWAY BASIN, AUSTRALIA

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The first evidence of seismic brightening linked with gas charged reservoirs was revealed in the early 1970s in the Gulf of Mexico. Since that time the terms bright-spots, flat-spots, AVO anomalies or gas anomalies have been used interchangeably (and often loosely) to imply positive evidence exists for gas charge of a prospect.

A seismic Direct Hydrocarbon Indicator (DHI) is an anomalous seismic attribute or pattern that could likely be explained by the presence of oil or gas in a reservoir. Conformance with depth structure is the primary attribute for ranking the quality of a DHI anomaly. It is very difficult to generate this conformance with depth structure in the absence of hydrocarbons. AVO anomalies and bright spots conversely may be generated by numerous lithological or seismic processing related phenomena.

By assessing the key criteria that determine the quality of a DHI anomaly associated with proven gas accumulations, it is possible to build a catalogue of DHI anomalies calibrated to known gas accumulations. Application of the DHI quality factor to modify the initial chance of geological success (Pg) is crucial to objectively grading drilling opportunities.

Two key questions arise:
(1) If DHI anomalies are so 'easy and powerful', why have there been so many DHI supported dry holes drilled around the world?
(2) If strong DHI anomalies are highly correlated with gas discoveries, how often is the lack of a robust DHI anomaly used to downgrade a prospect?

We use historical data from the Otway Basin to offer some answers

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9D EXPLORATION STRATEGY

BUDGET ALLOCATION AND THE STOPPING PROBLEM IN MINERAL EXPLORATION

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Most greenfields mineral exploration projects involve a process of testing targets that have been selected on the basis of geoscientific data. Although this data can be used to rank targets questions still arise as to how many targets should be tested before the area is dropped. This paper addresses this question with a probabilistic model of the exploration process and illustrates the method with a geophysical example.

It is shown that an exploration project should terminate when the Return on Investment (ROI) obtained by testing another target falls below that of other opportunities. In general the ROI for each target is different and is a function of the Likelihood Ratio $L = P_d/P_{fp}$. Where P_d is the probability that a mineral occurrence with the target's geoscientific parameters will be detected *and* P_{fp} is the probability that the same parameters will cause a false positive. In addition to these variables the model assumes fixed probabilities of finding a mineral occurrence without data and of a mineral occurrence being economic. Normal valuation and cost estimates complete the fixed parameters.

Clearly, the way L is constructed is critical to the whole process and, depending on the exploration strategy, might be very subjective. However, when simpler rules of the type often applied to geochemical or geophysical anomalies are used, it is possible to develop algorithmic approaches to define L. An example using geophysical data for kimberlite exploration will be discussed.

HOW A SYSTEMS THINKING APPROACH TO MINERALISING GEOSYSTEMS IS OPENING NEW SEARCH SPACES FOR ORE DISCOVERY

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Systems thinking is used to study interactions. It is different from simple event orientated thinking that implies chains of cause and effect along a time line. In systems, the systemic behaviour emerges from its structure, the flows and feedback loops, rather than any individual element. Mineralising geosystems and ore systems are often complex and self-organising. As mineral explorers it is unlikely that we will be able to truly understand complex mineralising geosystems if we do not understand the systems theory. Mineralising geosystems operate at different scales at different times and sometimes at several scales at the same time. By using systems theory tools we can beginning to close the gap in predictive targeting effectiveness between the regional and camp scale to unlock new search spaces. Feedback loops leave evidence in the geological record that can be measured and mapped.

A mineralising geosystems map for tin deposits, shown at Target 2017, has been extended and analysed using Stella and yEd software. Tin was chosen as an example of a well-studied simple magmatic mineral system. The mineralising geosystem map has already challenged several paradigms that also apply to other mineralising geosystems.

Most giant mineral systems are formed within a few kilometres of the Earth's surface. To ignore the role and overlap of the hydrosphere, biosphere and atmosphere systems in the upper crust is to miss important feedback loops.

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9E GEOPHYSICAL CASE HISTORY

IMAGING HIGH QUALITY CONDUCTORS AT GOLDEN GROVE

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The success of the DHEM method in detecting the Gossan Valley mineralisation, south of Gossan Hill mine, in 2008/2009 led to the systematic application of the DHEM method across the Golden Grove lease from 2011 to 2014. The method proved successful in identifying several new zones, including the Grassi resource. During these surveys it was noted that the EM method failed to elicit either in-hole or off-hole responses in a number of holes with economic intersections of lead, zinc and precious metal ore. It became clear that not all economic ore zones contained sufficient conductive sulphide to ensure detection using DHEM. This triggered an assessment of available methods to determine if other down-hole technologies could be used to complement the DHEM method.

A program of core petrophysic measurements and petro-physical borehole logging led to the realisation that because the host rocks were very resistive there existed a sufficient contrast for high frequency EM imaging to be viable. This led to a trial of the Radio Imaging Method at the Xantho resource of the Gossan Hill Mine in December 2016. The results of the trial suggested direct detection of the massive sphalerite ore is possible. Further work is being undertaken to better understand the optimum survey methodology in the Golden Grove Mine environment with a view to providing specific recommendations that if approved will see the use of the method expanded on the mine leases, both at Gossan Hill and Scuddles mines, as well as on the surrounding mine leases.

WOODLAWN REVITALISED BY DHEM

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This paper presents the critical and thought-provoking role DHEM has played in revitalising the Woodlawn mine since

2012. Woodlawn, a well-known volcanic-hosted massive sulphide deposit in New South Wales, had been dormant since mine closure in 1998. Attempts to reopen were stymied. DHEM surveys had been little used due to a general view that the mineralisation was poorly suited to EM. Despite this preconception, a deep exploration hole was approved for DHEM and importantly, the entire length of hole would be surveyed 'just in case'. The result was a large offhole conductor recorded in the upper portion of the survey, in an area considered very well tested by previous drilling. The resultant high grade discovery of the ~1 Mt 'Kate Lens', as well as several subsequent discoveries, many using DHEM, means that Woodlawn is now on track to reopen in the near future. This case study illustrates the importance of the 'never assume' approach to exploration, as well as the value that DHEM can add to exploration projects.

MINERAL EXPLORATION IN THE MOUNT LYELL REGION OF TASMANIA WITH THE HELITEM$_{35C}$® SYSTEM

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The Mount Lyell region contains more than 20 significant mineral deposits with 150 MT @ 1.23% Cu 5 g/t Ag and 0.35 g/t Au having been extracted. Many of the ore bodies occur along or near the Great Lyell fault, which is west-dipping and shows a complex history of movement. Significant reverse movement has occurred on the fault juxtaposing older volcanics against younger sediments to the east. Copper deposits are mainly disseminated pyrite-chalcopyrite and occur as sub-vertical pipes. Although historic ground EM surveys conducted in the 80s were not successful more recent CSAMT surveys did indicate that some of the known orebodies do exhibit a good conductivity contrast to the generally restive host. Transient EM DHEM utilising a large transmitting loop at surface did lead to the discovery of a new deposit.

Here we provide a case study of recent exploration work in the Mount Lyell region. We describe the geologic history around Mount Lyell and exploration activities. Recently an airborne electromagnetic survey was performed, using CGG's Helitem$_{35C}$ system with the MultiPulse waveform (both halfsine and square wave pulses are generated in a single waveform). We describe the Helitem$_{35C}$ results, along with 2D/3D inversion modelling, and how they fit with the known geology. A number of undeveloped mines were detected by the system and the data will be used to target possible extensions of the known ore bodies.

COMBINED GRAVITY AND MAGNETIC STUDIES OF SATELLITE BODIES ASSOCIATED WITH THE GIANT COOMPANA REVERSE MAGNETIC ANOMALY IN SOUTH AUSTRALIA

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The Geological Survey of South Australia has recently acquired ground gravity data to accompany the airborne magnetic survey over the Coompana Area of southwestern South Australia. The new gravity data reveals that the several negative magnetic anomalies, which accompany the giant (60 km diameter, 2000 nT range) main Coompana negative magnetic anomaly have corresponding well-defined positive gravity anomalies. All but one of these satellite magnetic anomalies can be matched with models of simple geometry and homogeneous remanent magnetisation. Similarly, all of the corresponding gravity anomalies can be matched with simple geometry, homogeneous density contrast models. However, only one of the density and magnetisation model pairs is self-consistent, revealing that these bodies do not have an internally consistent magnetisation to density relationship, and that at least one (probably both) of the property distributions are variable through the bodies. We present modelling of three of these bodies with magnetic and gravity ranges respectively of 800 nT and 15 μm/s^2, 5000 nT and 90 μm/s^2, and 3000 nT and 100 μm/s^2. A drilling program is underway, which should reveal the geological nature of the bodies, and also allow us to make direct density and magnetisation measurements. With these constraints available, we expect to construct models which more reliably reconcile the gravity and magnetic data. However, with no more than one hole into each body, and with those holes unlikely to reach the base of the bodies, there is still considerable interpretive challenge in this task.

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9F PETROPHYSICS

THE USE OF PETROPHYSICAL DATA IN MINERAL EXPLORATION: A PERSPECTIVE

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Recognising targets for testing and accurately mapping the geology are equally dependent on petrophysics, which constitutes a link between the geologist's largely mineralogical 'view' of the Earth and the geophysicist's physics-based 'view'. Despite their critical importance, petrophysical datasets tend to be small, are often collected in an ad-hoc fashion and are often not analysed in detail.

Semi-automated scanners are available which can rapidly make simultaneous, multiple, geochemical, mineralogical and physical property measurements. This allows larger volumes of petrophysical property data to be collected, and in a better geological context, than has been possible in the past. This is important because many rock physical properties are extremely heterogeneous and a large number of data is required. Accurate interpretation of the data requires analysis of the data as populations and in the context of all of lithology, alteration, stratigraphy and spatial location.

I will describe new ideas on the classification of petrophysical properties and their analysis and also suggest ways to better present these data in a geological context. A key message is that the current, largely lithology-based, approach is not optimal. In most cases it is essential to also consider alteration and porosity.

The proposed approach will be illustrated using case studies involving (1) altered ultramafic rocks from Archaean greenstone terrains, (2) dolomitised carbonate successions hosting base-metal mineralisation, (3) carbonatites associated with REE mineralisation and (4) mapping geology in the Broken Hill region.

PRACTICAL CONSIDERATIONS AND GOOD PROTOCOL FOR THE INTERPRETATION OF ULTRAMAFIC AND MAFIC ROCK PHYSICAL PROPERTY DATA

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An increase in the availability of inexpensive and easy-to-use geophysical tools has led to the interest in collection of larger rock physical property databases. More notably, magnetic susceptibility and density measurements are routinely made on drill-core specimens. These data are often interpreted at face value, with little consideration given to the selection of representative samples, sample preparation, or even the practical limitations of measuring tool. Consequently, uncertainty is unnecessarily inflated, and a diminished benefit perceived.

Bivariate-Henkel plots of multi-petrophysical data are useful in identifying key lithotypes and subpopulations that may be attributed due to alteration or mineralisation. These plots can form a basis from which to rank the applicability of geophysical methods, and may provide a means from which to select a third geophysical method that provides an optimal solution to constrain geology in a physical property driven model. P-wave velocity, magnetic susceptibility and density data are considered most common, and are discussed in detail. The use of p-wave velocity and density data are of great importance particularly when determining the acoustic impedance of rocks and the suitability of seismic programs.

Although less common, it is recommended that bivariate plots be used to compare petrophysical data derived from a variety of tools or measurement processes. Here, the validity of historical data may be better evaluated, e.g. the effect of volumetric problems, which is inherent of dry-bulk density, is discussed; as is the appropriateness of commonly employed electromagnetic-based magnetic susceptibility meters compared with Qmeter derived data using same samples.

PETROPHYSICS AND EXPLORATION TARGETING: THE VALUE PROPOSITION

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There is still much that needs to be understood about the physical properties of rocks in mineralised geological environments. This knowledge gap becomes more important as the transition to deeper exploration targets under cover occurs, with an associated greater reliance on geophysical exploration methods. The major challenge associated with understanding petrophysical data is not making the measurement, but rather understanding the results. The interpretation of the data is a cross disciplinary problem. Fundamentally it is necessary to understand the rock mineralogy and geochemistry to put the petrophysics in context with the geophysical results. Several case studies are presented where the petrophysics have determined not only which geophysical techniques to apply but whether a geophysical target has indeed been tested. For example, the sedimentary textures associated with sediment hosted copper mineralisation can compromise the inductive conductivity and resistivity response (anisotropy). Chargeability highs associated with porphyry copper mineralisation is indicative of disseminated pyrite in the propylitic and pyrite ± chalcopyrite ± bornite in the potassic alteration zones and higher chargeability does not necessarily mean more copper. Drill testing EM plate approximations for nickel sulphide and volcanogenic massive suphide (VHMS) ore deposits can benefit from inductive conductivity measurements on core as it can determine whether an EM conductor has been intersected. In most porphyry systems magnetite is coarse-grained, therefore a world class porphyry deposit should not have dominant remanent effects and the only likely source of remanence features in younger terrains are oxidised mafic intrusions and skarns.

DEFINING PETROPHYSICAL PROPERTIES OF ULTRAMAFIC AND MAFIC ROCKS IN TERMS OF ALTERATION

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It has become common practice to categorise rock physical property data solely by lithotype. This has led to the development of wide distributions in range within global petrophysical databases, as well as localised studies. Consequently, an uncertain relationship between reliable rock physical properties and geology is ever present. Characterising rock physical property data by alteration may mitigate this uncertainty. The use of mineralogical scanners, e.g. hyperspectral, and portable whole-rock geochemical analysers, e.g. pXRF, are able to put the petrophysical data in a correct mineralogical context while reducing the subjectivity of the interpretation of type and variable degree of alteration, which are often made by an individual geologist.

The effects of talc-carbonate alteration and serpentinsation on physical properties of ultramafic rocks are regularly presented but often within incomplete datasets, and as such, are poorly understood. The development of an integrated and more robust database is important. Consequently, two Western Australian greenstone terranes have been studied. Data from over 1000 samples taken from the Plutonic-Marymia Greenstone Belt and Eastern Gold Fields region are presented. New p-wave velocity, magnetic susceptibility, density, natural remanent magnetisation, hyperspectral and whole rock geochemical data are examined. An integrated approach of placing empirical petrophysical data within a rigorous mineralogical and petrological framework is undertaken. Consequently, this study is able to advance petrophysics beyond its current dominantly-data-acquisition phase towards a process-based predictive capability, serving to better understand alteration while providing a new mechanism from which to potentially vector toward mineralisation.

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9G GROUNDWATER

THE USE OF AIRBORNE EM TO INVESTIGATE A COASTAL CARBONATE AQUIFER, SEAWATER INTRUSIONS AND SUSTAINABLE BOREFIELD YIELD AT EXMOUTH, WESTERN AUSTRALIA

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Exmouth is a regional center located 1260 km north of Perth, Western Australia, that relies entirely on groundwater for its water supply. Its borefield extracts groundwater from an unconfined carbonate limestone aquifer within the Cape Range Group. Groundwater flows easterly from Cape Range to Exmouth Gulf where it discharges above a saline wedge at the base of the aquifer. The current borefield extraction has insufficient capacity to meet increased water demand due to population growth and the influx of tourists in holiday periods.

In 2016–2017, the Water Corporation decided to investigate optimising borefield performance through improved production from existing infrastructure. An Airborne Electromagnetic (AEM) survey, desktop review, 3D modelling, and pumping tests, helped define the extent/geometry of the saltwater interface and karstic features within the aquifer.

The AEM survey effectively mapped saline water. It identified existing bores in areas with lower salinity and away from the saline wedge. Twenty-four hour pumping tests of these bores was undertaken at rates much higher than their current extraction rate. The survey also identified existing bores in areas of higher conductivity where increased extraction is not recommended.

The AEM survey and new hydrogeological modeling have established a clear relationship between the extent of the saltwater interface, and the location of karstic features. Importantly, bores have been identified which could accommodate additional sustainable extraction. Other bores have been identified where extraction rates should not be increased, or should be reduced.

DEVELOPING WATER SUPPLIES FROM SAPROLITE REGOLITH

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Extensive areas of saprolite regolith are present on plateau land development over cratonic regions of the earth. These saprolite zones often contain significant water saturated sections and represent large storages of groundwater.

Groundwater storages in saprolite, although widely used for village and small rural supplies, particularly in subtropical regions where groundwater is at a shallow depth and of low salinity, are rarely developed as major water sources.

The principal reason for lack of usage of saprolite regolith results from inherent low to very low hydraulic conductive properties.

Much knowledge of saprolite hydrogeology has been gained through development of open pit mines in these rocks. Long term observations show that a considerable portion of dewatering results from drainage from saprolite rather than from the limited storage of fracture zones containing dewatering bores mostly sited in underlying crystalline rock.

This paper describes examples taken from widely separate climate regions of the earth where saprolite has been dewatered through use of underdrainage from linear structures in the bedrock. Underdrainage makes use of both inherent palimset structures in saprolite as well as the ‘delayed yield’ factor familiar in development of phreatic aquifers. This underdrainage has resulted in large sustained groundwater yield from the region.

Knowledge gained from open pit mine dewatering has provided sound examples on water storage and potential extractable storage values from saprolite. This knowledge has proven valuable when applied to planning water supplies from underdeveloped saprolite regions particularly those is arid plateau lands that lack alternative water sources.

FOCUSED ATTRIBUTES DERIVED FROM AEM SURVEYS USING THE CONTINUOUS WAVELET TRANSFORM

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Interpretation of a hydrogeophysical survey is a complex and comprehensive process. In addition to an areal coverage with AEM data, most often an interpretation involves additional data that are time consuming to collect and complicated to integrate into an overall model, e.g. borehole logs, borehole core samples, water chemistry, surface vegetation, satellite imagery plus the generally accepted geological background knowledge. Compared with the complexities of the interpretation process, the acquisition, QC and inversion of AEM survey data are a more straightforward affair and considerably less time consuming.

Interpretation basically has to do with identifying categories and finding boundaries between them so that depths, thicknesses, lithologies and a whole range of other model attributes can be estimated, qualitatively and quantitatively. To supplement the traditional product delivered by the inverter to the interpreter: inversion models displaying the distribution of subsurface electrical conductivity, I present two methods based on the Continuous Wavelet Transform that can deliver more focused attributes to assist the interpreter. In the first method, layer boundaries in the smooth multi-layer models that are most often used in the inversion of large data sets are found. In the second method, the spatial distribution of the natural categories of the model parameter is found. Both methods are based on the inversion models and, evidently, they are useful to the extent that the variations in conductivity reflect geological/hydrogeological boundaries and categories – which is for the interpreter to decide.

STRUCTURAL ANALYSES AIDING IDENTIFICATION OF WATER CONDUCTIVE FRACTURE ZONES IN CRYSTALLINE ROCK

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Development of hydraulic conductive zones in crystalline rock can result from a wide range of geological conditions that include primary structures, post crystalline tectonics, fluid solution and movement within a developing and eroding regolith.

Crystalline rock areas mostly have low water resource potential due to inherent extremely low storage and water conductive properties. Therefore, fracture zones of high hydraulic conductivity have an important role in developing groundwater resources in these areas.

Mechanisms for development of open tension or pull-apart fractures in brittle rocks are similar to those involving development of mineralised veins. The same structural analytical techniques can be applied.

Crystalline rock fracture zones can be amenable to rapid recharge through rainfall runoff. They are also significant in that they provide a mechanism for underdrainage through 'delayed yield' of surrounding or enclosing low conductive rocks such as saprock/saprolite, pelite and phyllite.

In addition to brittle rocks, open tension fracture zones of enhanced hydraulic conductivity may also occur in more fissile pelitic rocks such as slate and phyllite. These zones are often associated with crestal zones of folds and along saddles in cross-folds and in strike deviations produced by conjugate shears.

The development of conjugate joint sets in a region also provides a significant basis for this type of fracture analyses.

This presentation provides examples of water supplies developed from crystalline rock structures in a range of geological and earth environments.

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9H GROUNDWATER

COMPARATIVE EVALUATION OF 1D, 2.5D AND 3D INVERSIONS FOR RESOLVING TECTONIC ELEMENTS IN FLOODPLAINS AND NEAR-SURFACE INVERTED SEDIMENTARY BASINS

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This study reports the results of a comparative evaluation of 1D, 2.5D and 3D AEM inversions for resolving hydrostratigraphy and structural elements in two contrasting settings: unconsolidated Quaternary floodplain sediments affected by Neogene deformation; and a tectonically inverted Palaeozoic sedimentary basin.

Previous studies have demonstrated the importance of airborne electromagnetic (AEM) data optimisation to ensure that key elements of the hydrogeological system, including geological faults, are appropriately represented in inversion models. In the inverted sedimentary basin study, 1D inversions of AEM data indicated greater structural complexity than previously known. Initially, a suite of equivalent 1D inversion models produced very similar inversion model results. However, 2.5D inversions produced a disparity in solutions in key locations. To resolve these differences, 3D AEM inversion methods have been trialled. In the second study (floodplain setting), 3D inversions have helped resolve the geometry of hydrostratigraphic units and tectonic elements (folds and faults). In both study areas, independent validation of inversion results has involved an inter-disciplinary approach incorporating a range of borehole and ground geophysics techniques (e.g. passive seismic and Ground Magnetic Resonance (GMR)), tectonic mapping and analysis, hydrochemistry and drilling.

In summary, comparative evaluation of 1D, 2.5D, and 3D AEM inversions in two contrasting settings demonstrates the importance of optimising inversion procedures, taking into consideration all available geological, hydrogeological and tectonic data. The benefits of using 2.5D and/or 3D inversion procedures are particularly evident in areas of structural complexity. Confidence in 3D inversions is maximised when all elements of the system response are modelled appropriately.

RAPID ASSESSMENT OF GROUNDWATER SALINITY AND SEAWATER INTRUSION HAZARD IN THE KEEP RIVER FLOODPLAIN, NORTHERN TERRITORY, AUSTRALIA

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The Australian Government's White Paper on Developing Northern Australia recognised that expanding the size of the Ord irrigation area in the Kimberley Region, northwest Australia offers the potential to significantly enhance both the profitability and economic resilience of the region. This paper reports on the preliminary results of hydrogeological investigations in the Ord Stage 3 development area, a 14 500 ha area of black soil plains in the Keep River floodplain, Northern Territory.

Previous investigations in the Keep River floodplain identified potential for groundwater salinity, soil salinity and seawater intrusion (SWI) hazards. These earlier studies recognised that more comprehensive investigations were required to fully assess the risks of large-scale development of irrigated agriculture on groundwater quality and quantity. The Keep River Salinity Mapping Project has been established to provide baseline data on the groundwater system in the Keep River floodplain including aquifer and aquitard distribution and properties, and potential salinity hazards. Specifically, the main aims of the project are to: (1) map the 3D architecture and hydraulic properties of the soil, sub-soils and underlying paleovalley system; (2) map the SWI interface and variations in groundwater salinity; (3) identify potential surface water inundation risks; (4) identify groundwater-dependent ecosystems; and (5) carry out a hydrogeological assessment. Investigations include a program of airborne electromagnetics (AEM), ground geophysics (ground magnetic resonance (GMR), passive seismic and microgravity), drilling and borehole geophysics, hydrogeological and hydrochemical investigations, and regional soils, geological and morphotectonic mapping. Products generated in this project will be used to parameterise a numerical groundwater model.

VTEM ET: AN IMPROVED HELICOPTER TIME-DOMAIN EM SYSTEM FOR NEAR SURFACE APPLICATIONS

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Sampling the earliest possible transient EM decay in time-domain airborne electromagnetic data (TDEM) is critical for shallow near surface applications. In an effort to further improve near-surface resolution, starting in late 2015 and into 2016, Geotech Ltd developed its new VTEM ET system that uses a re-designed broadband receiver sensor, a re-configured transmitter system, and a new digital acquisition system to achieve precise, distortion free measurements of the time-domain EM decay as early as 0.005 ms after the transmitter turn-off. The new receiver features a much larger frequency bandwidth for lower distortion measurements. The new transmitter delivers a sufficiently high dipole moment, a long pulse-width and faster turn-off time than previous systems, but similarly using a single transmitter pulse. The new digital acquisition system operates at a much higher sampling rate, with significantly more decay channels, particularly in early times, and with low noise levels. The result is a new category of VTEM system that is specifically is designed for precise near-surface applications, such as groundwater and environmental problems, as well as in mineral exploration for lode gold and alluvial deposits, along with sufficient depth of investigation.

We present forward modeling and field survey test results comparing the VTEM ET system with our standard VTEM Plus system with full-waveform processing over a groundwater project with ground geophysical and borehole controls in the upper 30–50 m.

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10A NEW TECHNOLOGY – SEISMIC

LEAST SQUARE Q-KIRCHHOFF MIGRATION: IMPLEMENTATION AND APPLICATION

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Absorption effects caused by the anelastic nature of the earth leads to the attenuation of amplitude and distortion of phase of seismic waves. Conventional acoustic migration, formulated as the adjoint operator of forward modelling (Claerbout, 1992), cannot account for this effect due to the non-unitarity of the modelling operator in highly attenuative geologic environments. This may produce images with poor illumination, reduced resolution, and wrong placement of reflectors. The so-called quality factor 'Q' accounting for this absorption effect has to be included for correct imaging. The two main challenges in Q compensation are the ill-posed nature of the problem and the complex absorption patterns along ray paths in real geological structures. Conventional 1D inverse Q-filtering fails to address these two challenges and are only applicable under limited circumstances. Xie et al. (2009) proposed Q pre-stack depth migration (QPSDM) which compensates for absorption during migration by fully honouring ray paths, however, the ill-posed nature is still not well-addressed in the approach. This may result in over-boosted noise and migration artefacts masking high dipping structures including faults. Moreover, the anti-alias implementation in Kirchhoff migration further reduces the compensation of high dipping structures. To tackle the instability caused by the ill-posed nature of the problem as well as maintain the correct compensation for high dipping structures, we propose least squares Q-Kirchhoff migration (LSQPSDM) in which absorption is incorporated into the Kirchhoff modelling operator and Q compensation is achieved naturally via inversion with proper sparse constraints. The regularisation consisting of prediction filters from reference substacks and sparse constraint in image domain is built into our inversion process to reduce migration artefacts and improve both common image gathers and

the stack image. With better illumination and Q compensation, fault imaging is naturally enhanced through the proposed least squares Q-Kirchhoff migration. In contrast to standard least squares Kirchhoff migration, in our approach the inversion is approximated by inverse Hessian filtering (Wang et al., 2016; Khalil et al., 2016) to give a cost-effective solution. The proposed LSQPSDM approach has been applied to synthetic data for validation and a field dataset from NWS Australia. Better fault imaging and SNR are obtained compared to conventional Q migration.

MODELLING COMPLEX NEAR-SURFACE FEATURES TO IMPROVE SHALLOW SEISMIC EXPLORATION

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Land seismic exploration is often limited/impacted by complex structures in the near surface. These can include large variations in velocities caused by weathering (low velocity) or basalts (potentially high velocity).

Timing changes due to near-surface velocity variations are often accommodated by applying statics corrections during seismic processing. Shallow coal exploration requires high-resolution data to image structures and faulting. A good understanding of these is required for both safety and economic reasons. However, in some cases small errors in statics correction may have a significant impact on the viability of the use of seismic data in these complex environments.

Often near-surface structures also show non-planar characteristics which may attenuate or further complicated the seismic response.

In this paper we use finite-difference visco-elastic modelling to investigate the impact that a number of common near-surface structures have on seismic data. This modelling has been used to determine the optimal acquisition and processing parameters required for a seismic program in order to achieve desired results.

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10B NEW TECHNOLOGY – CO_2

CA-IDTIMS AND BIOSTRATIGRAPHY: THEIR IMPACT ON EXPLORATION

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Uranium-Lead zircon dating using Chemical Abrasion-Isotope Dilution Thermal Ionisation Mass Spectrometry (CA-IDTIMS) has largely overcome the problem of radiogenic lead loss, which gave ages significantly younger than that of crystallisation. Previous techniques gave 95% confidence intervals of 1% or worse, whereas CA-IDTIMS can deliver 95% confidence intervals of 0.1% or better. This has major implications for the correlation of strata.

Previous techniques allowed the dating of formations, subgroups or groups, but we can now date individual beds in a succession and provide a much better understanding of the timing of volcanic events and sedimentation rates. However, perhaps the most important facet of this new technique is the ability to date biostratigraphic zones. Previously, zones were calibrated against the numerical timescale often by a three-stage correlation. For instance, in the Permian, eastern Australian palynological zones were correlated with Western Australian palynological zones, on the assumption that they were coeval. Then limited Western Australian conodont or ammonoid occurrences were used to correlate to northern hemisphere zonal schemes, which form the basis for the international Geological Time Scale. Each of these steps added a degree of uncertainty that is rarely, if ever, quantifiable. The result is essentially presented as the best available estimate.

Where ash beds are common, the new technique allows robust calibration of biostratigraphic schemes directly to the numerical timescale. These new calibrations are often considerably different from those preceding them, and have a significant effect on age-depth plots, and thus burial history models, used in the petroleum industry.

ANALYSIS OF TIME-LAPSE SEISMIC AND PRODUCTION DATA FOR SYSTEMATIC RESERVOIR MODEL CLASSIFICATION AND ASSESSMENT

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The heterogeneous distribution of reservoir properties is one of the most important uncertainties in static and dynamic reservoir modelling. Petrophysical properties are usually interpolated within reservoir models from sparse well-log data, which can lead to highly uncertain estimates at inter-well locations that directly affect the reliability of fluid-flow model predictions of reservoir behavior. To address this issue, we build an ensemble of equiprobable models that combine different geostatistical realisations of reservoir properties to span the range of potential outcomes. While this process captures the impact of reservoir property distributions on the model response, a major challenge is classifying the subset of models in the ensemble best representing reservoir fluid-flow behavior. Thus, we introduce a methodology combining 4D seismic amplitude attributes and reservoir production data to classify fluid-flow models. This classification is based on applying thresholds for independent seismic and production objective functions. We test our methodology on the benchmark case UNISIM-I developed from observations from the Namorado Field, Campos Basin, Brazil. By comparing injection and production rates in relation to 4D seismic amplitude trends, we identify nine models out of an ensemble of 100 that judged optimal via the required seismic and production objective function thresholds and obtain an improved

quantitative evaluation of the impact of reservoir production on the 4D seismic signal. Ultimately, combining seismic and production data offers interpretation scenarios that automatically identify realistic fluid-flow models that can assist the update of permeability and porosity distributions within the reservoir.

INTEGRATING GEOPHYSICAL MONITORING DATA INTO MULTIPHASE FLUID FLOW RESERVOIR SIMULATION

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Simulation of multiphase flow systems are of critical importance in managing hydrological systems. Flow simulations are affected by a number of factors including structure and flow properties including porosity and permeability as well as the anisotropy and heterogeneity of these properties. In many cases traditional hydrological and reservoir data are highly affected by these parameters, but are not directly sensitive to them. As such modellers often adjust these parameters in an *ad hoc* manner until solutions numerically converge. Simulation models are generally based on structural data from reflection seismics whose physical flow properties are then populated using geostatistical extrapolation techniques utilising a sparse number of borehole logs and core analysis. In multiphase systems, including enhanced oil recovery and carbon capture and sequestration, uncertainties regarding phase-dependent physical properties confounds this challenge further. Geophysical methods provide a means by which to gain an improved understanding of phase distributions in the subsurface. In this paper we will look at applications from active carbon capture and sequestration and enhanced oil recovery applications, as well as synthetic examples. Geophysical data including electromagnetic and gravity are inverted using structural constraints from the reservoir model. Inversions are then mapped into flow properties using calibrated relations such as Archie's Equation. The coupled models can then be used to both verify and improve on the reservoir flow model, which improves its predictive power and utility as a management tool.

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10D STRATEGY AND GEOLOGY MODELS

DYKES, SYNCLINES AND GEOPHYSICAL INVERSION – IS GEOLOGY IMPORTANT?

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In the past 10 years the average depths of cover for gold and base metal discoveries was 60 and 128 m respectively. Existing methods of geophysical search techniques appear to lose their practical effectiveness below 200 m. This lack of success has been highlighted as part of the general UNCOVER movement in Australia. A critical and thoughtful response requires not just handwringing, but careful improvements to the whole methodology of exploration geophysics. Clever methods, that do not work effectively, can mask this lack of success for a period. The original popularity of the magnetic method is revisited and suggestions are made for what works and what does not. New Airborne ElectroMagnetic 2.5D inversion technology promises to regularly reach to 500m in most terrains, and produce geological sections with marker beds, indicating the local folding and faults.

Gunn and Dentith (1997) list a variety of mineral exploration targets associated with magnetic minerals and discuss the use of aeromagnetic methods. This methodology is a good proxy for the traditional interpretation of potential field and other geophysical survey datasets and how they are often still used. With the passing of time, the record for finding deeper buried 'orebodies' by direct detection from magnetic datasets, with follow up drilling, has not been very successful. The average depths of cover for gold and base metal discoveries was 60 and 128 meters respectively (Schodde, 2017). It is obvious that the 'one size does fits all' approach will not work for all mineralisation types and mapping the geology remains critical to exploration success. Despite this, the temptation remains that the Tier One deposit that is the only target of interest, has more massive mineralisation so hunting the 'blob' will work! Experimental evidence indicates this is not so.

In the 20 years since Gunn and Dentith (1997) was published much change has occurred in the technology space, including desktop computing that far exceeds what could be previously imagined. This has not always been a blessing, as ineffective methods that appear to have merit have emerged and been given much more credence than might have been warranted.

This paper briefly examines some of the technology advances now available, and attempts an update on the Gunn and Dentith review paper, in the light of the actual performance in the last 10 years of exploration.

COMMON UNCERTAINTY RESEARCH EXPLORER UNCERTAINTY ESTIMATION IN GEOLOGICAL 3D MODELING

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3D geological models describe geological information in a 3D space using structural data and topological rules as inputs. They are necessary in any project where the properties of the subsurface matters as they express our understanding of geometries in depth. These models, however, are fraught with uncertainties originating from the inherent flaws of the modeling engines combined with input uncertainty. Because 3D geological models are often used for impactful decision-making it is critical that all 3D geological models provide accurate estimates of uncertainty. This research focusses on the effect of various structural input data uncertainty propagation in 3D geological modeling. This aim is achieved using Monte Carlo simulation uncertainty estimation (MCUE), a stochastic method which samples from predefined probability distributions that are estimates of the uncertainty of the original input data set. MCUE is used to produce a series of altered unique data sets. The altered

data sets are used as inputs to produce a range of plausible 3D models. These models are then combined into a series of probabilistic models as a means to propagate uncertainty from the input data to several final models candidates. The proposed talk will present new and more reliable sampling workflows for structural data along with innovative ways to reduce uncertainty using model clustering based on topological signatures and sensitivity analysis. The methods will be demonstrated on two synthetic cases and a real case (Yerrida basin model, WA).

MULTIDIMENSIONAL TOPOLOGY TRANSFORMS

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Most currently constructed 3D geological models are to a first order the result of transformations of:

- 1D (at the mine scale),
- 2D data (at the regional scale) or
- 3D data (when high resolution 3D geophysical data are available, such as in basins),

data into 3D.

The datasets used to project between dimensions vary according to the scenario, however they generally consist of a mixture of 0D observations and local temporal or spatial relationships (their topology). Modern software systems are able to use a sub-set of these relationships (fault-stratigraphy relationships for example) to build 3D geological models, however the relationships are not typically used as an independent constraint on how much of the 3D model is constrained by observations, and how much is generated by the end user (or the algorithms they use).

This study explores the relationships between topological observations in 1, 2 and 3D in order to better understand how these may be used in the future as inputs to a revised 3D modelling workflow. We have investigated both synthetic cases, where we have full control, and natural examples, which permit alternate hypotheses. This approach has potential relevance to mine-scale and regional 3D models where the 3D topologies are poorly defined by the existing data, but 1D and 2D constraints are available.

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10E GEOPHYSICAL CASE HISTORY

AN ASSESSMENT OF GEOTEM, ZTEM, AIRMT AND FALCON SURVEYS OVER THE NEBO BABEL DEPOSIT, WESTERN AUSTRALIA

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The Nebo Babel Ni-Cu deposit was discovered in 2000 by Western Mining Corporation (WMC), then BHP Billiton and now Cassini Resources. Over this period, it has been the subject of extensive airborne geophysical investigations including Geotem, Falcon and more recently ZTEM, AirMt and Spectrem. Parts of the mineralised system respond well to the various airborne EM techniques, but the response overall is complicated by the presence of extensive paleochannel development. A combination of 1D, 2D and 3D processing techniques have been applied to the EM data so as to better understand the overall system responses and where possible, see if it were possible to separate the basement conductive response from that of the overlying Tertiary channels.

GEOPHYSICS FOR SEDIMENT HOSTED COPPER AND GOLD MINERALISATION, THE ROLE OF 3D IP

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Sediment hosted copper mineralisation involves redox precipitation of copper sulphides where oxidised basinal fluids interact with *in situ* organic material or migrated hydrocarbons. This is a common process in sedimentary basins so it is important to find fast and cost-efficient methods for their exploration. Airborne magnetic/ electromagnetic and ground gravity and electrical resistivity-induced polarisation (IP) methods are commonly used to explore for these types of deposits. The application of IP methods can be utilised as a direct targeting tool in the sediment hosted environment. Multichannel receivers, large transmitters, improvements in processing capacity has led to more confidence in inversion results and the recent popularity of the 3D IP technique. Examples of the application of large 3D IP surveys for sediment hosted copper deposits from Zambia and Alaska show that high grade copper mineralisation is associated with an IP response. Sedimentary textures associated with mineralisation compromise the inductive conductivity and resistivity response (anisotropy). An integrated exploration approach using geology, geochemistry and geophysics helps alleviate pursuing responses from digenetic pyrite, graphitic shales and specular haematite.

GEOPHYSICS OF THE PATTERSON LAKE SOUTH URANIUM DEPOSIT, SASKATCHEWAN, CANADA

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The Athabasca Basin's major uranium deposits and mines are generally proximal to graphitic conductors (reducing environment) and accompanied by an alteration 'halo' which is usually a resistive low, but can also be silicified (resistivity high). The sandstone environment is normally highly resistive, which makes things ideal for EM detection of weaker graphitic conductors at depth.

The Triple R deposit on Fission Uranium Corp's Patterson Lake South Property is located in Canada's Athabasca Basin, home to the world's richest uranium mines. The deposit is accessible by all-weather Highway 955, which continues north to the UEX-AREVA Shea Creek and to the Cluff Lake uranium mine. It is the only major, high-grade deposit in the region that is potentially open-pittable and is the largest mineralised trend in the region – currently standing at over 3 km in length.

The PLS discovery is chronicled from the initial airborne radiometric and EM surveys, to ground follow-up using DC resistivity and induced polarisation, horizontal loop EM, moving loop TEM and radon survey, leading up to the discovery holes.

The deposit shows excellent correlation with a VTEM conductive 'bright spot', an interpreted conductor and a resistivity low segment. Also significant is the evidence of cross structure seen in the resistivity at the west side of the displayed deposit outline.

The continued success of the resource delineation and expansion is attributed to the dedicated Fission staff for their work to bring the project forward. From discovery to resource estimate, the Triple R Deposit was achieved in just two years of drilling.

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10F MAGNETICS

EXTENDING MAGNETIC DEPTHS PAST 1000 M

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Technology to characterise and differentiate multi-basalt flood events that are well separated in geological time, but subject to subsequent sedimentation and erosion in the sedimentary sequence, has been developed and applied in the NT. Extensions to this ongoing effort have been made to create optimised workflows, to present an interpreter with the weighted evidence both interactively, and also in pseudo-borehole logs, in the 3D context. A further extension is to modify the tuning parameters to look for deeper basalt flow-like targets.

Rather than continue with inefficient methods that require a super-computer to get the job done, engineering efforts have been made to make a tool that works simply and effectively on generic desktop computers.

By assuming that a TMI anomaly is due to layers of random dipoles, equivalent magnetic depths can be obtained from its power spectrum. The shallow limit is perhaps half of one flight spacing, above which the signal vanishes into noise.

Despite good S/N at the lower frequencies, the standard Fourier transform does not supply enough points to extract signal for depths much below twice the flight spacing. Intrepid is widening the window by changing the transform so that more points are available to estimate depths well below two flight spacings.

A demonstration assigns depths to the Derim Derim Dolerite, a marker in the Roper Group of the MacArthur Basin, assisting the tracking of the Velkerri Formation between boreholes.

USING AMS AND PALAEOMAGNETIC DATA TO ASSESS TECTONIC ROTATION: A CASE STUDY FROM SAVANNAH NICKEL MINE, WA

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In structural geology it is common to evoke shortening directions, which are assumed to apply to all rocks regardless of their rheology. This is not realistic. However, resolving the partitioning of strain is not straightforward, particularly for intrusive rocks, which tend not to develop visible tectonic fabrics, but act as rigid blocks which typically rotate to accommodate strain during deformation, rather than compress or shear. Unfortunately there are few methods that can be used to quantify such rotation.

Intrusions near Savannah Nickel Mine, East Kimberley, WA, were observed to have different deformation histories, despite being temporally equivalent. In this study we measured anisotropy of magnetic susceptibility (AMS) and remanent magnetisation in four intrusions. The observed K3 AMS vectors are typically normal to the magmatic layering in layered intrusions. Where K3 vectors sit along a great circle, the pole to that great circle indicates the rotation axis. Although original palaeomagnetic vectors needn't be normal to magmatic layering, they can be used similarly to test the consistency of the inferred rotation analysis.

The rotations inferred for the intrusions tested were consistent between the two techniques. Savannah and Savannah North, were subjected to N–S, NE–SW and NW–SE shortening, consistent with the Halls Creek Orogen. However, N–S shortening was dominant at Savannah and NE–SW dominant at Savannah North. Although Dave Hill displays evidence of NE-directed thrusting, later E-W shortening was dominant at both Dave Hill and Wilsons. Therefore, despite their equivalent emplacement ages and implied tectonic history, each intrusion has undergone very different deformation.

MAGNETIC FIELD SURVEYS OF THIN SECTIONS

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There is a significant challenge in trying to correlate bulk magnetic properties of rock bodies with their magnetic mineralogy. Magnetic responses of rock bodies are measured at different scales and reflect different attributes depending on the nature of the method. Bulk magnetisation is a vector sum of all the constituents, including direction and intensity of both remanent and induced components. New high-resolution ground and aeromagnetic surveys can measure bulk properties of bodies with increasing accuracy and very high sensitivity. To bridge the gap between magnetic surveys and detailed rock-magnetic measurements on mg-sized and 2.54 cm paleomagnetic core samples, we have developed a scanning magnetic microscope that produces magnetic maps over thin sections, or rock slices. These surveys can be performed in a field-free environment, so that only remanence is mapped, or alternatively (unique to our lab) magnetic fields can be applied in any direction. Therefore, we can map only the remanent component, or remanent plus

induced magnetisation. Such surveys allow direct comparison of the measured bulk-magnetic properties with the magnetic response of minerals in a rock sample. Case studies have been done to compare these thin-section measurements to larger-scale ground- and aero-magnetic surveys.

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10G GROUNDWATER

GAINING INSIGHT INTO THE T_2*–T_2 RELATIONSHIP THROUGH COMPLEX INVERSION OF SURFACE NMR FID DATA

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One of the primary shortcomings of the standard surface nuclear magnetic resonance (NMR) measurement, called the free-induction decay (FID), is the uncertainty about the link between the signal's time dependence and the geometry of the pore space. Ideally, the FID signal's time dependence, described by the parameter T_2*, carries an intimate link to the geometry of the pore space, allowing robust estimation of pore-size and permeability. However, T_2* can also be strongly influenced by background magnetic field (B_0) inhomogeneity, which can mask the link to pore geometry. To improve the utility of surface NMR FID measurements, we investigate whether complex inversion of surface NMR data can be used to provide insight into the link between T_2* and T_2 (the parameter carrying the link to pore geometry). Synthetic and field measurements are presented to demonstrate that an alternative forward modelling approach that involves direct modelling of relaxation during pulse (RDP) effects can help constrain the relationship between T_2* and T_2. Complex inversions are performed using forward models that include RDP for varying magnitudes of B_0 inhomogeneity (consistent with observed T_2* values) and it is observed that satisfactory data fits can only be obtained given reliable B_0 distributions. Thus providing insight into the T_2*–T_2 relationship. Ultimately, we demonstrate that an alternative forward modelling approach may help improve the utility of FID measurements for estimation of pore-scale properties.

CONSTRAINED MAGNETOTELLURIC INVERSIONS FOR CHARACTERISATION OF COMPLEX AQUIFER SYSTEMS

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To investigate a key zone of hydrogeological interest, a 2D MT survey was carried out across the Badaminna fault zone, which is a basin-scale extensional fault system, running roughly North/South in the northern Perth Basin of Western Australia. The hydrogeology of the basin consist of a multi-level system of heterogeneous sedimentary aquifers and aquicludes. These aquifers supply the majority of water for Perth City. The Badaminna Fault separates aquifer systems of different salinity and age, and displaces both the Leederville and Yarragadee aquifers by about 500 m. The north-trending Darling fault separates the basin from the Archean Yilgarn Craton in the east, and thins towards oceanic crust in deep water about 150 km offshore, adding to the complexity of MT inversion.

Constrained MT inversions, using seismic, airborne EM and well logs, was able to define the electrical properties surrounding the Badaminna Fault zone as well as the hydrostratigraphy on both the eastern and western sides spanning a depth range from the near surface to more than five km. The near surface inverted MT electrical conductivities show good agreement with results from 1D inversion of AEM surveying. The MT inversion results moreover corresponds to resistivity logs from nearby wells. Based on the MT data salinity estimates were obtained for the deep portion of the Yarragadee aquifer, providing a better understanding of both the solute concentration and distribution of deep clay sealing formations.

A NEW GENERATION, PORTABLE, TIME-DOMAIN EM PROFILING SYSTEM

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Loupe is a new, portable time-domain electromagnetic system specifically designed for rapid reconnaissance and near-surface conductivity measurements. The receiver and transmitter are each carried by one person on a back-pack. Loupe incorporates a 3-component coil sensor with 100 kHz bandwidth, a fast-switching transmitter loop, a simple user-interface and the ability to navigate and recover position using RTK GPS. We believe that the ability to rapidly measure conductivity distribution in 3D in the near-surface using a rapid acquisition system will change how many geotechnical and mineral exploration programs are conducted.

We anticipate that the paper will present examples of data from a geotechnical investigation, an iron ore mine and a base metal sulphide deposit. Results will be compared against other techniques to illustrate the increase in near-surface resolution and speed of data collection.

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10H GROUNDWATER

NOVEL METHODS FOR NEAR-SURFACE HYDROGEOLOGICAL FEATURE ENHANCEMENT FROM HIGH-RESOLUTION AIRBORNE MAGNETIC DATA

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The delineation of near-surface (0–300 m) hydrostratigraphy and tectonic features is essential for successful characterisation of groundwater systems and subsequent hydrogeological modeling.

While most remote sensing of such systems is commonly achieved using high-resolution airborne electromagnetic data, validated by drilling data, and complemented by the use of terrain and multispectral data, it is shown that there is also a useful role for high-resolution magnetic survey data. Various filtering of gridded magnetic data, when image-enhanced and interrogated with other datasets, reveal features such as faults, dykes and other structures which may influence the distribution and movement of groundwater. One of the most useful enhancements of magnetic data is tilt, in which the range of data from ±90° acts as an automatic gain control to highlight both strong and weak source responses. While it is difficult to obtain accurate depth information from magnetic data, useful relative depth estimates can be obtained by using, for example, the Tilt-depth method, in which half the width between the ±45° contours of the tilt grid is a measure of the depth to source. These depth estimates can be calibrated, where possible, by comparison with other data. Dip directions of source contacts can be estimated by using the attitudes of multiscale edges, derived from the maxima of total horizontal derivative data. Examples of the utility of high-resolution magnetic data, in its complementary role, are presented for two groundwater assessment project areas – the Menindee Lakes region in western NSW and the Keep River catchment in the Northern Territory.

RECENT ADVANCEMENTS AND APPLICATIONS OF LOGGING AND SURFACE MAGNETIC RESONANCE FOR GROUNDWATER INVESTIGATIONS

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Enhancing groundwater investigations, nuclear magnetic resonance (NMR) geophysics allows direct measurement of hydrogen in pore fluids and characterisation of groundwater flow and storage parameters, including porosity, pore size, and permeability. In the field, NMR can be applied both downhole, with logging NMR tools, and non-invasively with surface NMR methods. We present recent technical advancements in logging and surface NMR, all of which are aimed to improve measurement flexibility, efficiency, and accuracy. These advancements include hardware development as well as adaptation of survey methodologies. We present applications of current logging and surface NMR technology from a range of international sites as part of practical groundwater investigations. Applications considered include characterisation of the vadose zone, determination of aquifer hydrogeologic properties, detection of hydrocarbon contaminants, and imaging of thaw water in artic environments.

IMPROVED GROUNDWATER SYSTEM CHARACTERISATION AND MAPPING USING HYDROGEOPHYSICAL DATA AND MACHINE-LEARNING WORKFLOWS

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The Australian machine-learning workflows apply fusion, clustering, and estimation operations to hydrogeophysical data for deriving hydrostratigraphic units (HSUs). Data fusion is performed by training a self-organising map (SOM) with these data. The application of Davies-Bouldin criteria to K-means clustering of SOM nodes determines the number and location of HSUs. Estimation is handled by iterative least-squares minimisation of the SOM quantisation and topographical errors. Two workflows provide 3D characterisation of HSUs (and related attributes) from different hydrogeophysical data (measured, derived, interpolated, and estimated values) sets.

In Workflow 1, the SOM learns to recognise relationships among a subset of borehole geophysical and hydrogeologic data. Using the data-fusion approach described above, the missing hydrological data are estimated using these learned relationships and HSUs determined at borehole sample locations resulting in a low lateral density and high vertical density spatial distribution. Variogram modeling of the regional field data and HSU estimates is undertaken to evaluate the spatial statistical structure of selected attributes.

In workflow 2, the learned relationships between borehole data and the more spatially extensive AEM conductivity model are used to estimate the key attributes and HSUs at a number of locations away from the borehole. The AEM conductivity profile at a number of random locations are mapped to the SOM network and estimation performed to arrive at a set of continuous HSUs with high lateral density and medium vertical density (based on m-layer modelled structure). Performance metrics and validation are used to test each step of both workflows.

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1320–1345

Monday 19 February 2018

Energy

P001. CARBON ISOTOPE FRACTIONATION IN COAL AND MARINE SOURCE ROCKS AND IMPLICATIONS FOR EXPLORATION

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Stable isotope composition of gas is widely used in hydrocarbon exploration to determine the composition and thermal maturity of source rocks. Analyses of Australian coal and marine shale samples indicate that during gas desorption both molecular and isotopic compositions change with time. Therefore, a detailed understanding of the mechanism of isotope fractionation is required to improve our ability to better characterise source rocks and fluids.

δ13C of Permian coals range between –22 and –26‰ (VPDB) and that of thermogenic methane generated from these range from –25 to –40‰. δ13C of gas desorbed from coal varies with time according to molecular weight and sorption properties. For example, in a set of deep Bowen Basin coals the difference in δ13C-CH4 between early and late desorbed gas varies from 2‰ to 29‰. For higher hydrocarbons this fractionation is lower, where for ethane it is <8‰ and for propane <3‰.

Similar isotope fractionation happens during desorption from marine source rocks in the Beetaloo Basin. δ13C for an immature kerogen from the Velkerri shale is –33‰. Where the Velkerri shale is gas mature, during desorption, δ13C-CH4 shows fractionation of up to 28‰. δ13C-C2H6 and δ13C-C3H6 show lower isotope fractionation of 1.6‰ and 0.9‰, respectively.

Many published classification systems relating isotope composition of gas to source rock and thermal maturity do not consider the effects of such isotope fractionation. The fractionation mechanism may also have an impact on the so-called 'isotope reversal' behaviour in some shale reservoirs which, at present, is poorly understood.

P002. BIOMARKER SIGNATURES OF UPPER CRETACEOUS TO PALEOGENE HYDROCARBON SOURCE ROCKS FROM THE LATROBE GROUP, GIPPSLAND BASIN

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Gas chromatography-mass spectrometry analyses have been carried out to investigate the geochemical characteristics of shales and coaly shales from the Latrobe Group in the Gippsland Basin, Australia. The depositional environment, organic matter sources and thermal maturity of hydrocarbon source rocks in the study area were evaluated using biomarker analyses. The distribution of isoprenoid alkanes and pentacyclic triterpanes reveals an oxic environment with fresh water (Pr/Ph >3.0, gammacerane index <0.3). The carbon preference indices (CPI) ratios of the n-alkanes are higher than 1.0, suggesting terrigenous higher plant-derived organic matter in the sediments. The high predominance of C_{29} sterane over C_{27} sterane as well as the occurrence of conifer and angiosperm biomarkers (i.e. labdane, isopimarane, phyllocladane, rimuane, oleanane, retene, chrysene, and piece, etc.) corroborates input from higher vascular land plants. Biomarker thermal maturity indices, such as C_{31} 22S/(22S+22R) hopanes, C_{30} βα/(βα+αβ) hopanes and C_{29} ααα 20S/(20S+20R) steranes, indicate rather thermally immature hydrocarbon source rocks, in agreement with the above CPI data. This maturity trend is also supported by the triaromatic sterane index [TA(I)/TA(I+II)], which is generally lower than 0.2.

P003. IDENTIFICATION OF CLAY MINERALS WITHIN THE SPRINGBOK FORMATION, SURAT BASIN

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The Walloon Coal Measures in the Surat Basin in Queensland are an important coal seam gas resource. Development of this resource requires a thorough understanding of the surrounding lithologies. The Springbok Sandstone unconformably overlies the Walloon Coal Measures in a significant portion of the basin. Despite this, there have been limited studies undertaken to understand the well log response of its clay phases.

The Springbok Sandstone has previously been classified as a generally permeable sandstone aquifer, however reported lithologies presented in the literature range across sandstones, mudstones, tuff, and coal layers. Conventional well log analysis (for instance using gamma logs) has proved insufficient in differentiating relatively low clay sandstones from more clay rich sandstone and mudstone layers.

Here we investigate the hypothesis that potassium free or low-potassium clay minerals are the dominant clay minerals in the Springbok Sandstone, and that the low overall potassium content throughout may explain the inability of traditional well log analysis to successfully highlight high clay content rock units within the formation. A laboratory analysis program comprising mineralogy and major and trace element analysis using drill core from 5 wells within the basin provides new and detailed insight into the composition of this important formation. Results from XRD, XRF, and ICP-MS analysis will be presented.

P004. VTI ANISOTROPY IN THE BROWSE BASIN: CASE STUDY OF TOROSA-6 WELL

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Overburden shales that overlay and seal hydrocarbon reservoirs usually exhibit polar anisotropy, also called Vertical Transverse Isotropy (VTI). This anisotropy is important to correct seismic data processing, seismic to well tie as well as geomechanical applications. P-wave anisotropy cannot be determined from a vertical well unless a walkaway vertical seismic profile (VSP) has been obtained, however, such measurements are still rare.

S-wave anisotropy though can be estimated when the speed of sound in mud and Stoneley wave velocity in the shale are known. The Stoneley wave velocity is nowadays routinely measured by acoustic tools and the absence of reliable sound velocity in mud can be overcome by calibrating the signal in an isotropic interval. Then, P-wave anisotropy can be restored using theoretical models or empirical trends. Using this method, we analyse VTI anisotropy in Torosa-6 well in the Caswell Sub-basin of the Browse Basin, the North West Shelf of Australia. Torosa-6 intersected the Jamieson, Echuca Shoals and Plover shaly formations and a walkaway VSP was acquired. The S-wave anisotropy ranges from 0.2 to 0.6 and shows good correlation with the volume of clay within each of the shaly formations. However, in different formations, the anisotropy displays differences within intervals with similar clay content. A mineralogy model is built to explain these differences. It is worth noting that the observed VTI anisotropy shows no positive trend with the burial depth.

P005. THE STRUCTURAL EVOLUTION OF THE NORTH WEST SHELF: A THERMOMECHANICAL MODELLING APPROACH USING STRATIFIED LITHOSPHERIC RHEOLOGIES AND SURFACE PROCESSES

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The processes involved in the structural and stratigraphic evolution of the North West Shelf (NWS), one of the most productive and prospective hydrocarbon provinces in Australia, remain controversial. The complex structural characteristics of the NWS include large-scale extensional detachments, difference between amounts of crustal and lithospheric extension and prolonged episodes of thermal sagging after rifting episodes. It has been proposed that the succession of different extensional styles mechanisms (Cambrian detachment faulting, broadly distributed Permo-Carboniferous extension and Late Triassic to Early Cretaceous localised rift development) is best described in terms of variation in deformation response of a lithosphere that has strengthened from one extensional episode to the next. However, previous models invoking large-scale detachments fail to explain changes in extensional styles and over-estimate the structural importance of relatively local detachments (e.g. Scholl Island Fault). Here, we hypothesise that an initially weak lithosphere would distribute deformation by ductile flow within the lower crust and that the interaction between crustal flow, thermal-evolution and sediment loading/unloading could explain some of the structural complexities recorded by the NWS. To test this hypothesis we run a series of fully coupled 3D thermo-mechanical numerical experiments that include realistic thermal and mechanical properties, as well as surface processes (erosion, sediments transport and sedimentation). This modelling approach aims to provide insights into the thermal and structural history of the NWS, and a better understanding of the complex interactions between tectonics and surface processes at the scale of the margin.

P006. MULTIPHASE DFEORMATION OF THE NORTHERN CARNARVON BASIN

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The Northern Carnarvon Basin has experienced a complex history of deformation, which has been well documented in the past. However public domain 2D and 3D seismic data allows regional scale mapping over large parts of the Basin in unprecedented detail, and allows re-evaluation many aspects of that history. Observations from different parts of the Basin show that N–S to NE–SW oriented rifts were active from the Devonian into the early part of the Carboniferous, but a significant change in fault orientation occurred in the Upper Carboniferous-Permian, forming the NW–SE structural grain that dominates the North West Shelf. After a significant phase of post rift subsidence in the Triassic, extension resumed during the uppermost Triassic and continued until to the Middle Jurassic. The E-W oriented extension was more or less perpendicular to the Devonian to Lower Carboniferous structures, but oblique to the Upper Carboniferous to Permian structures, resulting in highly segmented margins of Jurassic depocentres, including the structures that contain the fields defining the Rankin Trend. Triassic shales provide a detachment which influences the geometry of some Jurassic faults, accounting for the development of large synclinal structures associated with some Jurassic rifts, as well as some antiformal traps. Sediment supply from the east resulted in a sediment starvation in the western parts of the Exmouth Plateau and erosion of uplifted fault block crests.

A significant plate tectonic re-organisation occurred in the Upper Jurassic and Lower Cretaceous. There is some rotation of the stress field, resulting in a change in orientation of active faults in parts of the basin. There was also a significant change in sediment supply, with uplift to the south, possibly associated with hot spot activity resulting in a large influx of sediment that drowned previously exposed fault block on the Exmouth plateau, but with reduced sediment supply in the east. The more uplifted parts of the plateau may have nucleated a later (Neogene) large scale compressional fold which contain one of the larger gas fields in the basin.

P007. TRIASSIC PROVENANCE ANALYSIS OF THE ROEBUCK BASIN, NORTH WEST SHELF OF AUSTRALIA

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The Roebuck Basin is on Australia's North West Shelf, between the Browse and northern Carnarvon basins. The Basin consists of Paleozoic to recent fluvial to deep marine mudstones and sandstones, carbonate platforms and reefs, and volcaniclastics. Recent hydrocarbon discoveries in the Bedout Sub-basin have renewed exploration interest and changed existing perceptions about the regions prospectivity.

The interpretation of U-Pb detrital zircon dating from offshore petroleum well cuttings provides new information regarding the origin of sediments and changes in sediment provenance. This analytical work has the potential to better understand reservoir

quality within the Triassic Upper and Lower Keraudren deltas (and equivalent sequences). A range of detrital zircon age spectra were obtained. Analyses of zircon grain shapes (i.e. roundness) somewhat supports transportation of some distance, but could also signify multi-phase recycling. However, the combined detrital age spectra and grain shape reveals that the Roebuck Basin deltas had multiple sediment sources. The Roebuck Basin's Triassic sediments appear to be derived from Australia's interior, potentially transported either directly via large rivers or from subsequent sediment reworking and transport via long-shore drift.

Seismostratigraphic interpretations have identified potential sediment transport mechanisms including clinoforms and submarine canyons. Significant landward uplift and erosion associated with the latest Permian-aged Bedout Movement supports the reworking of Permian sediments. Integration of additional samples, and linking these to palaeogeographic settings, will provide additional clarity of the potential Australian and non-Australian Triassic sediment sources. This study aims to provide further insight into the origin of the reservoir units in the Roebuck Basin.

P008. THE NORTH WEST SHELF (NWS), A DIGITAL PETROLEUM ECOSYSTEM (PDE) IN A BIG DATA SCALE

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The North West Shelf (NWS) and its associated petroleum systems have varied geographies, geomorphologies and complex geological environments. In spite of the ongoing exploration activities in many sedimentary basins, the appraisal and field development campaigns are challenging. Besides, interpreting the connectivity between petroleum systems is challenging. The heterogeneity and multidimensionality of multi-stacked reservoirs associated with multiple oil and gas fields complicate the data integration process. Volumes and varieties of data existing in these basins are in different scales, sizes and formats, demanding new storage and retrieval methods, emphasising both data integration and data structuring. Since the data are in terabyte size; the multiple dimensions and domains need to be brought in a single repository, we take advantage of Big Data tools and technologies. In this context, we aim at articulating the digital petroleum ecosystems and petroleum database management systems with new data modelling, data warehousing and mining, visualisation and interpretation artefacts. This approach facilitates data management not only for individual basins but groups of basins in the NWS. Warehoused cuboid metadata can explore the connections providing new insights in the data interpretation and knowledge of new prospective areas. The multidimensional warehousing repository that is supported by cloud computing, data analytics and virtualisation features, provides new opportunities for delivering quality and just-in-time online ecosystem services. Other goals are deducing an integrated unified metadata model and characterising the connectivity among the basins of the NWS and associated oil and gas fields. The study supports the features of PDE and its knowledge management.

P009. FULL-VOLUME INTERPRETATION METHODS: APPLICATIONS FOR QUANTITATIVE SEISMIC STRATIGRAPHY AND GEOMORPHOLOGY OF THE LOWER BARROW GROUP, NORTHWEST AUSTRALIA

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Following decades of technological innovation, geologists have now access to extensive 3D seismic datasets. How these data will help understanding the complexity of the subsurface relies on developing stratigraphic workflows that allow very high-resolution interpretation in a cost-effective timeframe.

Here, the use of full-volume, semi-automatic horizon tracking tools allowed interpreting ultra-high resolution seismic sequences (~40 000 years duration) within a Cretaceous prograding shelf-margin (Lower Barrow Group (LBG), Northwest Australia).

Initially, semi-automated horizon tracking allowed mapping key regional unconformities defining 3rd-order seismic sequences. In a second step, a very high resolution grid (nodes corresponding to seismic traces) was generated in each 3rd-order sequence. An automatic propagation algorithm then linked the nodes based on their similarities, resulting in a very dense network of 'proto'-seismic horizons. Volume interpolation resulted in the creation of a Relative Geological Time model from which a very high number of chronostratigraphic surfaces were extracted. This allowed a full volume 3D mapping of every clinoform in each 3rd-order sequence, from which quantitative data (clinoform height, slope, topset vs bottomset thickness) and seismic attributes (seismic geomorphology) were extracted.

This analysis unveiled the high resolution changes in sediment supply and accommodation in time and space in the LBG, and provided new insights on the distribution of shallow and deep marine plays in the basin. This innovative workflow constitutes a new step in sequence stratigraphy as it allows interpreters to map sequences in a true 3D environment hence taking into account the full variability of depositional systems in time and space.

P010. RECALIBRATING AUSTRALIAN TRIASSIC PALYNOSTRATIGRAPHY TO THE INTERNATIONAL GEOLOGIC TIMESCALE USING HIGH RESOLUTION CA-IDTIMS DATING

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The Triassic is an important interval for Australian petroleum exploration, with Middle to Upper Triassic Mungaroo Formation reservoirs in the Northern Carnarvon Basin, and recent Lower Triassic discoveries in the Roebuck Basin. The chronostratigraphic understanding of Triassic petroleum systems

is underpinned by biostratigraphic dating using palynological zonations. The numerical ages of these zones are usually assigned through inference and interpolation, often via tenuous correlations to the international geologic timescale using scattered marine biota, (primarily foraminifera, and rare ammonites, conodonts and/or dinoflagellates). In contrast, we tie Australian biozones to the timescale through Chemical Abrasion-Isotope Dilution Thermal Ionisation Mass Spectrometry (CA-IDTIMS) dating of interbedded volcanic tuffs. Such ashfalls are reasonably common in Australian basins, and can provide high-precision CA-IDTIMS ages if they contain magmatic zircons. We recently recalibrated Australian middle and late Permian palynozones using this approach and preliminary results suggest that Triassic biozone ages are likewise in need of considerable revision.

We have targeted Triassic tuffs across Queensland, (Tarong beds, Brisbane Tuff, Moolayember Formation, Rewan Group), New South Wales (Garie Formation, Coal Cliff Sandstone, Milligan Road Formation), and Tasmania (upper Triassic coal measures) to provide numerical ages for palynozones. Additional dates in New Zealand (Murihiku Supergroup) and Timor-Leste (Wailuli Formation) will allow international correlation of dinocyst and spore-pollen zones. Numerical constraints for Triassic biozone boundaries facilitate correlation of Australian biozones with the international geologic timescale. This can impact burial history models used in petroleum exploration anywhere these biozones are used, often far beyond the basins from which the samples were collected.

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Mineral Geoscience

P011. SURFACE PROCESS MODELS OF THE LAKE EYRE BASIN USING BADLANDS SOFTWARE

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Surface process dynamics play an important role in sedimentary basin evolution. They affect hydrologic and carbon cycling, which are particularly difficult to simulate because of their complex interactions and the large range of spatial and temporal scales on which they operate. By considering uplift/subsidence, sea level change and climate change, surface process models are able to assimilate and represent several dynamic processes, including crustal deformation, mantle-convection-driven dynamic topography, erosion, sediment deposition, burial, and compaction. In order for these models to be useful for the industry they need to be able to reproduce depositional histories in sedimentary basins. Here we propose to use Badlands (BAsin anD LANdscape DynamicS), a landscape evolution modelling software, to evaluate the topographic and sedimentary evolution of the Lake Eyre Basin, a large, dominant feature in the Australian landscape with economic resources and good data coverage. Analyses of the long-term Lake Eyre sedimentation can provide valuable information about the connection between processes operating at the Earth's surface and the deeper mantle. From our calibrated models, we will be able to characterise reconstructions of the burial of stratigraphic layers in a sedimentary basin through space and time. Our approach will provide an integrated set of forward models and data assimilation framework which may help us better constrain source-to-sink basin models, and shed light on the contribution of mantle convection processes on the stratigraphic evolution of basins. Furthermore, data science and machine learning methods can be used in conjunction to develop surrogate-assisted models in order to assist existing model for large-scale implementation.

P012. U-PB GEOCHRONOLOGY OF APATITE AND CALCITE AT THE ERNEST HENRY DEPOSIT, NW QUEENSLAND; IMPLICATIONS FOR HYDROTHERMAL EVOLUTION AND ORE GENESIS

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The Ernest Henry deposit represents the largest known Iron Oxide Copper Gold (IOCG) deposit in the Eastern Succession of the Mount Isa Inlier. The orebody consists of a structurally controlled pipe-like breccia hosted in complexly altered Proterozoic volcanics with mineralisation occurring post-peak metamorphism during a regional transpressional deformational event (D_3). Ore formation was controlled by the mixing of magmatic, metamorphic and basal fluids, resulting in the precipitation of chalcopyrite, pyrite, calcite, quartz, magnetite and accessory gold. Coarse-grained apatite is present as an accessory mineral in areas of high sulphide mineralisation and in shear zones adjacent to the orebody.

The paragenesis and relative timing of the alteration and mineralisation stages have been well constrained by previous workers. However, advances in U-Pb geochronology via the *in situ* laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) method means that for the first time apatite and calcite from the ore body and adjacent structures may be suitable for age dating.

This project will use an established apatite dating technique and aims to develop a calcite dating technique to provide dates for individual paragenetic stages. These time constraints will improve the current understanding hydrothermal evolution and ore genesis at Ernest Henry. As calcite is a common accessory mineral in ore deposits, this technique could be widely implemented to date mineralisation events and may allow hydrothermal events at different deposits to be linked.

P013. 3D MAPPING OF NSW PROJECT: SYDNEY–GUNNEDAH BASIN

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The Geological Survey of NSW (GSNSW) is using its geological databases to create a digital seamless geology map of NSW. This is being integrated with subsurface information such as drillhole logs and seismic data to generate 3D models in areas

of geological interest. A statewide depth to basement model, with consolidated and unconsolidated cover, has been completed and provides a framework for more detailed models of specific basins and orogens. The Sydney–Gunnedah Basin model includes best available geological mapping from the NSW Seamless Geology Project and new 3D modelling.

The onshore Sydney Basin comprises the southern section of the Permo-Triassic Sydney–Gunnedah–Bowen system. This basin system initiated in a back-arc extensional setting during the Permian, and was followed by thermal subsidence and subsequent foreland basin down-warping. The Sydney Basin contains up to 4500 m of Permo-Triassic clastic sedimentary rocks and overlies the Lachlan Orogen and Late Carboniferous volcaniclastic rocks. To the north of the Liverpool Ranges, the Gunnedah Basin extends the basin system, containing alluvial and deltaic sequences. The Hunter–Bowen Orogeny formed the adjacent New England Orogen and resulted in uplift and erosion that deposited Jurassic sedimentary sequences of the Surat Basin over large parts of the Gunnedah Basin.

In addition to the Sydney–Gunnedah Basin, the Tamworth Belt, the Clarence–Moreton Basin, the Hunter Coalfields and the Southern Coalfields have also been modelled. Integration of surface and subsurface geology provides strategic information to companies and government, to inform resource assessment and land-use decision-making in NSW.

P014. MODELLING RIFTING SEQUENCE STRATIGRAPHY COUPLED WITH SURFACE PROCESS AND THERMO-MECHANICAL MODELLING

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Rift settings preserve high-fidelity records of their depositional history in response to multiple processes, such as climate change, which significantly influences the sediment input, and tectonic deformation, which contributes to accommodation generation or consuming. Integrated studies of geomorphology, thermochronology, analog experiments and numerical modelling improved our understanding of the rifting processes and associated structural evolution. However, the interplay between climate change, sediment transport from eroding highland to rift basins and rift-related deformation is poorly understood.

We present a forward numerical scheme that couples surface process with thermo-mechanical modelling on a rift setting. In the coupling numerical framework, a 2D (potentially 3D) lithospheric scale model is set up. The erosion, sediment transport and deposition are controlled by surface processes with the boundary conditions of climate force (precipitation) and erosion coefficient. The resulting sediment volumes are transferred to the thermo-mechanical system, which has a significant effect on crustal deformation. The produced tectonic uplift or subsidence then contributes to the change of surface topography and thus the sediment routing. We focus on investigating the climatic controls on source dynamics, sediment transport, and the deposition in both marine and nonmarine environments. We then quantify the influence of sediment accumulation on crustal deformation and rift evolution. The resulting stratigraphic architecture will be analysed through evolving stratal stacking patterns and shoreline trajectories to explore the feedbacks between erosion/deposition patterns and the rift structural. We will then apply our modelling to typical rifting examples such as East Africa rift system.

P015. CONSTRAINING UPLAND ERODIBILITY IN CATCHMENTS DELIVERING SEDIMENT TO THE GULF OF PAPUA

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The landscape of Papua New Guinea is very young, shaped by Plio-Quaternary tectonic events. Tectonic uplift rates exceed 400 m/Myr and rainfall exceeds 10 m/year. Uplift and rainfall combine to generate very high erosion rates. The Gulf of Papua is the ultimate sink for a very large terrigenous flux of ~$365{\cdot}10^6$ t/year stemming from the southern New Guinean mainland and from the Papuan Peninsula. Sediment cores indicate sediment accumulation rates of 0.12–0.8 mm/year in the deep-sea basin since the Late Pleistocene.

Rock types and erosion rates determine the nature and burial rate of the sediments delivered to the basin. Understanding their evolution through space and time helps predict the petrological stratigraphy of the basin. We use Badlands, a surface process numerical model developed by the Basin Genesis Hub, which simulates sediment erosion, routing and deposition, in order to simulate present-day fluxes and assess their evolution in the past. To reproduce landscape evolution in deep time we need to constrain the erodibility of the source areas. To achieve this we calibrate the model over the present-day landscape, using the present-day topography, rainfall patterns, distribution of source rocks, recent surface uplift field, and estimates of Late Quaternary sediment fluxes. Relative uplift along the southern flank of the Papuan Peninsula is constrained by the elevation of remnants of extensive late Miocene volcanics and by the modern elevation of contemporary low-lying surfaces. They reveal an uplift rate that increases from 0 m/Myr at the coastline to 440 m/Myr in the headwaters.

P016. DATA VISUALISATION AND INTEGRATION: AN UNDERGRADUATE PERSPECTIVE ON THE FRANK ARNOTT AWARD

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Over the summer of 2016/17, a team of students from the University of Adelaide were brought together to develop a unique proposal for the Frank Arnott Geophysical Challenge (http://www.frankarnottaward.com), with a focus on data integration and visualisation.

Geoscientific data is critical to exploration success, yet as projects move deeper under cover it is more critical than ever to maximise the value of existing data. Our challenge was to develop a means of integrating and manipulating the data to provide a clearer picture to better tell the story of the geological structures of the Gawler Craton. For this we used Wavelet

Transformations to alter 2D geophysical datasets into 3D datasets using the Poisson Wavelet and to work out the Fractal Dimensions. Subsequently we were tasked with developing an innovative method of visualising that data to give a unique experience and improve interaction and comprehension of the data. This was achieved by interactively projecting data onto a 3D surface to be able to locate areas of interest and see through the subsurface to better understand the geology.

Ultimately the aim of this project is to lend itself to the exploration industry and examine new ways to approach the challenges faced by geoscientists today and tomorrow. We developed a simple method of data integration and visualisation that uses all open source programs and accessible materials.

P017. IMPROVED IMAGING OF THE SUBSURFACE GEOLOGY IN THE MOWLA TERRACE, CANNING BASIN USING GRAVITY GRADIOMETRY DATA

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A study was undertaken to test whether it is possible to map the basement configuration and sedimentary horizons from the gravity gradiometry (AGG) data within the EP431 Buru Energy permit on the Mowla Terrace in the onshore Canning Basin.

By applying the Horizon Mapping (ESA-MWT) method to AGG data, we conducted a test study in a narrow 8 km long swath along 2D seismic traverse, HCG-300, and at three wells: Pictor-1, Pictor-2 and Pictor East-1, and three additional wells located nearby.

ESA-MWT, which is based on energy spectral analysis, was applied to gridded Bouguer and tensor gravity data. The ESA-MWT procedure was conducted at stations 1 km apart. At each station, multiple spectra were computed over incrementally increasing windows. For each spectrum, the depth was interpreted and plotted versus window size, and from these graphs, multiple *Depth-Plateaus* were detected at each station. These *Depth-Plateaus* which correspond to density contrasts within the sediments and the underlying basement, were laterally merged with those from adjacent stations forming density interfaces. These results were then validated with seismic and the litho-stratigraphy from well data showing a good correlation with the tops of several sedimentary formations and intra-formational lithological boundaries. Ten density interfaces were mapped: Top Precambrian Basement, Top Nambeet Formation, Intra-Willara Interface, Top Acacia Sandstone, Top Willara Formation, Intra-Goldwyer Interface, Top Goldwyer Formation, Top Nita Formation, Intra-Tandalgoo Group Interface and Intra-Tandalgoo Group Interface.

The geological model built along the test profile from interpretation of the AGG data shows good correlation with the wells and seismic data.

P018. GROUNDFLOOR EM: A NEW ADAPTATION

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Geotech has been working on new methods for exploring for higher conductive targets such as nickel and VMS. One method which is early in its development is an adaptation of the Ground Floor EM concept proposed by Vale in 2015.

Since 2004 Vale had been experimenting with the idea of using surface based EM receiver equipment in conjunction with an airborne transmitter, known as Groundfloor EM and described by Bengert (2015) using a case-history from Melville Peninsula, Nunavut, Canada.

Groundfloor EM was the term given to an electromagnetic surveying method that uses receiving equipment on the surface with an airborne transmitter. This technique has several significant advantages that cannot be achieved with an airborne receiver. Given the large transmitter-receiver separation, it is possible with Groundfloor EM to compute the received primary field from the airborne loop with sufficient accuracy to allow non-decaying anomalies to be observed in the system on-time. This allows the detection and discrimination of the kinds of extremely high conductivity targets that are commonly encountered in nickel sulfide exploration.

Groundfloor EM can be used in conjunction with a traditional airborne EM survey with only a minor increase in effort. This increases the confidence in the airborne data, and reduces the need for surface follow-up. This can be of great benefit to projects where surface geophysics is hampered by topographic, logistic, or land access issues.

The new adaptation proposed for Groundfloor utilises a lower frequency signal generated from the airborne transmitter and will be showcased using field results.

P019. ENHANCING THE RL SMITH TEST RANGE – A DEMONSTRATION OF IMPROVED PROCESSING AND NOISE RESULTS USING FULL SPECTRUM FALCON DATA

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During May of 2017, CGG re-acquired data over the RL Smith Test Range using the Full Spectrum Gravity system. The Full Spectrum Gravity system combines the high resolution Falcon Airborne Gravity Gradiometer (AGG) data and the sGrav strap-down gravimeter log wavelength gravity data. This system is the product of years of development work in both technology and processing improvements.

In previous years, we have demonstrated that Falcon has the lowest noise data using the RL Smith Test Range. Using this enhanced processing technique we are able to better differentiate acquisition noise from geologic signal. This allows us to better remove the acquisition related noise, while retaining higher resolution data and getting improved noise results.

With the introduction of Full Spectrum Gravity, we have had to create new quality control mechanisms to evaluate data accuracy. We will demonstrate these quality control tools that

can be applied to verify the Falcon data, sGrav data and Full Spectrum Gravity data.

In conclusion, we show the improvement achieved after years of development with the Full Spectrum Gravity System. We demonstrate the improved noise results and new quality control measures used to evaluate the quality of the Full Spectrum Gravity data using the RL Smith Test Range.

P020. RESEARCH ON DC RESISTIVITY FOR AN ARBITRARILY ANISOTROPIC EARTH USING CIRCULAR SCANNING MEASUREMENT

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The electrical anisotropy of underground media increases the non-uniqueness and uncertainty of geophysical interpretation in electrical prospecting. In order to identify the electrical characteristics of the arbitrarily anisotropic subsurface objects, we extend the existing researches and present a 3D anisotropic forward modelling algorithm using adaptive finite-element method based on unstructured grids. The adaptive finite-element code was validated against 1D semi-analytical solutions for a layered arbitrarily anisotropic earth. Considering the existence of anisotropic paradox, circular direct current (DC) scanning measurement is applied. We study the characteristics of apparent resistivity by simulating an arbitrarily anisotropic half-space and an arbitrarily anisotropic ore body surrounded by an isotropic or anisotropic rock. Based on this, we demonstrate how to identify the underground anisotropy from DC resistivity data. The algorithm and results from our numerical experiments can offer technical support in processing and interpreting DC resistivity data in areas with distinct electrical anisotropy.

P021. ACCELERATION OF 3D POTENTIAL FIELD DATA INVERSION USING A BB ITERATIVE ALGORITHM

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The efficiency of 3D inversion of potential field data can be paid enough attention by scholars owing to the arrival of the big-data age. A new solution method was considered for 3D inversion of potential field data in the geophysical data process. This program takes as an input gravity or magnetic vector and tensor measurements and produces 3D volumes of density and susceptibility with a fast convergence method. Here, in this paper, the gravity data is used to represent the potential filed data to test our method. To achieve this aim, the survey area is divided into a large number of rectangular prisms with unknown densities. In the potential filed data inversion, the inversion process is usually to solve an underdetermined linear system of equations problem. The problem was formulated by incorporating regularising constraints to obtain the stable inversion results. According to these acceleration requirements of inversion method, a new Barzilai–Borwein iterative algorithm was applied to accelerate the convergence of inversion method. Iterative gradient descent algorithms and iterative conjugate gradient algorithms were studied as the comparisons. To test the potential of the application of the new fast developed method, synthetic gravity data and real gravity data were performed. Numerical test and practical test indicate that this method is promising for practical potential field data inversion.

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Near Surface and Groundwater

P022. TRACE ELEMENTS AND NATURALLY OCCURRING RADIOACTIVE MATERIAL ASSOCIATED WITH PRODUCED WATERS IN COAL SEAM GAS AND SHALE GAS RESOURCES AND MECHANISMS THAT INFLUENCE FLUID MIGRATION

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The aim of this project is to determine the chemical properties of formation, produced and flowback fluids and to analyse the mechanisms that could contribute to fluid migration associated with coal seam gas and shale gas resources by reviewing global case studies. This can be achieved by: (a) determining the concentration of naturally occurring radioactive material (NORM) and trace elements associated with mining fluids; (b) determining the quality and quantity of produced water extracted at the surface; and (c) analysing the mechanisms that contribute to fluid migration through subsurface geology, which involves evaluating stress fields surrounding hydrocarbon resources.

The geochemical trace element and NORM composition associated with produced water depend on the type and grade of the fossil fuel, the original depositional environment, composition of the source rock, post depositional genesis processes and the mobility of trace elements by their capacity to dissolve into an aqueous solution. Therefore, an analysis of the geochemical characteristics of various formations around the world on a case study basis should be able to illustrate the variation of toxic concentration in numerous hydrocarbon bearing rock formations. Furthermore, having a clear understanding of regional hydrogeology and the mechanisms that relate to stress magnitude and orientation should illustrate the impact of stress characteristics to well integrity and fluid migration through sub-surface geology.

Lastly, the information compiled should provide a framework for decision makers to make recommendations on ways to monitor, control and minimise impact to important ground and surface water resources.

P023. THE USE OF GEOPHYSICS AS AN AID FOR CRICKET UMPIRES

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A particularly difficult part of cricket umpiring is judging whether the batsman has ‘nicked’ the ball on its way from the bowler to wicket keeper. If they have then the batsman is

dismissed, if not, or if the batsman has hit his pad rather than the ball, then the batsmen remains in. Even with modern high-speed cameras discerning a nick by eye is virtually impossible so during international cricket matches the umpire is aided in their decision making by an audio recording. This can be inconclusive, however, if there is considerable other noise being made (usually by the crowd), and especially if there is the possibility that the batsman may have hit the ground or another part of his body or equipment. To a geophysicist the solution to this problem is obvious, attach three component vibration sensors to the bat, record the data, and then look for any impacts, and this is in-effect what we have done. The results are convincing, not only can we detect impacts but also the type of impact and even the position of the bat upon which the impact occurred. Not only is the data superior to audio recordings but can be obtained more easily and cheaply making its application to the lower levels of cricket possible.

P024. USE OF ELECTRICAL GEOPHYSICS TO DELINEATE SHALLOW GROUNDWATER PATHWAYS

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Soil erosion poses significant consequences from an agricultural, economic and infrastructural perspective on a global scale. In particular, gullying processes have been a scientific focus for an extended period of time now in an attempt to understand and quantify the initiation and development of these erosion features (Beavis, 2000). Gullying is a natural process that is accelerated by unsuitable farming practices, clearing of vegetation and alterations to the local hydrological conditions; all of which are associated with European settlement of Australia over two centuries ago (Sidochuk, 1999). In order to develop appropriate management options a greater understanding of gullying is required, part of this is the prediction of head-cut movement (knickpoint) retreat uphill. Prediction of gully retreat would allow for preventative measures to be implemented to specific areas minimising affected areas and costs of management. Shallow geophysical investigations have the potential to track the preferential pathways of water through the soil/rock profile uphill from existing gully formations, effectively tracing the future movement of the knickpoint. Specifically the most appropriate geophysical techniques involve electrical resistivity and frequency domain electromagnetics, implemented to locate shallow conductors associated with existing gullies.

P025. STRUCTURAL EVOLUTION OF THE THIRLMERE AND MOUNT TOMA MONOCLINES SOUTHERN SYDNEY BASIN NSW - A GROUNDWATER PERSPECTIVE

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The Southern Sydney Basin is a geological region of almost flat lying conforming strata, with significant coal measures that have been mined for over 100 years. This apparently simple ‘layer-cake’ geology has resulted in the overlooking of many complexities associated with intrusions and a variety of geological structures. This over-simplification has contributed to the non-negligible, unpredicted impacts from mining on the surface hydrology and groundwater systems. The aim of this study was to identify and characterise geological complexities within the Southern Sydney Basin with a particular focus on near surface groundwater and wetlands that could be sensitive to these mining impacts.

An initial desk top review of existing drill-hole data and outcrop maps was undertaken to highlight areas of possible structural inconsistency and areas with a high probability of faults or other structures such as monoclines. This data was then used in combination with field based geological mapping and high quality digital terrain modeling to develop a series of kinematic cross-sections.

This enabled the modeling of fault propagation folds associated with the inversion of growth faults, which was important in the development of a framework to better identify and define the geometry of aquitards, associated with the Thirlmere Lakes and groundwater surface expression dependent ecosystems (swamps) over the Southern Sydney Basin. This greater understanding of the features around the Thirlmere Lakes area has led to the development of a structural evolution model that explains the incision of Blue Gum Creek and the development of Thirlmere Lakes within an entrenched meander.

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Energy

P026. DETERMINING UPFLOW/OUTFLOW ZONE AND FLUIDS FLOWS IN GEOTHERMAL PROSPECT AREA BASED ON GEOINDICATOR COMPARISON VALUE: A CASE STUDY OF MT TELOMOYO, CENTRAL JAVA, INDONESIA

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Mt Telomoyo is situated in Magelang Regency, about 400 km from Jakarta. In the studied area, eight geothermal surface manifestations were found, consisting of four hot springs and four cold springs. This research aims to identify upflow and outflow zones in the geothermal area using compared values of geoindicators and tracers obtained from sampled geothermal surface manifestations, and also to identify fluids flow of the Mt Telomoyo geothermal system. The method used in this research is to compile geoindicator comparison results, which are B/Li, Cl/B, Na/Ca, Cl/SO4, SO4/HCO3, and Na/K. Comparison results are then converted into geoindicator comparison maps. Faults and fractures are used to identify density of lineaments, also direction of lineaments where manifestations are found. Afterward overlain geoindicator maps and FFD maps are correlated to identify upflow/outflow zones and flow trends of geothermal fluids. The results of this research show that the upflow zone in the study area is located beneath Mt Telomoyo, the upflow zone has a high density of lineaments. Furthermore, the outflow zones are found with two tendencies. The major trend of outflow is directed toward the western part of upflow

zone, where geothermal manifestation APPD and APCU were found in ENE-WSW direction. The other outflow trend is directed toward the northeastern part of interpreted upflow zone, where geothermal manifestation APCD-1 and APCD-2 were found in NNW–SSE direction.

P027. SOIL AND FLUIDS GEOCHEMISTRY ANALYSIS TO DETERMINE NON-VOLCANIC GEOTHERMAL POTENTIAL, CASE STUDY OF BAYAH, BANTEN, INDONESIA

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Bayah is an area with complex geological conditions located administratively in Lebak District, Banten Province, approximately 80 kilometres southwest of Jakarta. In this area, six geothermal manifestations were found in the form of four hot springs and two cold springs, also 139 soil samples were taken. This study aims to determine the non-volcanic geothermal potential of the Bayah area. The method used in this research is the calculation of the geothermometer and geoindicators of geothermal manifestations to know the estimated reservoir temperature and the origin of the fluid manifestation. After that, a map was created based on soil chemistry data, which are Hg and CO_2 distribution anomalies in the soil. Analysis of Fault and Fracture Density (FFD) were also carried out to determine the fracture density developed in the study area. The results were used to calculate the real prospect area. The results of this study show that the geothermal prospect zone in the Bayah region is located in the southeast of the research area, precisely around APPC-1, APPC-2, and APPC-3 manifestations, having an area of about 10.36 km^2. Based on the geothermometer calculation, geothermal potential of Bayah area has medium enthalpy with reservoir temperature around 141–161ºC. The resources calculated in this study were 103 MWe.

P029. STRUCTURAL GEOLOGY ANALYSIS USING REMOTE SENSING METHOD AND ITS CORRELATION TO GEOTHERMAL OCCURENCE IN BAYAH DISTRICT, BANTEN

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The research area is located in Bayah District, Lebak Regency, Banten Province. The research location is approximately 80 km southwest of Jakarta. This area has a complex geological structure, as well as many intrusive and metamorphic rocks. In this research area, geothermal manifestations were found in the form of four hot springs (APPC-1, APPC-2, APPC-3, and APC) and two cold springs (ADC-1 and ADC-2). This study aims to identify the relationship of geological structure control with the occurence of geothermal manifestations in the research area, as well as to determine the Bayah non-volcanic geothermal prospects. The method used is Fault and Fracture Density (FFD) analysis for structural analysis of research area, and magnetic map analysis for interpretation of geothermal prospects. Structural analysis methods performed in the form of lineament delineation, determination of lineament density and major trends, and application of structural sequence model. The results of the structural analysis will be correlated with the occurences of geothermal manifestations with the aim of identifying the most influential structural patterns as the pathway for geothermal fluid to reach surface in the study area. Magnetic data is also used to determine the possibility of Bayah non-volcanic geothermal prospects. The developing structure in the research area has NE–SW and NW–SE directions. The FFD analysis shows that high-density lineament is located in the southeast of research area where three hot spring manifestations APPC-1, APPC-2, APPC-3 are present. These manifestations appear in the lineament with NE–SW direction. Magnetic data also obtained negative magnetic anomalies in the southeast of the study area. It can be concluded that the lineaments with NE–SW direction influence the fluid outflow the most, and Bayah non-volcanic geothermal prospect areas are located around APPC manifestations.

P030. GEODYNAMIC AND SURFACE PROCESS EVOLUTION OF NEW GUINEA SINCE THE JURASSIC

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Regional scale flooding of New Guinea has occurred episodically since the Jurassic. The most recent flooding event during the Miocene occurred despite falling long-term eustatic sea levels. Recent work has suggested dynamic topography, the long-wavelength low-amplitude topographic response to mantle flow, as a factor in the emergence and flooding of this region, and therefore influencing the depositional history of New Guinea basins. The link between deep Earth and surface processes has not yet been explored for this region. We use forward numerical models coupling plate kinematics, mantle convection, paleogeography and eustasty to investigate the time-dependent topographic response of the New Guinea margin. Dynamic topography estimates derived from mantle convection models are then coupled with surface process modelling code *Badlands* to study the landscape evolution of New Guinea and the adjacent Australian continent. Reproducing the inundation history of New Guinea, our models show that continental scale dynamic topography plays a significant role in the development of drainage systems, and erosion-deposition regimes. Our work demonstrates the necessity in linking geological processes that operate across wide spatial and temporal scales to better understand how the interplay between deep Earth and surface processes control the source to sink evolution of basins.

P031. NEW PERSPECTIVE OF MESOZOIC HYDROCARBON PROSPECTIVITY WITHIN WEST TIMOR

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Compared to the success of a Mesozoic play in the Westralian Superbasin (WASB), the lack of hydrocarbon discovery in West Timor within Timor Trough and North West Shelf Australia is still an enigma. The West Timor is still a frontier petroleum province with problems in uncertainties of working petroleum system plays as well as the hydrocarbon prospectivity.

This study tries to approach this issue by integrating of fieldwork data with published well data and offshore seismic data from recent publications to re-evaluate potential hydrocarbon prospectivity in this area. Using these datasets, this study identifies structural framework across West Timor Island and offshore area, as well as potential petroleum system plays including source rock, reservoir presence and trap configuration.

The results of this study identify two potential petroleum province regions including Timor deformation front and Australian passive continental margin. Within these areas, three main plays based on structural configuration were identified, which are fold related fault, sub-thrust and tilted fault block. Reservoir targets for these main plays are Jurassic sequences including sandstone of the Early-Middle Jurassic of Plover equivalent and Late Triassic Malita equivalent with seal rock including Early-Middle Jurassic shale of Wai Lui Formation and Early Cretaceous shale interval. These plays are expected to be charged from source rock intervals of Triassic formations.

The novelty of hydrocarbon prospectivity in this study will guide exploration screening of petroleum system analysis in the West Timor area where current play analysis has not yet been tested.

P032. UNRAVELLING DEEP STRUCTURES ALONG A PASSIVE-TRANSFORM MARGIN: INSIGHTS FROM AN INTEGRATED GEOPHYSICAL STUDY OF THE NORTHERN PERTH BASIN

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The Houtman Sub-basin lies adjacent to the Wallaby-Zenith Transform Margin, an under-explored region of Australia's continental margin located at the transition between the non-volcanic margin of the northern Perth Basin and volcanic province of the Wallaby Plateau. New data in the Houtman Sub-basin enables better understanding of the structural architecture and rifting development along a passive-transform margin and provides the framework for a detailed integrated margin-scale basin evaluation.

Profile modelling of potential field data, combined with 2D seismic, reveals complex along strike and dip variability in the crustal thinning of the Houtman Sub-basin, with extreme thinning (<5 km thick) beneath the main Permian depocentre. Outboard of this hyperextended zone, along the basin margin, is a zone of volcanic SDRs. Five different structural domains have been mapped across the margin, reflecting abrupt change in crustal thinning and volcanic emplacement. These domains trend roughly NW-SE to NNW-SSW, parallel to major basement terrane boundaries. Magnetic modelling suggests that the nature of the basement underlying the proximal domain and the hyperextended domain in the central Houtman Sub-basin are different and that a major Proterozoic basement terrane boundary lies beneath the necking domain.

The margin was structured during polyphase Permian and Late Jurassic rifting events which led to hyperextension prior to continental magmatic break-up and formation of oceanic crust during the Early Cretaceous. Our results suggest that the distribution of Early Permian rifts localised strain during Jurassic–Early Cretaceous rifting and strongly controlled the location and style of rifted margin during Valanginian continental break-up.

P033. STRUCTURAL CHARACTERISTICS OF THE NORTHERN HOUTMAN SUB-BASIN, PERTH BASIN

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The northern Houtman Sub-basin is an under-explored region of Australia's continental margin. It is located at the transition between the non-volcanic margin of the northern Perth Basin and the volcanic province of the Wallaby Plateau and lies adjacent to the Wallaby-Zenith Transform Margin. In 2014, Geoscience Australia acquired new 2D seismic data (GA-349, 3455 km) across the northern Houtman Sub-basin to assess its hydrocarbon prospectivity. Previous studies of the Houtman Sub-basin indicated that en-echelon basin bounding north-northwest trending faults are associated with the Permian half graben complex, however, it was not known if this structural style continued into the northern area of the Houtman Sub-basin.

This study integrated interpretation of the recently acquired survey with regional interpretation of the Houtman Sub-basin, underpinned by ties to well data and geophysical modelling, to develop a regional 2D structural and stratigraphic interpretation. Structural mapping was done for several surfaces: the basement, Early Triassic (Woodada Formation) and Early Jurassic (Eneabba Formation).

The basement structure of the northern Houtman Sub-basin is controlled by a series of large en-echelon northwest-southeast trending southwest dipping faults, some of which have a throw of more than 10 km. They control a series of Permian half graben separated by transfer zones and fault ramps. This basement architecture is similar to the inboard part of the southern Houtman Sub-basin, but the structures are larger. The Early Triassic and Early Jurassic faults trend northwest-southeast similar to the basement-involved faults, however the focus of faulting shifts westwards in the younger successions.

P034. TECTONO-STRATIGRAPHIC DEVELOPMENT OF THE NORTHERN HOUTMAN SUB-BASIN, PERTH BASIN

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New 2D seismic data (GA-349) acquired by Geoscience Australia in the northern Houtman Sub-basin, Perth Basin, provides important new insights into the tectono-stratigraphy of this frontier area. Interpretation of the GA-349 data tied to a regional interpretation of the Houtman and Abrolhos sub-basins reveals that the northern depocentre contains up to 19 km of Permian to Cenozoic sediments. As there are no wells in the northern Houtman Sub-basin, the age and lithologies of the mapped sequences were derived from regional mapping, stratal relationships and seismic facies. A series of large half-graben (7–10 km thick) extend the length of the inboard part of northern Sub-basin. These are interpreted to have formed as a result of rifting during the Permian. Overlying these half-graben,

and separated by an unconformity, is a thick succession (up to 6 km) interpreted to represent a subsequent late Permian to Early Jurassic phase of the thermal subsidence. A second phase of rifting started in the Early Jurassic and culminated in breakup in the Early Cretaceous. The sedimentary succession deposited during this phase of rifting is highly faulted and heavily intruded in the outboard part of the basin adjacent to the Wallaby Saddle, where intrusive and extrusive complexes are clearly imaged on the seismic. In contrast to the southern part of the Houtman Sub-basin that experienced rapid passive margin subsidence and regional tilting after the Valanginian breakup, the northern Sub-basin remained mostly exposed subaerially until the Aptian, as the Wallaby Zenith Transform Margin continued to develop.

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P035. TOWARDS A U–PB AGE MAP FOR NORTHERN AUSTRALIA

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Understanding the geological evolution and resource prospectivity of a region relies heavily on the integration of different geological and geophysical datasets. Age datasets are key to understanding the geological evolution and resource prospectivity of a region.

Northern Australia is a vast and relatively underexplored area that offers enormous potential for mineral and energy resource development. The area has a long and variably complex tectonic history, which is yet to be fully understood. Numerous geochronology studies have been completed at various scales throughout northern Australia over several decades; however, these data are scattered amongst numerous sources limiting the ease with which they can be used collectively.

To address this, over 2000 U–Pb ages from the Northern Territory, Queensland and eastern Western Australia have been compiled into a single, consistent dataset. Data were sourced from Geoscience Australia, State and Territory geological surveys and from academic literature. The compilation presented here includes age data from igneous, metamorphic and sedimentary rocks. Thematic maps of magmatic crystallisation ages, high-grade metamorphic ages and sedimentary maximum depositional ages have been generated using the dataset. The maps allow for spatial and temporal trends in the rock record to be visualised up to semi-continental scale. Further, the integration of U–Pb age maps with other isotopic, structural, geochemical and geophysical thematic maps enables a visual multi-component approach to better understand the geological evolution and resource potential of northern Australia.

P036. INTERPRETING GEOLOGY FROM GEOPHYSICS IN POLYDEFORMED TERRANES: THE OTAGO SCHIST, NEW ZEALAND

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Acquisition of airborne geophysical data across Otago, New Zealand, presents a unique opportunity to explore in detail the subsurface geometries of the Otago Schist, a polydeformed Mesozoic belt. A relationship is known for hard-rock Au (±W) occurrences with increasing metamorphic grade across the exhumed metasedimentary belt, though structural controls are less clear at a regional scale. Using new geophysical data, this study aims to identify the structural controls leading to mineralisation in the schist within the broader framework of the tectonic evolution of the South Island since ca. 150 Ma. Interpreting geology from geospatial data requires critical assessment and integration of this data with detailed structural field mapping and other geochemical and petrophysical analyses. This workflow aims to identify lithology distributions, patterns and anisotropies resulting from tectonic juxtaposition and the development of structural fabrics at regional scales. The Otago Schist preserves a complex history of deformation and metamorphism beginning with terrane accretion to southeastern Gondwana in the Paleozoic, to the present dextral translation of terranes along the Australian-Pacific plate boundary. This study presents for the first time a detailed geological interpretation of 3-dimensional geometries of the Otago Schist using regional geophysical data and places it in a regional tectonic context for the crustal assimilation and deformation of the South Island.

P037. HOW TO ACCESS NEW SOUTH WALES GEOPHYSICAL DATA

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The Geological Survey of New South Wales (GSNSW) is custodian of geophysical data sets acquired by private companies and the NSW government. Many are open file, free and can be accessed via the GSNSW website.

NSW government acquired surveys (magnetic, radioelement, digital elevation model and ground gravity surveys) can be accessed using the Geoscience Australia GADDS portal or purchased on portable hard drive. The hard drive also includes government hyperspectral, airborne electromagnetic and airborne gravity gradiometry data.

Statewide merges of NSW government surveys and open-file company data are available through the Geoscientific Data Warehouse (GDW) (and portable hard drive). Seven different geophysical images, displaying magnetic, gravity, radiometric and geothermal data, can be downloaded for use in Google Earth, as mobile phone maps, or for use in common GIS platforms. The GDW can also clip statewide images to your project area.

The 250K geophysical imagery suite was generated to enhance subtle features not readily visible in statewide imagery. More than 20 types of geophysical georeferenced imagery have been

generated for each map sheet area and are available through the DIGS online system.

Company geophysics includes geophysical data acquired by exploration companies and submitted to the NSW Government as part of exploration reporting requirements. The NSW Government recently legislated that all data must become open file five years after submission. Data submitted before June 2016 will become available in June 2021. These data commonly have higher resolution than government-acquired regional surveys and can be searched and discovered using the MinView online system.

P039. ELECTRICAL RESISTIVITY MAPS OF THE AUSTRALIAN LOWER CRUST

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Crustal silicate rocks at sub-solidus temperatures normally have high electrical resistivities. However, although upper crust is typically >1000 Ω.m, it is not unusual for lower crust to be <100 Ω.m, and in places ~1 Ω.m. That lower crust (below 15 km) can be as electrically conducting as seawater is remarkable, and indicates a substantial and highly-connected mineral, melt or aqueous phase. To date, temporal and spatial mechanisms to give rise to the low resistivity are speculative and poorly constrained by observation and laboratory measurement.

We present new maps of the Australian lower crust resistivity. The project addresses the question as to whether the low resistivity is primary in the formation of the crust, or overprint due to melt and fluid migration from a deeper thermal source. A secondary question is how regions of low resistivity from an interconnected phase can be preserved through time-scales of billions of years. Observations are drawn from: the Australian Lithospheric Array Magnetotelluric Project (AusLAMP); 2D MT transects, and legacy MT and geomagnetic depth sounding (GDS) data.

Our research demonstrates a strong spatial correlation of lower crustal resistivity with tectonic domains in Australia. Lowest resistivities are often imaged just below the rheological boundary between upper and lower crust at ~15 km. Below, low resistivity is often imaged as a broad zone, tens of kilometres wide and thick; above the boundary, regions of low-resistivity appear as narrower pathways. We show a strong spatial correlation between gradients of lowest crustal resistivity and major mineral systems.

P040. WHY DO WE NEED TO KNOW THE ELECTRICAL RESISTIVITY STRUCTURE OF OCEANIC LITHOSPHERE?

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Regional-scale continental MT programs such as AusLAMP are naturally bounded by continental shelf and oceans. Within a few hundred kilometres of the coastline, long-period MT data are strongly influenced by conductive seawater. Thus, 3D modelling of the continental lithosphere requires good constraints on the resistivity of the seawater, oceanic crust and upper mantle, and into the asthenosphere where there are no data.

Oceanic lithosphere is generated at mid-ocean ridges with the extraction of melt and volatiles from upper mantle. With distance, oceanic lithosphere thickens as the plate cools. In contrast to continental lithosphere that undergoes cycles of deformation and magmatism over billions of years, oceanic lithosphere exhibits more uniform properties across all basins, and varies in age by at most 200 million years.

However, determining the resistivity of oceanic lithosphere from seafloor long-period MT is surprisingly difficult. Primarily, this is because oceanic lithosphere is depleted of conducting phases during formation, and is very electrically resistive (>10 000 Ω.m). As a consequence, all coastlines boundaries, thousands of kilometres away from seafloor MT sites, will distort the observations.

In this paper, we show that analytical and 3D models of the entire Pacific Ocean are required to reproduce observations on 30 Ma seafloor about 1000 km from the coastline of California. By allowing for distortion at the surface, we show that the oceanic lithosphere resistivity is largely a function of conduction in olivine with temperature. We demonstrate that this new oceanic lithosphere resistivity is very important in 3D AusLAMP models in defining the continental properties.

P041. CONSTRAINING AIRBORNE ELECTROMAGNETIC REGOLITH MAPPING WITH LANDSCAPE EVOLUTION

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A typical product from an airborne electromagnetic (AEM) survey is a conductivity depth image (CDI) along each of the flight lines. These CDIs overcome the problem of non-uniqueness by choosing one model that fits the data, typically a smoothest model. However, in the case of using AEM for mapping regolith, an understanding of the landscape evolution processes that formed the regolith gives us knowledge about what the stratigraphic units are that make up the regolith, and also something about their likely geometry. In addition, knowledge of their mineralogy tells us something about their likely ranges of conductivity, and understanding of the processes that formed them tells us about their geostatistical properties. For example, materials which are well mixed, such as channel clays, will typically be homogeneous over large distances, whereas material that has formed by *in situ* weathering could be much more heterogeneous. It therefore makes sense to try to invert the AEM data for stratigraphic boundaries and conductivity variations within stratigraphic units rather than smooth models. This immediately gives estimates, with uncertainty bounds, for the depths to various interfaces, which are of more direct interest to a geologist than the conductivity values in the CDI.

The work presented here shows how the use of this information can produce improved inverted models of the regolith from AEM data. A better understanding of regolith structure then allows for optimisation of drilling sites for geochemical sampling, focussing on stratigraphic units where the geochemical footprint of an orebody is likely to have been concentrated.

P042. DEVELOPMENT OF THE MTPY SOFTWARE PACKAGE FOR MAGNETOTELLURIC DATA ANALYSIS

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The magnetotelluric (MT) method is increasingly being recognised as a valuable geophysical technique for exploration, as data analysis and inversion tools have become more sophisticated. However, the software available for MT data processing and analysis is still very limited in comparison to other geophysical methods such as gravity, magnetic and seismic. Using such software often requires specialist knowledge, and this has impeded the widespread use of this technique.

MTpy is an open source software package, originally developed at the University of Adelaide to assist with MT data processing, analysis, modelling, visualisation and interpretation. Written in Python, it contains modules to carry out much of the processing and analysis that needs to be applied to MT data, working with the industry standard EDI file format amongst other formats. It also contains modules to create inputs, and visualise outputs, from many of the inversion codes that are currently in use in the MT community. However, despite continued development of this software, it is still largely untested, and contains bugs and gaps. These factors, together with a lack of user interface, have limited its use in the wider MT community to date.

Geoscience Australia (GA) is continuing development of MTpy to improve its functionality and provide increased user support. The aim in doing this is to provide software to the MT community that will make it easier to work with MT data and thus facilitate the use of MT as an exploration method.

P043. DETRITAL ZIRCON ANALYSIS FROM THE GALILEE BASIN, QUEENSLAND

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Little is about the effects of the Permian onset of the Hunter-Bowen Orogeny on sedimentation patterns in the Galilee Basin of Queensland. Through a comparison of age populations of detrital zircon grains in sandstone of the Galilee Basin, a potential shift in sediment provenance has been recognised. One key well (OEC Glue Pot Creek 1) was selected from the Galilee Basin for detrital zircon analysis. This well intersected both Cisuralian (early Permian) and Lopingian (late Permian) strata. Nine sandstone samples were collected (three from the Cisuralian and six from Lopingian) and zircon grains were extracted. U-Pb isotopic data was gathered using the Laser Ablation – Inductively Coupled Plasma Mass Spectrometer (LA-ICPMS) technique.

A total of 271 concordant ages were obtained from the nine samples. The Cisuralian samples a varied age population range, with multiple peaks between 300 and 1200 Ma, suggesting numerous sources and orogenic recycling. In contrast, the Lopingian samples have a dominant peak of 250 to 300 Ma zircons, with a singular minor peak of 1500 Ma zircons, suggesting a transition in provenance between the Cisuralian and Lopingian. This transition corresponds with the onset of the Hunter-Bowen Orogeny and may mark a change in the tectonic setting of the Galilee Basin from an earlier back-arc (extensional) setting to a subsequent foreland basin position.

P044. SQUARE-WAVE PROCESSING OF MEGATEM DATA

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The recording of raw or streaming data, as done by CGG during a MEGATEM survey, allows for the reprocessing of the acquired EM data, including square-wave processing. During the latter, the recorded EM response to the actual half-sine waveform is replaced by the EM response to a square-wave, derived via deconvolution/convolution in the frequency-domain. This makes the on- and early-time information more accessible for data modelling, including 1D inversions and conductivity-depth transformations. Square-wave EM data can also be corrected for survey height, transmitter-receiver offset and transmitter attitude. That correction allows for the interpretation of early-time EM response grids, which generally offer better spatial resolution than derived conductivity-depth slices.

The advantages of square-wave processing are demonstrated on a MEGATEM data set acquired in 2013 in South America. With survey terrain clearance ranging from 100–1600 m, due to the rugged topography, early-time grids of elevation-corrected square-wave data outlined the shallow conductivity structure, whereas early-time grids of the original half-sine data mostly reflected the variable system elevation. Further, derived conductivity-depth sections of the square-wave data show more continuity than the sections derived from the original half-sine data. These results show that the early-time information of square-wave is more accessible than in the original data, facilitating interpretation of shallow conductivity structures.

P045. MERCURY AND SOIL CARBON DIOXIDE ANALYSIS TO DETERMINE GEOTHERMAL RESOURCES IN MT TELOMOYO, CENTRAL JAVA, INDONESIA

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Mercury and soil carbon dioxide are elements that can be used to determine the approximate of geothermal resources. The elements are commonly present in geothermal fluids and can migrate to the surface. The study area is located in Mt Telomoyo, Central Java Province. This area is located approximately 400 km east-southeast of Jakarta. Around the mountain, four hot springs and four cold springs were found, also 144 soil samples were taken. The study aims to determine geothermal resources using soil and fluid geochemistry analysis. In this study the geothermal prospect zone is determined using mercury and soil carbon dioxide analyses of soil samples from the Mt Telomoyo area. Geoindicators and geothermometer calculations on the geothermal surface manifestations and fault-fracture density mapping are used. The result zones were

then overlain to create the prospect zone. After that, the area value of the prospect zone was applied in the formula to calculate geothermal speculative resources of the study area. The results of this research show the geothermal prospect zone is located at the northern side of the Mt Telomoyo and the area is about 5.65 square kilometres. Based on the geothermometer calculation, the geothermal area of Mt Telomoyo has high enthalpy with a reservoir temperature about 236–250ºC. From the calculation of all existing data obtained geothermal resources in the Telomoyo area are about 84.7 MWe.

P046. EXPLORING MAGNETOTELLURIC MODEL SPACE

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Magnetotelluric (MT) inversions are inherently non-unique. Due to the large computational requirement of 3D MT inversions, there is often a trade-off between exploring model space and the amount of time invested in the inversion process. A standard approach is a 2 stage inversion, where the coarse features are resolved in the first inversion. The output from the coarse inversion is then used as the starting model for a finely discretised final inversion. Inversion may be followed by a combination of sensitivity analysis and forward modelling to test the robustness of features returned during inversion. This approach leads to a low RMS model but has a limited capacity to explore the range of potential models.

In this paper, we compare inversion results from a range of inversion parameters. Three inversions were run using a starting half space with only the input data varied: one inversion using the un-rotated full tensor and tipper data; one inversion using only the tipper data; and the third inversion using the rotated tensor and tipper data.

In addition to these half-space models, two inversions were run using starting models based on geological constraints. One used three domain boundaries with roughness penalties turned off between units. The other starting model was subdivided into fault blocks and roughness penalties between blocks eliminated. Resulting inversions explore a larger section of model space than more typical workflows.

P047. USING DOWNHOLE RESISTIVITY TO BETTER UNDERSTAND MAGNETOTELLURIC INVERSION

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Previous studies have used downhole resistivity either as a direct constraint during magnetotelluric inversion or as a qualitative validation of inversion accuracy. This study instead uses synthetic magnetotelluric data based on downhole resistivity to better understand inversion results in the context of a depth to basement study.

One-dimensional models with representative geology for the area were generated directly from downhole resistivity data. These models were used to generate synthetic data, which was then inverted using a range of methods. The synthetic modelling made a significant contribution to selecting an appropriate inversion technique and the quality of the interpretation.

Joint use of 1D and 2D inversion proved the most effective combination to understand the geology of the project area. The synthetic modelling also enables production of realistic error bars on the interpretation.

P048. 3D AIRBORNE EM ANISOTROPIC EFFECT AND IDENTIFICATION MODELING BY SE METHOD

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Spectral-element (SE) method is a kind of higher-order finite-element method based on weighted residual technique; however, the basis functions for SE are polynomial, like Gauss–Lobatto–Legendre (GLL) or Gauss–Lobatto–Chebyshev (GLC) polynomials. Because of its high modeling accuracy and flexibility, it has been successfully used in computational electromagnetism. In this paper we use the SE method for 3D frequency-domain airborne electromagnetic (AEM) modeling for an anisotropic earth and we take horizontal coplanar and vertical coaxial coil systems as example for the modeling. We first derive the discrete governing equation from Maxwell equations, in which the conductivity tensor is obtained by 3 Euler rotations of a principal conductivity tensor. GLL polynomial is selected as the vector SE basis functions, while GLL integration is applied for calculating matrix elements. A direct solver is used for the solution of the matrix equations system. The modelling accuracy is checked against a semi-analytical solution. Further, we calculate AEM responses for different anisotropic models and demonstrate that SE method can obtain high precision by either increasing SE order or refining meshes, so that it can save computation cost vastly. Numerical results further confirm that the anisotropy of both 3D body and host rock can be identified from the polar plots of ratio of magnetic field components.

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P049. TRANSCONTINENTAL CENOZOIC PALEOVALLEYS OF WESTERN AUSTRALIA

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Transcontinental palaeovalleys 800–2400 km long straddle the modern landscape of Western Australia (WA). These valleys formed following emergence of the Canning Basin at the end of the Lower Cretaceous, and reached their greatest development during Eocene time. They owe their preservation to limited erosion/burial and to an overall drying climate since the Upper Cretaceous. They represent the largest network of inactive valleys visible at the Earth's surface.

They connect at their downstream end to well-dated depocentres and palaeo shorelines, which provide their age and firm milestones on their temporal and spatial evolution. The geometries of the drainage network and of the valleys' long profiles constrain the timing of long (~1000 km) to intermediate wavelength (~200 km) variations in uplift rate over the continental interior since the Upper Cretaceous. We use them to document the respective contributions of regional tectonics and dynamic topography to the evolution of the Northwest Shelf. Uplift determined the shape of the drainage that initially grew over the emerging landmass. The changing uplift field later triggered drainage rearrangements during the Cenozoic. Rearrangement resulted in piecemeal rerouting of surface sediments and groundwater, with progressively increasing the area shedding to the Northwest Shelf.

Increasing aridity during the Neogene contributed to the tectonic defeat of the rivers. We use the *Badlands* software developed by the Basin Genesis Hub to quantify sediment and water delivery to the North West Shelf, and to constrain the development of aridity in the continental interior, which we find to be quite advanced by the Early Miocene.

P050. MAGNETIC IMAGING OF ULTRAMAFIC BODIES ON THE SITE OF THE OHI NUCLEAR POWER STATION, CENTRAL JAPAN

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The Ohi nuclear power station is located at the northern Oshima Peninsula in the Wakasa Bay on the coast of Japan Sea, central Japan. The geology of the site of the power station is composed mainly of shales, diabases, gabbros and ultramafic rocks of the Paleozoic Yakuno Ophiolite. Ultramafic rock is a key geology since fracture zones in the study area can be found only in the ultramafic bodies.

To map the distribution of ultramafic bodies, we conducted magnetic surveys on ground and at sea around Daibahama beach. A ground magnetic survey was carried out on a grid and along specified lines on a small peninsula and some reeves by using a proton magnetometer. A seaborne magnetic survey was also conducted by a small rubber boat on which a Cesium magnetometer was mounted. Both measured data were merged and IGRF residual magnetic anomalies were reduced onto a smoothed surface at an altitude of 2.5 m above ground and above sea level at sea assuming equivalent anomalies below the observation surface.

3D magnetic imaging has been applied to the magnetic anomalies and the magnetic structure is generally associated with a dipping-dike by a previous 2D modeling. A reversely magnetised body was imaged with a seaward dip below the surface along the 2D profile but has a horizontal limitation. This means the magnetic imaging is helpful to reveal the three-dimensional subsurface structure of the area.

P051. USING HYDROGEOPHYSICAL TECHNIQUES TO CHARACTERISE AND MAP SEA WATER INTRUSION AND PREFERENTIAL FLOW PATHS IN HOWARDS EAST AQUIFER, DARWIN RURAL AREA, NORTHERN TERRITORY

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In the Howards East Aquifer (HEA) in Darwin's Rural District, groundwater resources in a dolomitic and karstic aquifer system provide important water security for Darwin and a large horticultural industry. Previously (2011), a widely spaced (550 m) regional airborne electromagnetics (AEM) survey in this area mapped conductivity anomalies that were interpreted as potential zones of seawater intrusion (SWI) coincident with major fault zones. Subsequent drilling confirmed elevated groundwater salinities in some bores marginal to the main aquifer. It was recommended that more detailed investigations be undertaken to better define the SWI risk.

The Howards East Project is an inter-disciplinary study which focussed on delineating and characterising the present SWI interface and potential future hazards from sea water intrusion. The Project is funded by Geoscience Australia (GA) as part of the Exploring for the Future (EFTF) Program. New data acquisition includes 2096 line-kilometres of 100 m line-spaced AEM and airborne magnetics data, ground magnetic resonance (GMR), and borehole nuclear magnetic resonance (NMR) data, drilling and pump testing; and hydrochemistry. The main aims of this study are to: (1) delineate potential SWI zones; (2) quantify the porosity, permeability and transmissivity of the Koolpinyah-Coomalie Dolomite aquifer along potential fault zones (coincident with magnetic anomalies) and (3) identify other structural and/or sedimentological preferential flow paths or barriers to ingress.

This paper reports on: (1) initial AEM inversion results and spatio-temporal changes in groundwater quality arising since acquisition of previous AEM in 2011; and (2) the interplay between the sea water intrusion interface and structural/sedimentological flow paths/barriers.

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P052. MIDDLE ORDOVICIAN CONODONTS AND FISH FROM THE STAIRWAY SANDSTONE, AMADEUS BASIN

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The Middle Ordovician Stairway Sandstone consists of a succession of siliciclastic shallow marine sediments,

stratigraphically positioned between the dark organic-rich siltstones of the Horn Valley Siltstone, and the regressive siltstones and shales of the overlying Stokes Siltstone, in the Amadeus Basin. The Stairway Sandstone is notable for containing early arandaspid fish fossils, and is a prospective reservoir for Larapinta Petroleum System hydrocarbons. The unit has not been directly dated, but a field sample from the uppermost Stairway Sandstone has yielded an abundant and well-preserved fauna, including micro-vertebrate and conodont fossils that enable correlation to high resolution international conodont biozonation schemes. Vertebrate microfossils represent three agnathan genera, *Arandaspis*, *Porophoraspis* and *Sacabambaspis*. Conodont species include *Microzarkodina ozarkodella* and *Baltoniodus medius*; index fossils that allow correlation to the upper subzone of the *Eoplacognathus pseudoplanus* Zone of the Middle Darriwillian. The conodont fauna also includes stratigraphically wide-ranging larapintine species, as well as endemic forms and new species. The abundance of the fauna, and the presence of *Erraticodon*, indicates sea-level rise at the time of the latest Stairway Sandstone deposition. The global Stein Lowstand event, represented by a hiatus at the top of the Horn Valley Siltstone and the subsequent shallow or aeolian influence over the lower and middle parts of the Stairway Sandstone, occurs at 463.71 ma, and the top of the *E. pseudoplanus* zone occurs at 462.52 ma (GTS2016). The intervening time constrains the end depositional age of potential reservoir sands of the Stairway Sandstone, and age of the earliest Gondwana fish fauna.

P053. THE CONDUCTIVITY STRUCTURE OF THE GEORGINA-ARUNTA REGION FROM MAGNETOTELLURICS

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The 09GA-GA1 deep magnetotelluric (MT) and seismic survey was collected in 2009 under Geoscience Australia (GA)'s Onshore Energy Security Program. The survey, also known as the Georgina-Arunta line, extends approximately north-south across the Georgina Basin, Irindina and Aileron provinces of the Arunta Region, across the Casey Inlier and onto the northeastern Amadeus Basin.

The MT data comprise 39 broadband stations with a spacing of 10 km, and 17 long period stations spaced 20 km apart. In 2009, the broadband data were processed to a period range of 0.04 to 100 s, while the long period data were processed to a period range of 10 to 10 000 s. Preliminary 2D inversions were carried out; however little was done in terms of geological interpretation of these inversions.

As part of GA's Exploring for the Future program commencing in late 2016, the broadband MT data have been reprocessed, giving an extended period range of 0.04 to 1000 s. The data have been merged with the long period data. The phase tensor ellipses correlate well with the mapped geology. Inversions have been carried out in 2D using the Occam inversion code, and in 3D using ModEM. The conductivity structure revealed by these inversions show consistency with the results of the deep seismic reflection survey carried out in this area, and reveal new insights into the conductivity structure of the key geological domains crossed by this survey.

P054. METAL MOBILISATION DURING WATER REACTION OF THE ROSENEATH AND MURTEREE SHALES OF THE COOPER BASIN

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Production or flow-back water from shale gas stimulation has been reported in the USA to have high salinity, TDS and variable concentrations of potentially toxic metals such as uranium, barium, or lead. A few studies have performed experiments to understand the controls on metal mobilisation from gas shale, mainly for the Marcellus shale. The Roseneath and Murteree shales of the Cooper Basin REM sequence have a high prospectively for unconventional gas. Water reactions of shale core samples were performed under mildly oxic conditions and at elevated temperature (75°C) and pressure (200 bar). The shales both contain (Mg)-siderite, quartz, illite/muscovite and kaolinite with traces of pyrite. The Roseneath shale core contained sphalerite, and the Murteree core a higher proportion of siderite and also ankerite. A relatively higher concentration of lead, vanadium, chromium, zinc and copper, was measured in the Roseneath shale, which on water reaction mobilised a higher concentration of uranium, cadmium, cobalt, chromium, zinc, copper and nickel. Mobilised metal concentrations were, however, mainly <10% of the amount available in the core. Higher concentrations of calcium and sodium were mobilised from the Murteree shale. SEM-EDS and geochemical modelling indicated that the carbonates were most reactive, with dissolution creating pores in the Roseneath shale. Fe-rich precipitates were also formed in both cases. We found the presence and type of carbonate and sulphide minerals have a strong control on water chemistry and generated acidity. This is in agreement with other studies on black shales from Germany, and the Marcellus shale, USA.

P055. DRAINED PORE MODULUS DETERMINATION USING DIGITAL ROCK TECHNOLOGY

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Geomechanics helps us understand the life-cycle of a hydrocarbon reservoir and, in turn, impacts geophysical monitoring programs. One common problem is to predict reservoir compaction. This estimation uses static poroelasticity parameters. We present a digital rock workflow to determine poroelastic parameters that are difficult to extract from well log or laboratory measurements. For the compaction problem, the drained pore modulus ($1/K_p$) is determinant. This modulus is the ratio of pore volume change to confining pressure when the fluid pressure is constant

$$\frac{1}{K_p} = -\frac{1}{V_{p0}} \frac{\partial V_p}{\partial p^c}\bigg|_{p^f = 0} \quad (1)$$

V_{p0} is the initial pore volume. In laboratory experiments, bulk volume changes are accurately measured while pore volume changes are notoriously difficult to measure. Hence, determining the drained pore modulus is challenging. We simulate static

deformation experiments at the pore-scale utilising digitised rock images.

We model an Ottawa F-42 sand pack obtained from X-ray micro-tomographic images. We stack 2D micro-CT images to generate the 3D F-42 sand pack sample. We extract a sub-volume from this sample to model numerically. The small sample consists of grains and pore spaces, which are segmented and used to generate a volumetric mesh. We compute the elastic, linear momentum balance in the structural domain (grains) and solve the system using the commercial software package ABAQUS. The grains are assumed elastic, isotropic, and homogeneous. We calculate the change in pore volume using an in-house post processing tool, which computes the change in pore spaces due to applied load. Finally, the drained pore modulus is obtained using equation (1).

P056. OPTIMUM IMAGE RESOLUTION OF A MICRO-CT IMAGE TO CHARACTERISE SHAPE DESCRIPTORS AND MICROSTRUCTURE OF AN UNCONSOLIDATED SAND

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The quality of a micro-CT image and its resultant quantitative outputs are highly dependent on spatial resolution. High resolution images of an unconsolidated sands, which are common reservoirs for petroleum and groundwater, capture the outer voxels of the grains in so much detail that they can provide accurate shape characteristics such as sphericity and roundness. However, in the high resolution images, the trade-off is the number of imaged grains, as the numbers might be too small to be representative of the whole volume. To get an acceptable result from micro-CT images without compromising the representativeness of the sample, we need to determine an optimal resolution on the basis of grain size distribution and shape complexity prior to image acquisition.

Comparing grain shape characteristics in the same sample at a different resolution, we find that the sphericity and the roundness show lower and higher values respectively. Moreover, other microstructural properties such as coordination number and contact surface area show lower values. The number of boundary voxels that delineate the grains' perimeter is responsible for this difference in results. To mitigate this discrepancy in choosing a standard result, we are studying sand particles with different sizes and shapes captured at a range of resolutions. Our goal is to get the optimal resolution of an image with respect to any particular grain size, shape and microstructural properties. This optimum image resolution can help acquiring images with appropriate resolution to study reservoir characterisation from micro-CT image analysis.

P057. COUPLED MEASUREMENTS OF HYDRAULIC PERMEABILITY AND FULL STIFFNESS TENSOR COMPACTION TRENDS IN ARTIFICIAL SHALES

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The knowledge of compaction trends of elastic and hydraulic properties of anisotropic shales is crucial for energy resources exploration, nuclear waste disposal and hydrogeological applications. However, complexity of the natural shale mineralogy and shortage of quality data available for analysis results in lack of understanding of these compaction trends.

This deficiency was to some extent compensated with compaction experiments on artificial shales. However, these experiments usually limited to measurements of compressional and shear velocities normal to bedding. Here for the first time we present methodology and describe a setup that allows simultaneous acquisition of all five independent elastic constants and extremely low hydraulic permeability values of transversely isotropic artificial shale samples during mechanical compaction experiments (porosity ranges from 40% to 15%).

Hydraulic permeability values of artificially compacted samples are comparable to those of natural shales. Permeability drops exponentially with compaction. Silt fraction and clay mineralogy are the two key parameters that are responsible for broad variations of permeability in shales with the same porosity. We provide analytical equations that allow calculating permeability if porosity and silt fraction are known.

Elastic constants of clay matrix exhibit positive linear trends with the porosity decrease. Small variations in clay mineralogy have a minor effect on absolute values of elastic coefficients or anisotropy but lead to noticeable increase of the compressional (V_p) to shear (V_s) velocities ratio at the same porosity. Finally, strong correlations (R^2 above 0.95) of the hydraulic permeability with acoustic impedance and V_p/V_s ratio are observed for all the prepared samples.

P058. A COMPARISON OF CONVENTIONAL BOREHOLE TOOLS AND DISTRIBUTED ACOUSTIC SENSING AT A DEDICATED FIELD LABORATORY

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Distributed Acoustic Sensing (DAS) uses standard telecom fibre optic cables to detect acoustic signals. The technique utilises optical time-domain reflectometry; a 'light-box' measures the light backscattered from a series of laser pulses emitted into the fibre. As acoustic waves impinge on the cable, the fibre is strained, causing variations in the time taken for the backscattered light to travel back up the fibre. The acoustic signal can then be reconstructed by analysing phase differences in the backscattered light. DAS is especially suited for VSP applications, as it offers significant efficiency advantages when compared to conventional borehole acoustic sensors. Conventional VSP surveys usually take an extended period to acquire as the tools need to be placed in multiple positions in the well to record data. With DAS, the complete fibre is a sensor, and thus all levels are acquired simultaneously, and no tools are required, reducing the cost considerably. In this work, we compare the results of acquiring a VSP survey using three difference sensors: DAS, a conventional 3-component geophone tool, and a conventional hydrophone tool. The datasets were acquired in a 900 m deep, vertical well, located on the campus of Curtin University in Perth, Western Australia. Results show that DAS approached the quality of a conventional geophone VSP survey, and presented superior quality when compared to hydrophones.

Downhole Assay: A game changer for the mining industry

Huw Rossiter (Kinetic Logging Services), Vincent Flahaut (Sodern)

From exploration to mining, quantifying grade and tonnage of the mineral resource requires an enormous effort. Collection of geochemical data is achieved by drilling to sample the ore body. This generates a huge amount of samples, and significant costs and time in preparation and assay. A new technology to the mining industry – The FastGrade™ Pulsed Fast & Thermal Neutron Activation (PFTNA) has been proven to have several advantages over conventional sample based assays including improving safety through reduced site exposure to manual handling, the measurement size of the sample, depth accuracy, cost, and reducing the cycle time for results from up to months to almost immediately once the hole has been logged with the tool.

Figure 1. The FastGrade™ being run in hole

Introduction

Currently 100mm diameter tools are primarily run in iron ore where the tools are being used to log in excess of 150km / year. One major resource company has stated that the tool has saved them in excess of USD 10 million in a year. The main elements measured for iron ore are shown in figure 2. The chart shows typical results compared against 3m sampled reverse circulation (RC) holes assay data (column 2) across the range of values (columns 3 and 4)

	RMSD Validation 3 m	Min%	Max%
Fe	2	0	70
SiO2	2,5	0	90
Al2O3	1	0	35
TiO2	0,1	0	4
Mn	0,2	0	10
MgO	0,5	0	30
CaO	0,5	0	60
S	0,1	0	15
K2O3	0,15	0	10
Na2O	0,02	0	1
C	0,2	0	15
O	1	30	60
H	0,15	0	3
LOI	1,5	0	50
P	Not representative		

Figure 2: FastGrade™ vs RC sample assays

Minor elements can also be measured depending on ore grade – these include some of the base metals such as Cu or Ni, and also elements such as potassium and chlorine. The FastGrade™ is currently being scheduled to be demonstrated in a selection of base metal deposits that will show how the tool can provide value across a wide resource base.

A key component of the tool is the pulse neutron generator. In contrast to a chemical source used in conventional neutron and density logging tools, without power the tool does not produce radiation. This removes the risks associated with exposure at surface and mining issues in the unlikely event that the tool is lost in hole.

Measurement Theory

The FastGrade™ technology uses an electronic pulse neutron generator source to emit neutrons that penetrate the surrounding rock and lose their energy when colliding with nuclei. As they penetrate, they initiate interactions according to the formation, as fast inelastic collisions or neutron capture that result, nearly instantaneously, in the emission of gamma photons. Each element produces photons with a set of characteristic energies, which is the key to identifying and

quantifying them. A high resolution, scintillating material coupled with a photomultiplier converts the photons into electrical pulses and a fast processing, specialized circuit digitizer sorts and counts them to build their spectrum.

At this point a computer can extract element footprints out of the spectrum to determine the chemistry of the formation.

Figure 3: SODERN sealed Neutron Tube

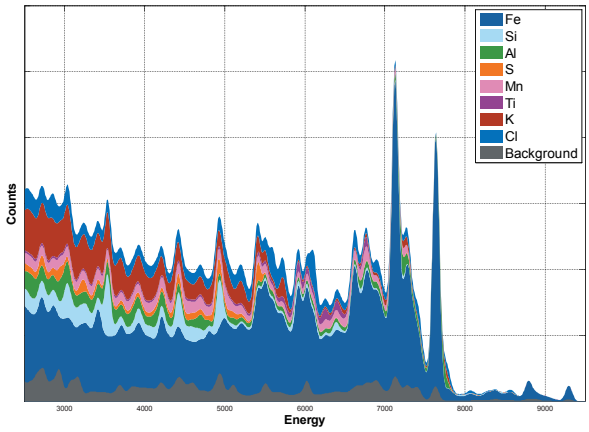

Figure 4: FastGrade™ Spectrum & individual elemental response

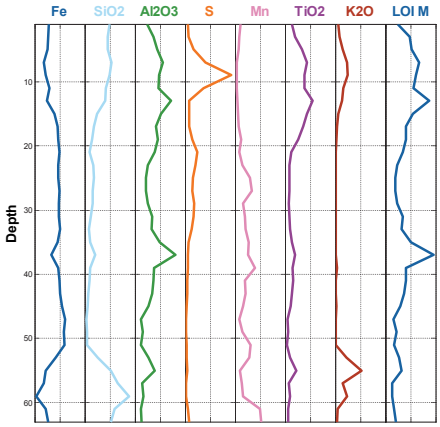

Figure 5: Multi elemental log

Measurement accuracy compared to conventional sampling

Using the FastGrade™ technology is fundamentally different to collecting a physical sample and sending it to the laboratory, and whilst there are limitations around the ability to accurately measure elements present in very small quantities the method of gathering data through this technique has many advantages when compared to physical samples gathered through the drilling process. These include:

- Accurate depth of sampling.
- No lost zones of data.
- No sample contamination.
- No damage to samples on surface.
- Almost immediate return of results.
- A large sample volume provided through the 30 – 50cm radius of investigation.
- The preservation of the natural profile variability when heterogeneous deposits are explored.

Figure 6. Damaged sample bags

Figure 7. Missing core

In figure 8, the accuracy of data from blasthole, RC and diamond drilling is shown versus the Fastgrade™ technology. It highlights the inherent accuracy deficiencies associated with the different methods of gathering physical samples. Whilst it can be seen that samples derived from diamond core drilling are superior to both RC and blasthole samples the method is still liable to core loss and the cost of diamond core drilling limits the amount of sampling that can be done within budget constraints. Therefore Fastgrade™ has the potential to replace all of these methods with a more cost effective, quicker and accurate way of gathering assay information in the correct geological environment.

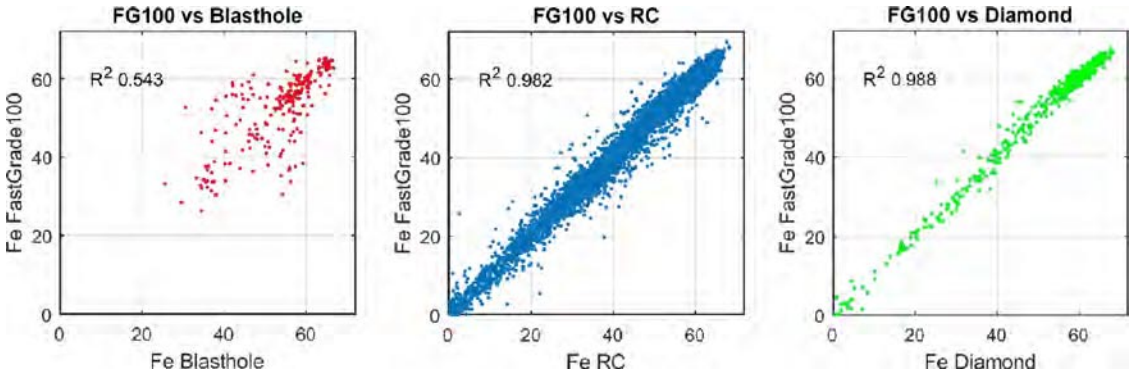

Figure 8. A comparison of FastGrade™ Fe% vs assay data from Blasthole, RC drilling and diamond drilling samples (Chi *et al.*, 2017).

RC drilling is often used in preference to diamond drilling due to the cost differential between the two techniques. Diamond drilled twinned holes drilled within 10m of an RC hole are commonly used to verify mineralisation identified by RC samples. The data is used to assess whether there is any sampling bias in the RC sampling technique (Chi *et al.*, 2017).

Figure 9, shows this technique can be flawed as the comparison of the data assumes the geometry of the geology is flat lying with consistent thickness, and that the inherent errors associated with both techniques are comparable.

In deposits where it is suitable, the use of the Fastgrade™ technology as an alternative to RC sampling would improve the accuracy of the data from the parent hole and remove the requirement for expensive twin hole drilling campaigns.

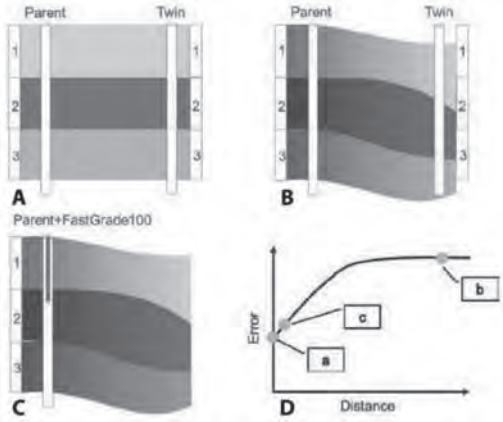

Figure 9. Flaw in twin hole pairing technique: (A) is the assumed case; (B) is a more realistic RC – diamond drilling case; (C) is the twinning case with a FastGrade™ tool under the same realistic conditions as (B); (D) demonstrates these concepts on a schematic semi-variogram type plot where we can see that as the distance between pairs increase, the error increase due to change in geometry and grade variability (Chi *et al.*, 2017)

Figure 10 shows how improving orebody knowledge through the use of Fastgrade™ to reduce the errors associated with sampling, can have major impacts on mining operations. The example which is based in an iron ore environment shows that reducing error associated with the grade assessment from 3% to 1% can have a significant impact on ore recovery.

The decrease in error leads to a reduction in stripping ratio and loss of ore, increasing the amount of ore that can be sold. This has the added benefit of reducing the environmental impact during operations through the reduction of waste at the minesite.

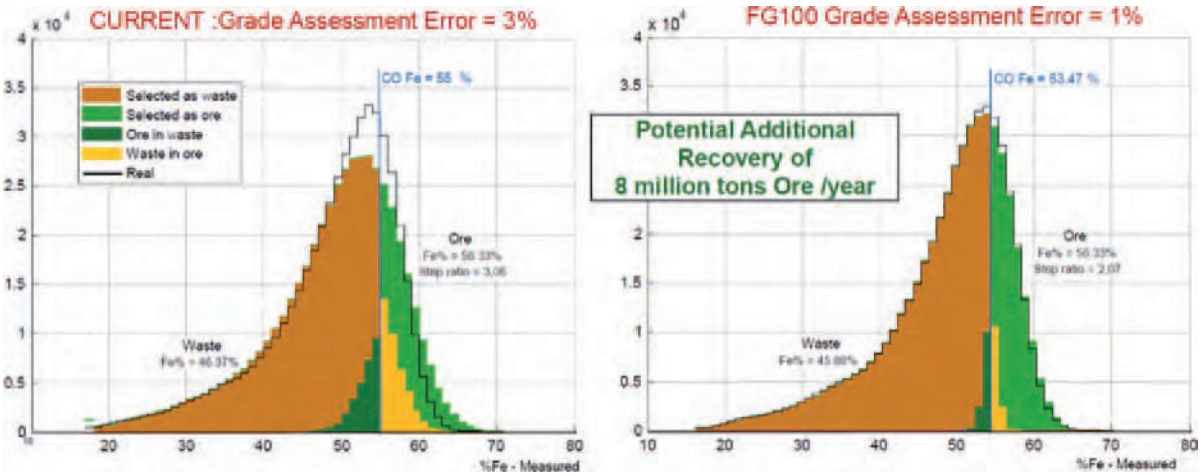

Figure 10. Showing how decreasing grade assessment error can lead to potential increased ore recovery

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Reference:

Chi, B. *et al.* (2017) 'Near real-time assay with downhole assay tool (FastGrade™ 100)', in *Eighth World Conference on Sampling and Blending*. Perth: AUSIMM, pp. 137–144.

P059. CARBON ISOTOPE FINGERPRINTING PALAEO FLUID INCLUSION GASES USING A CRUSHING-TRAPPING TECHNIQUE

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Carbon isotope fingerprinting has been widely used to study gas origin and maturity, and gas-source correlations. However, natural gas accumulation in gas reservoirs could be affected by secondary alteration processes. In contrast, palaeo gases trapped in fluid inclusions (FIs) are free of any secondary alterations that may have occurred in the reservoir. It can also provide more gas geochemistry information in an area where no or little geochemistry data is available due to a low exploration degree.

FIs are formed when crystals grow, usually trapping fluids such as oil, gas or water. FIs are normally less than 10 um in diameter, hence the gases trapped are at trace level amounts. Due to the analytical challenges involved in obtaining carbon isotopic signatures from such trace levels of gases trapped in FIs, very few papers have been published regarding carbon isotopes of FI gases. An online crushing-trapping system has been developed in this study, which mainly comprises of a gas-tight crusher and a gas concentrator. The micro-trap is the key aspect of the gas concentrator, which results in sharp chromatographic peaks, enabling carbon isotope analyses of high molecular weight hydrocarbon gases which are normally in low concentrations.

Compound specific carbon isotope analysis of hydrocarbon gases (C_1-C_5 except nC_4) and CO_2 released from a FI sample from the Cooper-Eromanga Basin was achieved for the first time as a proof of concept of the technique. Subsequently, preliminary research on FI gases have been carried out in Australia's Browse Basin and China's Sichuan and Pearl River Mouth Basins.

P060. INTEGRATED EARTH DATA INTERPRETATION WORKFLOW – A RECIPE FOR SUCCESS IN ONSHORE FRONTIER HYDROCARBON EXPLORATION

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The interior of Australia plays host to a series of vast sedimentary basins spanning c. 2.5 billion years of the island continent's geological history. Many of these basins contain significant reserves of both conventional and unconventional hydrocarbons. In addition to being active offshore, Santos Ltd has a long history of hydrocarbon exploration (generally as Operator) in several of the onshore basins, which notably include the Bowen, Gunnedah, Cooper, Amadeus and McArthur Basins. Frontier exploration involves various regional geological studies, these being geared towards deriving an early assessment of hydrocarbon potential and directing the geographical focus of future exploration work. Due to the general lack of data in the early exploration phase, much effort is expended in maximising the interrogation and understanding of all available open source and proprietary datasets. These typically include surface geology, surface elevation, surface vegetation, Landsat, gravity, magnetics, radiometry, existing seismic and existing boreholes (including water bores). The key to extracting every ounce of useful geological information from these data is through data integration and co-visualisation. To this end, Santos has developed a tried-and-tested regional exploration workflow, which often involves some novel visualisation techniques (e.g. use of 3D anaglyphs). This presentation will include discussion of basic workflows, the various data types and principles of data integration and interpretation, illustrated with numerous real-world examples from Santos' extensive exploration experience in several of the aforementioned basins.

P061. VOLCANICS: A COMMONLY UNDERESTIMATED PART OF PETROLEUM EXPLORATION

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The presence of volcanics and their impact on sedimentary rocks may lead to complex overprints for oil and gas exploration. They can provide both positive and negative effects on the petroleum system.

Positively, impermeable volcanic rocks can act as a barrier, or seal, to lateral or vertical hydrocarbon migration. Alternatively, volcanics with some permeability can serve as reservoirs. Negatively, circulating hot fluids, in the presence of organic rich source rocks, or where hydrocarbons are accumulated in traps, lead to unsuccessful wells.

It is therefore important to understand the origin of the volcanics as well as their timing with respect to hydrocarbon generation and migration from source rocks, and reservoir traps.

In the North-West Shelf (NWS) of Australia, volcanics are quite common and some wells have penetrated them by hundreds of metres. 3D seismic images of these features can dramatically demonstrate their morphology including features like ring dyke complexes.

Sometimes the interpreter is lucky and they are simple and easy to interpret on seismic data, however it's not always the case. The visibility of volcanics in seismic data depends on their acoustic impedance contrast in comparison to the sedimentary layers. If this contrast is not high enough (such as when the volcanics are highly weathered), then it's a challenge to map their spatial extent.

The presence of volcanics is documented by several operators including Woodside and Inpex at NWS: Anhalt-1 penetrated volcanics at its TD and cutting descriptions from Dinichthys North-1 indicates the presence of volcanic material, as another example.

P063. ANALYSIS ON BRITTLENESS CHARACTERISTICS OF TIGHT OIL SILTSTONES

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We obtain the basic parameters of the rocks of Qingshankou Formation by performing rock uniaxial and triaxial compression mechanics experiments. Different brittleness indexes are

computed and we select the best brittleness index of $B2$ (E/υ, Young's modulus/Poisson's ratio) to evaluate rock brittleness characteristics. The coefficient of brittle stress drop is introduced to evaluate rock brittleness characteristics, which coincide with the selected brittleness index. The relationships between brittleness indexes and rock parameters such as elastic parameters, mineral components and reservoir physical properties (porosity, and density) are analysed. Results show that E and υ are the good indicators of rock brittleness, while shale content has no obviously influence on the elastic parameters. Quartz and carbonate minerals are considered as brittle components for evaluating rock brittleness. There is a good correlation between the brittleness index $B2$ and reservoir porosity, which is important for analysing rock brittleness characteristics in the study area.

P064. FULL SPECTRUM GRAVITY – HIGH QUALITY GRAVITY DATA FOR ALL APPLICATIONS

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Over the last two years, CGG has introduced the Full Spectrum Gravity initiative. This merges the short to medium wavelength data from the Falcon Airborne Gravity Gradiometer (AGG) system and the medium to long wavelength data from the sGrav strap-down gravimeter. These complementary technologies allow for the delivery of sub-milliGal gravity data at resolutions from hundreds of meters up to hundreds of kilometers.

In this work, we demonstrate the acquisition and processing methods involved in Full Spectrum Gravity and the accuracy of the final data product. The long wavelength data is required first. The sGrav is used to create a free air anomaly gravity product. The accuracy of the data at various filter lengths (15–30 km) is evaluated to determine the optimal merging spatial wavelength for the sGrav and Falcon datasets. Using the sGrav data, free air anomaly differential curvature components are created.

Using the optimal wavelength as the cut-off frequency, a low-pass filter is designed to be applied to the sGrav curvature gradients and a high-pass filter is designed to be applied to the Falcon AGG curvature gradients. By combining these together, we create the Full Spectrum Gravity dataset.

In conclusion, we demonstrate the acquisition technologies and the processing methods to create the Full Spectrum Gravity data and demonstrate that it achieves sub-milliGal accuracy across the largest bandwidth of the gravity spectrum.

P065. A CLOUD-BASED WELL LOG DATABASE PROTOTYPE

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Geoscience data including seismic, well log, sensor and core measurements are fundamental for petroleum exploration. Due to recent advancements in sensor and computer technologies, the volume of this data is constantly increasing. Having a unified repository of this data of various types, structure and complexity is crucial for maintaining data integrity. This study addresses petroleum exploration data integrity issues. Current trends in data management technologies and current data practices in petroleum geoscience are explored and a practical data management solution to facilitate data access, storage and sharing is recommended. A prototype of a well log database was developed to demonstrate an example of a common repository for downloaded and sanitised data to avoid duplicate downloads from public websites by petrophysicists and make data use more efficient within a particular organisation. The prototype was developed using cloud-based technology and the PAWSEY supercomputing facility (a joint venture of CSIRO with Western Australian universities) for storing both the raw (.las and .DLIS files) and the sanitised well log datasets from Bonaparte Basin. PostgreSQL database was used to store the sanitised well log data, metadata and links to raw data. PostgreSQL architecture was selected for its ability to support advanced data types (arrays, JSON etc.), plug in to languages like Python, and link to PostGIS, a spatial database extender. A web-based graphical user interface was developed to view, upload and download well log data. In addition, meaningful metadata standards were established in collaboration with expert petrophysicists.

P066. EXPERIMENTAL AND THEORETICAL STUDY OF WATER RETENTION EFFECT ON ELASTIC PROPERTIES OF OPALINUS SHALE

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Understanding the elastic properties behavior of shales with saturation changes is important for the geological storage of nuclear waste and CO_2 sequestration as well as for development of conventional and unconventional shale oil and gas reservoirs. Existing data describing the effects of saturation on elastic properties of shales are sparse and contradictory. To improve understanding of the effects of changing water content on elastic properties in shales, we conducted an experimental study on Opalinus shale samples.

We measured vertical and horizontal ultrasonic P- and S-wave velocities on the same set of samples with controlled water content. The measured velocities were used to calculate components of elastic stiffness tensors in the shale at different saturations assuming its vertical transverse isotropy. Obtained results show increasing C_{11} and decreasing C_{33} with drying of the samples. Moreover, we observe 80% increase of shear moduli C_{44} and C_{66} with reduction of water content from 5.5% weight in the preserved state to 0.3%.

Conventional rock physics models are not designed to explain the observed dynamics. Here we develop a rock physics model suitable to describe these effects that takes into account (1) mechanical softening of the rock with substitution of saturating water with gas; (2) shrinkage of clay leading to reduction of microporosity and opening of interlayer fractures; (3) chemical hardening of clay particles; and (4) enhancing stiffness of contacts due to removing of water lubricant between clay particles.

P067. TIME-LAPSE SURFACE SEISMIC PROCESSING FOR STAGE 2C OF CO2CRC OTWAY PROJECT

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Stage 2C of the Otway project aims to establish capabilities of economic and effective seismic monitoring of geological storage of CO_2. Over the past two years, we produced five vintages of high-quality 4D seismic images of the injected CO_2 plume. We have also built reference 4D synthetics that are used to validate workflows used in the processing of the field data. These tested workflows allow rapid time processing of the time-lapse data and allow fast monitoring of small incremental injections (about 5000 tonnes each) of a CO_2-rich mixture into a saline aquifer at ~1500 m depth. The results show plume stabilisation one year after injection has finished. The quality of the field data and obtained images suggests that these data can be processed in 'true amplitude' sense. Onshore time-lapse processing is a difficult task that requires good understanding of how processing routines affect time-lapse signal. Using model-guided approach to processing, we now address issues of amplitude restoration, prestack imaging, and cross-equalisation of the 4D seismic data acquired with a permanent geophone array during Stage 2C.

P068. THE SEISMIC SIGNATURE OF RAIN

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Rain has long been a problem for land seismic surveys. I measured the seismic signature of rainfall using both water dripped from height using a pipette, and natural rain in Winchester, England, over a three month period. My results showed that rain noise is concentrated at frequencies above 80 Hz with a detectable range of less than 1 m. Drops of water landing directly on a geophone result in events with amplitudes nearly 30 times larger than those landing next to the geophone. Items placed on the surface of the ground, such as cables, absorb the energy of the impact and reduce the level of the resulting seismic noise. Burying geophones results in attenuation of rain noise by between 7.7 and 8.6 dB/0.1 m. But, given the effort required to bury geophones, it is likely that data processing algorithms, or the placement of vibration absorbent matting, are likely to be the preferred strategies for dealing with noise.

P069. NOISE IN URBAN LAND SEISMIC SURVEYS

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Although most frequently conducted in remote areas, seismic surveys in urban areas, or other settings with high seismic noise levels, are becoming increasingly common. Examples of the most frequent sources of noise encountered in such settings include electrical installations, vehicles, the wind, and aircraft. In this paper we describe the results of a variety of experiments conducted that aim to characterise the nature of the different noise sources and their relative contribution to the overall noise level. We then describe the effectiveness of a range of noise mitigation measures and develop recommendations for seismic surveys conducted in urban environments.

P070. SEISMIC SIGNATURES OF FRACTURED RESERVOIRS: THEORY VERSUS NUMERICAL SIMULATIONS

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Seismic dispersion and attenuation are potentially important attributes for the detection and characterisation of fracture networks. A primary mechanism for these phenomena is wave-induced fluid flow (WIFF), which can take place between fractures and the embedding background, as well as within connected fractures. In this work, we propose a theoretical approach to quantify the related seismic attenuation and velocity dispersion for rocks containing two orthogonal sets of fractures. The approach is based on existing theoretical models for rocks with aligned fractures, and we consider three types of fracture geometries: periodic planar fractures, randomly-spaced planar fractures, and penny-shaped cracks. Synthetic 2D rock samples with non-intersecting and intersecting fractures are then studied by both numerical simulations and the proposed theoretical framework. The numerical simulations are carried out using an upscaling method based on Biot's quasi-static equations of poroelasticity. The results show that the theoretical predictions are in overall good agreement with the numerical simulations. For the seismic dispersion and attenuation caused by WIFF between fractures and the background, the theoretical model for penny-shaped cracks matches the numerical simulation results best. On the other hand, for representing the effects caused by WIFF within connected fractures, the theoretical model for periodic planar fractures turns out to be the most suitable. The proposed theoretical approach is easy to apply in practice, and is applicable not only to 2D but also to 3D fracture system. Hence, it has the potential to constitute a useful framework for the characterisation of fractured formations, especially in the presence of intersecting fractures.

P071. 3D INVERSION OF LARGE SCALE MARINE CONTROLLED-SOURCE ELECTROMAGNETICS

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Three-dimensional controlled-source electromagnetic (CSEM) surveys can be a useful technique for oil and gas hydrate detection in marine environments. Electromagnetic waves are emitted from sources, and the ensuing electric and/or magnetic fields are recorded at one, or more receivers. The number, frequency and position of sources and the placement of receivers depends on the particular application. To recover the earth's conductivity, which can be either isotropic or anisotropic in nature, an inverse problem is solved.

A major issue with either an isotropic or anisotropic CSEM inversion is the computational cost associated with the solution of many linear systems of equations. This is a result of a large spatial domain with the potential presence of complicated bathymetry, as well as the existence of thousands of source and frequency combinations. Overall, there could be thousands or even millions of systems of equations to solve on expansive meshes. To assist with these numerical issues, we use ideas developed for airborne electromagnetic inversions. First, we incorporate a locally refined mesh for the forward problem, specifically optimised for a source and set of receivers. Second, we use stochastic programming techniques to solve the CSEM problem with many sources and receivers. These methods dramatically reduce the numerical cost of each forward model as well as the total number of simulations.

In this work we describe the methods used to overcome the computational difficulties and then demonstrate the techniques applied to field data sets.

P072. THE IMPACT OF WATER SATURATION ON THE ELASTIC ANISOTROPY DISPERSION IN THE WELLINGTON SHALE AT SEISMIC FREQUENCIES

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The anisotropic behavior of shales is commonly associated with the properties of a transversely isotropic (TI) medium, which are determined by five elastic constants such as five independent components of the compliance or stiffness matrix. In this study we utilise the laboratory low-frequency technique based on stress-strain relationship to measure the dispersion of five independent stiffness tensor components and Thomsen's anisotropy parameters of shale samples saturated with water at four different humidities in the range from 12% to 97.5% (12, 44, 72 and 97.5%). We have investigated three shale samples from the Wellington Formation cored along the horizontal, vertical and 45°-inclination directions with respect to the bedding plane at seismic frequencies between 0.1 Hz and 100 Hz.

The obtained experimental data show an increased softening of the samples, which manifests itself in reduction of the TI Young's moduli and Thomsen's parameters of elastic anisotropy ε and γ, no noticeable changes in parameter δ were found. We also found large reductions in normal and shear stiffness tensor components with saturation. When the samples were saturated at a relative humidity of 97.5%, the softening at the higher frequencies was partly compensated by the modulus dispersion.

We presume that the weakening of the elastic moduli and components of the stiffness tensor is caused by the significant percentage of water-swellable smectite in the Wellington shale.

P073. EFFECT OF AMPLITUTE ON WAVE PROPAGATION

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It is common to use ultrasonic techniques to measure elastic properties of porous media. However, conventional methods are unable to measure local strain in ultrasonic waves, and changes in velocity due to the different amplitudes. To fill this gap, in this work we, (1) measured the particle displacement using Laser Doppler Interferometry (LDI) and (2) measured changes of P-wave velocities with wave amplitude for pure elastic (aluminum), viscoelastic (Polymethyl methacrylate), and granular media (Gosford sandstone). We checked this phenomena using a conventional ultrasonic receiver and linked this changes to local strain in wave. The study indicated that for elastoplastic material local strain in wave increases from $7.2*10^{-6}$ to $1.9*10^{-5}$ for changing the voltage between 100 to 400 volts and the velocity increases by 0.85% for same sequences. The presented technique generates pulses by a conventional transducer and has a laser beam receiver. The main advantage of this approach is monitoring small changes of 0.03 mm^2 in particle size on the surface of the sample, which enables precise measurements of directional properties along with the different amplitudes.

P074. FORWARD AND INVERSION MODELLING OF THE ULTRASONIC WAVE IN A HOMOGENEOUS MEDIUM USING P-WAVE TRANSDUCERS

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Elastic properties of rocks are usually obtained from ultrasonic measurements using first break travel time picking or correlation approaches. The presence of factors such as boundary reflections, unwanted noise, and velocity dispersion can affect the estimates of elastic parameters from these methods, particularly when using shear wave arrivals. The problem becomes sophisticated in a viscoelastic medium. One way to improve the robustness of the interpretation is to use inversion of the entire wave train.

To this end, we build a robust forward and inversion model of the displacement waveforms using ultrasonic P/S-wave transducers which matches the experimental data. ABAQUS finite modelling software is used to estimate Poisson's ratio and Young's modulus of a homogeneous medium.

One challenge is to accurately represent the input displacement field emitted by the source transducer. We show that the measured displacement waveforms can be modelled assuming that the normal displacement is uniformly distributed over the entire surface of the transducer. In addition, we develop an inversion algorithm with python modules to search iteratively the elastic parameters. We show that to best model the elastic parameters, a minimum difference threshold can affect the results and has to be carefully selected. The results of both forward and inversion modelling show a great consistency with the experimental measurements. These results provide a new modelling workflow to estimate the elastic parameters of homogeneous and isotropic sample challenging traditional assumptions.

P075. PERMEABILITY AND SEISMIC-FREQUENCY ELASTICITY OF CRACKED GLASS

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Elastic properties of fluid-saturated crustal reservoirs are of key interest in exploration and production geophysics where the

role of cracks and pores on seismic properties is increasingly receiving more attention due to increasing economic significance of efficient seismic characterisation and time-lapse monitoring of crustal reservoir rocks in various contexts. These include petroleum production, geothermal energy production, carbon dioxide sequestration and efficiency of nuclear waste repositories. On a set of thermally cracked synthetic glass specimens - as simplified proxies for crustal rocks, *in situ* permeability and low frequency forced-oscillation measurements are being undertaken to investigate frequency-dependent seismic properties of a cracked media. We address some of the outstanding issues from a prior intensive study across a wide range of frequencies. Our preliminary results demonstrate the potential of improved methods for the measurement of the very low permeabilities of such cracked glass media, the feasibility of torsional forced oscillation measurements at longer oscillation periods and lower differential pressures, and the benefits of improved alignment of our specimen assembly for complementary flexural oscillation tests.

P076. INTERPRETATION USING EXPLICITLY ENCODED PHASE, AMPLITUDE AND FAULT DATA

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Current horizon interpretation techniques are based primarily on the use of seismic reflectivity. While there have been robust algorithms developed to work with seismic data, there are limitations and trade-offs with each of these approaches.

In this presentation we investigate the merits of interpretation based on the use of a colour blend comprised of phase, amplitude and fault datasets. The colour blend used in this workflow is a Hue-Saturation-Value (HSV) blend. In this blend the hue/colour is controlled by the instantaneous phase, the saturation is controlled by the amplitude, and the value/blackness is controlled by a fault detect volume.

Combining these three datasets provides a greater level of explicit information when interpreting an event. In standard cases this information can be inferred by the interpreter using secondary attribute volumes, or an autotracking algorithm performing extra calculations in the background. However, both of these approaches add extra overhead to the work being performed, reducing efficiency. Explicitly encoding phase, amplitude and fault information allows:

- reduced incidence of cycle skipping,
- the ability to pick on a particular phase angle,
- honouring of faults in autotracking,
- increased visual information in manual interpretation.

These points will be reviewed through the interpretation of a number of 3D seismic datasets, with varying data quality and covering a range of geological settings.

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Mineral Geoscience

P077. BOREHOLE MEASUREMENTS WITHIN HIGHLY MAGNETIC BODIES – CORRECTIONS OF MEASURED MAGNETIC FIELDS AND GRADIENTS

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Inside a magnetic body the magnetic field and gradients are modified by the self-demagnetising field and its gradients. For a homogeneous ellipsoidal body in a uniform applied field, the self-demagnetising field is uniform. However, a non-uniform applied field, due to external sources, results in internal field gradients and a non-uniform magnetisation. The perturbation of the internal gradient tensor components due to self-demagnetisation is shape-dependent, but differs from the effects of self-demagnetisation on field components. Non-ellipsoidal bodies and inhomogeneous bodies produce non-uniform demagnetising fields, i.e. they modify the applied gradient, particularly near edges, vertices, and surface irregularities, or in zones of rapidly changing properties. This paper gives explicit expressions for the internal field and gradient components for a layered earth, a dipping sheet, a sphere and a cylinder, that are exposed to an external field with a uniform gradient.

The internal field and gradient components cannot be measured directly, as magnetic sensors must be placed within a cavity in the magnetic medium. This modifies the measured field and gradients. For low to moderate susceptibilities, the cavity effect can be calculated assuming that the magnetisation of the surrounding medium is essentially unperturbed by the presence of the cavity. However this assumption is unacceptable when the surrounding medium has high susceptibility. This paper gives expressions that allow the true field and gradient components within a high susceptibility body to be calculated from measurements made in cylindrical cavities, such as boreholes, or in spherical or disc-like cavities.

P078. MAGNETIC FIELD SURVEYS WITH A SOURCE OF KNOWN MAGNETISATION

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To develop new magnetic field analysis algorithms and software we generally use synthetic computed survey datasets, and then to establish their practical value we apply them to real test-case datasets. However, application to real data is hampered because we do not confidently know the total magnetisation of geological sources. To span the gap between synthetic computed fields and survey measurements we have surveyed small-scale magnetic fields due to a cylindrical palaeomagnetic core of measured magnetisation and magnetic susceptibility. A profile is acquired by drawing a 3 component fluxgate magnetometer along a carefully engineered track. The track is fixed and the sample

moved between measurement of successive profiles (the opposite of a conventional survey, but achieving the same relative sensor to source mapping of the field). Results show many similarities to typical aeromagnetic data, with the added benefit that we can directly measure the regional field by removing the source. We measure profiles of 60 to 100 cm length, moving the sample up to 15 cm to either side of the track centre. Our preferred sample has a Koenigsberger ratio >10, with a strong, stable remanence conveniently directed close to the cylinder axis (providing ease of orientation to set a desired source magnetisation direction). We have used data from these surveys extensively in our research to improve determination of magnetisation direction from magnetic field data.

P079. PETROPHYSICAL CHARACTERISATION OF SOUTH EAST DOME COPPER GOLD DEPOSIT, NORTHWEST ZAMBIA

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The Katangan sequence of the Domes region in Northwest Zambia has delivered major copper-gold mines such as Kansanshi, Lumwana and Kalumbila, making it a prime area for exploring for sediment hosted copper. Kansanshi with its 750 Mt @ 0.74% Cu and 0.13 g/t Au is among major copper-gold producer in Africa. SE Dome, a satellite deposit of Kansanshi, was recently explored and drilled out with a significant input from both surface and borehole geophysics surveys including airborne magnetic and radiometric, airborne electromagnetic (AEM), natural source audio-magnetotelluric (NSAMT), Sub audio magnetics (SAM), induced polarisation (IP) and 2D seismic profiles and downhole acoustics and radiometric. Systematic physical property data such as magnetic susceptibility, specific gravity, resistivity and IP have been measured on cores. This paper intends to integrate and visualise the data in order to fully characterise the deposit.

P080. DEPTH ESTIMATE OF A REMNANTLY MAGNETISED SOURCE USING MULTI-LEVEL MAGNETIC DATA

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The depth to the top of a remanently magnetised source near Teetulpa in South Australia is estimated using multi-level (airborne and ground) magnetic data.

Remanently magnetised sources are considered challenging to interpret, mainly because the shape of the anomalism is a product of both the dip of the source and the magnetisation vector, with the two indistinguishable if both are unknown.

It is shown here that by interpreting the source geometry, in this case a sub-vertical pipe, the appropriate formula to calculate the magnetic response can be integrated with respect to z (vertical separation of source and sensor) irrespective of the dip or magnetisation vector, and when data exists at multiple z levels the z values can be estimated by solving a system of linear equations.

P081. DEPTH ESTIMATION OF SOURCE BODIES USING 2D MAGNETIC GRADIENT RATIOS

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Depth estimation remains an important interpretation goal of the exploration geophysicist, especially when cover of uncertain thickness is present. There are many methods of estimating depth using magnetic data ranging from simple 1D (profile) analysis to complex 3D inversion, each with respective strengths and weaknesses. The method discussed here involves analysis of standard 2D magnetic grids.

The dipolar nature of magnetic anomalies is exploited, with the location of the nearest pole in relation to the magnetic sensor the parameter estimated. For sphere-like sources the result plots the centre of the body, where-as for bodies with extensive strike in 1D (pipe) or 2D (dyke) the result plots at the pole nearest the sensor (the depth to top).

Reduction to pole (RTP) filtering is performed on the standard 2D total magnetic intensity grid to make the anomalies symmetrical and centred over source bodies (assuming induced magnetism). The 1st order total horizontal gradient (THG) and vertical gradient (1VD) of the RTP grid are then generated. The ratio of 1VD/THG is then calculated and gridded with contouring used to highlight the isograd with a value of 1 (THG=1VD). The depth estimate is calculated by dividing the shortest diameter of this isograd by 2 and subtracting the ground clearance. Dip information can also be interpreted.

Forward modelling of simulated data illustrates the method, proves the concept and discusses weaknesses. Several different scenarios identify the role of source topology. A real world example using open file magnetic data with known depths from drilling is then presented.

P082. GEOPHYSICAL SIGNATURE OF THE SOUTHERN-GURUBANG BASE METAL OCCURRENCE IN SOUTHEASTERN NSW

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Ground-based, time-domain electromagnetic, magnetic and gravity data were obtained for the southern-section of the Gurubang base metal deposit, in southeastern NSW. The aim was to ascertain the usefulness of high-resolution geophysical techniques in targeting and evaluating a small-scale polymetallic massive suphide deposit. Acquired data were analysed using a forward modelling approach. Due to the deposit's high concentration of conductive material, a coincident loop time-domain electromagnetic 2D survey effectively delineates the sulphide mineralisation, and is useful in interpreting and adapting deposit parameters such as the azimuth, dip and strike length. Based on the target deposit, it was determined that a high-resolution magnetic and gravity survey was not an effective method in directly targeting the mineral deposit, due to the nature of the mineralisation. However, these methods were effective in delineating the surrounding geology, such as intrusive volcanic plugs and basement geologies and structures.

P083. INTEGRATION OF BOREHOLE DATA IN GEOPHYSICAL INVERSION USING FUZZY CLUSTERING

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Geophysical inversion problems are non-unique solutions and multiple physical models can adequately fit the data to the desired degree. To choose a reliable model extra information such as borehole data is essential. In fact, we may have many boreholes, but the parameter used in the inversion model is only valuable in a few holes. Thus, the question is how we can exploit other borehole features to assist the inversion. We present the application of fuzzy clustering to incorporate multiple borehole features such as lithological, assay and wireline logs in the geophysical inversion. In this approach, we utilise the ability of fuzzy logic to resolve 'unclear' classification situations common in geology. Hence it is better than a 'hard' clustering technique such as the K-means method. The integration of this extra information produces physical parameter distributions that fit surface geophysical data and simultaneously honour the prior information. Consequently, the model likely resembles the true rock units. We have applied this technique to a case study over the Kevitsa deposit within the Kevitsa ultramafic intrusion in northern Finland. Our inversion process can produce a 'cluster' model defined by similarity of the model attributes. The cluster model can help the interpretation process better than using geophysical models.

P084. CONTINUOUS HYDROGEOLOGICAL CHARACTERISATION IN IRON ORE DEPOSITS USING BOREHOLE MAGNETIC RESONANCE

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In situ dewatering of iron ore deposits is essential for safe and efficient mining operations, as well as reducing requirements for subsequent moisture removal for processing and transportation. Evaluating porosity, residual moisture content, and hydraulic conductivity is key to designing effective dewatering schemes.

Modern borehole magnetic resonance has been used in the oil and gas industry for over twenty years to provide continuous evaluation of porosity, bound and free fluid volumes, and permeability. As such, it is uniquely suited to provide subsurface characterisation data for dewatering scheme design. However, applying these methods in iron ore settings introduces complications that are not observed in typical oil and gas environments due to the high concentrations of ferromagnetic iron-containing compounds making up the ores. This requires modification of standard approaches for estimating fluid volumes and permeability from magnetic resonance measurements.

Using an extensive data set of both core and log measurements, optimised workflows and algorithms for evaluating porosity, residual moisture content, and hydraulic conductivity from borehole magnetic resonance measurements in iron ore deposits have been developed. This allows the practical application of borehole magnetic resonance measurements in iron ore settings, providing continuous and cost effective hydrogeological characterisation.

P085. CONTINUOUS DRY BULK DENSITY EVALUATION USING BOREHOLE MAGNETIC RESONANCE AND DENSITY MEASUREMENTS

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Dry bulk density is a key parameter in resource estimation and mine and process planning. Ore bodies are mapped as volumes, whereas mineralisation grade is reported as mass fractions, requiring rock density to complete the reserves calculation. Similarly, although a volume of rock is to be excavated, planning for the transport and processing of this material takes place in terms of the mass of ore to be handled, again requiring rock density information to convert between the two.

Although many different densities can be defined based on the underlying mass and volume definitions, the one of most interest to the mining industry is dry bulk density, or the dry mass per unit volume of *in situ* rock. This contrasts with the *in situ* bulk density, which includes the mass of any fluids in the pore space of the rock. *In situ* bulk density can be accurately measured using borehole geophysical techniques, but no direct downhole measurement of dry bulk density is possible. Therefore, common practice is to determine mass, after drying, and volume of core samples for calculation of dry bulk density. However, this process can be time consuming and problematic with porous or unconsolidated samples.

Another approach to estimate dry bulk density, amenable to downhole application and therefore avoiding many of the complications related to core measurements, utilises *in situ* bulk density and magnetic resonance porosity measurements. Combining these two measurements allows for continuous dry bulk density evaluation without the need for coring.

P086. DIGITAL OPENCAST MINING ECOSYSTEM (DOME) FOR MANAGING THE AUSTRALIAN MINING INDUSTRY IN A BIG DATA SCALE

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Many opencast mines inhabit thousands of square kilometres, which are productive and commercial Australia wide. Hundreds of volumes and varieties of data dimensions and facts exist in the opencast mining areas. The data sources linked with various opencast mines are often heterogeneous and multidimensional. Data modelling is challenging in a Big Data scale, at times precluding the data integration process. The mineralisation connected to opencast mines occurs in shafts, pit slopes, ramps and benches with varying geometries and configurations in large-scale geographic and periodic dimensions. The limits of the mineralisation at places are either unknown and or ambiguously interpreted. The Big Data, in the context of the Australian mining industry, are due to the explosive growth of data sources and their uncontrolled management in many national and multinational companies. New knowledge is

required for interpreting new opencast mining areas and their mineralisation. For sustainable production, the knowledge of the connectivity between mineralisation and its associated opencast mines is constrained. We propose an empirical modelling, analysing hundreds of attribute dimensions and fact instances of geological and geophysical vintages in the mining areas. Different data constructs and models are built for logical metadata, accommodating it in a multidimensional warehouse repository, as a DOME solution. It is an innovative solution to the mining industry's Big Data problem including the opencast mine planning and design, adding values to the existing domain knowledge with new interpretations. Various geological events attributed to the interpretation and distribution of mineralisation are useful for the opencast mine managers.

P087. EFFECT OF FINELY-LAYERED STIFF CARBONATES ON A SEISMIC RESPONSE, CARNARVON BASIN SYNTHETIC STUDY

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Fine layering is known to cause both attenuation and VTI-anisotropy of seismic waves. In typical geological environments the contrast in elastic properties of adjacent layers rarely exceeds 30% so that the layer-induced effects are negligible. However, it's not true for the overburden of Carnarvon basin (Northern shelf of Western Australia) that is characterised by thin interlayering of very stiff carbonates and soft porous sands.

In this paper we present a workflow for preliminary analysis of a seismic wavefield and, in particular, effects of layer-induced scattering attenuation and anisotropy in the target area. The workflow is based on the walk-away VSP full-wave modelling (5–100 Hz) for a flat-layered elastic model that is constructed using logs of four wells, namely, Dampier 1, Withnell 1, Wilcox 2 and Parker 1.

We show that particular sequences with stiff carbonates produce significant amplitude loss and degradation of spectrum of a transient seismic pulse. Maximum attenuation is observed for Withnell 1 borehole and is characterised by the drop of 35% in the centroid frequency in the 200 m interval. Anisotropy anellipticity parameter η is estimated by fitting the moveout curves and varies from 0.3 to 1.5. In addition, the modelling reveals very complex wavetrain with energetic reflected and converted waves at large offsets. All these effects should be taken into account in seismic processing and imaging.

P088. APPLICATION OF IMAGE PROCESSING METHODS IN EDGE DETECTION OF POTENTIAL FIELD DATA

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On the basis of conventional methods for edge detection on potential field data, various source edge enhancement techniques have been studied to improve signal-to-noise ratio and localisation accuracy. But problems such as low resolution, noise interference and false edge information introduced still exist. In this paper, three image processing methods are introduced, which are Canny, LoG and Sobel operators. We describe briefly the principle of the methods and apply them to edge detection of geological bodies. And three typical numerical calculation methods of edge detection are selected and compared with image processing methods on edge detection effect. The results show that image processing methods can effectively identify the edge of geological bodies, especially for Canny operator, which can prevent introducing error information and is insensitive to noise. To verify practical application effects of image processing methods, the data in gravity anomaly of Sichuan basin and magnetic anomaly of Zhurihe area are processed in this paper. The results indicate that Canny operator is capable of detecting the edge position of geological bodies in the study area more clearly, which corresponds to known information. Therefore, image processing methods can be used in edge detection and satisfactory practical application effects can be achieved.

P089. FAST THREE DIMENSIONAL DENSITY INVERSION BASED ON MULTI-SCALE ANALYSIS OF WAVELET

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Low calculation efficiency and insufficient resolution in depth direction exist in inversion of underground 3D density distribution. In this paper, we proposed a fast inversion algorithm. It decomposed the gravity anomaly on multi-scale with wavelet, represented the original data sparsely with wavelet coefficients on each scale and carried on the inversion in wavelet domain. An appropriate threshold is set to process the coefficients in order to enhance the sparsity of coefficient matrix. This would furthermore improve the compressed ratio of data and save calculation time. Gravity anomalies on each scale represent responses of sources at different depths as an inverse relation exists between scale and frequency. So the inversion results would mainly reflect density distribution at the corresponding depth and the final inversion could be achieved by summing up results at all scales. It is not necessary to set the range of depth related to anomalies at each scale and besides, the inversion scheme is applied without depth weighting. The method could increase the resolution in depth direction of inversion results effectively and provide more detailed deep density distribution. As an iterative algorithm, which can take advantage of sparse matrix to improve calculation efficiency, conjugate gradient was used for inversion. The proposed method will be applied to inversion of synthetic model data and real gravity anomaly to demonstrate its effect.

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P090. THE NEW GENERATION TEMPEST SYSTEM

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The development of the new Generation TEMPEST system was driven by an expectation that TDEM data would find increased utility, at regional scale, for both geological mapping and regolith characterisation. Achieving the correct balance of affordability and technical capability was determined to be a key component to the success of this endeavor.

Designed as a system suited to contemporary demands for high quality calibrated data whilst maintaining a good depth of penetration, a number of new innovations were necessary. These include the development of a 'low frequency bird' (12.5 Hz and below) in conjunction with UWA, a faster switching higher power transmitter and new signal processing algorithms to accommodate these changes. Additionally, continuous measurements of system geometry, transmitter/receiver orientation etc. for use in modern inversion codes enables the potential for both improved results and better quantified data and associated uncertainty.

Historically the cost of operating a TDEM system also limited the widespread use of quality EM data for mapping purposes. In order to contain these operational costs an inexpensive and robust platform, the Cessna C208B, albeit with an upgraded engine, was selected as being most suitable. CGG embarked on a certification journey with the Civil Aviation Australia (CASA) for the issue of a Supplemental Type Certificate. This 2.5 year endeavor provides a unique insight into the trials and tribulations of equipment development in an increasingly legislated environment.

In this paper we present both the development path and technical achievements of a project designed to improve the accessibility of quality Airborne EM data.

P091. RAPID ESTIMATION OF VOLUMETRIC GROUNDWATER RECHARGE IN THE VADOSE ZONE VIA GROUND PENETRATING RADAR

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Rapid bulk estimation of the stored water content in a high-permeability sandy vadose zone at the coastal margin is made using velocity corrections for time-lapse ground penetrating radar measurements.

Ground Penetrating Radar (GPR) is an invaluable tool for shallow high-resolution geophysical investigation. It is applicable to a wide range of near-surface problems, such as archaeological investigation, engineering assessments, and medical imaging. The speed and simplicity of acquisition and processing lends itself to the rapid detection and evaluation of subsurface features.

Shallow hydrogeological applications, such as delineation of stratigraphy mapping (Davis and Annan, 1989), soil water content definition (Huisman et al., 2003), porosity estimation (Bradford et al., 2009; Turesson 2006), and water table/vadose zone depth evaluation (Strobach, 2013; Strobach et al., 2010) are well-suited towards GPR investigation due to the shallow nature and large contrasts in the physical properties of the target.

Volumetric water content stored in the vadose zone will reduce the electromagnetic wave velocity of a ground penetrating radar signal. We demonstrate the effect of increased volumetric water content through repeat acquisition of GPR data in a highly-permeable dune system in the coastal margin of Perth, Western Australia.

The increase in bulk stored water content between successive transects is estimated through manipulation of the topographic correction velocity to achieve a flat, or near-flat water table consistent for both datasets. The flat water table assumption is validated via nearby well logs and the highly permeable sandy environment. The changes in velocity allows for the estimation of saturated water increase over the elapsed time period, which can be correlated with rainfall and evapotranspiration to estimate the total stored water in the vadose zone.

P092. ASSESSING AQUIFER COMPARTMENTALISATION IN THE DALY RIVER BASIN, NORTHERN TERRITORY: A HYDROGEOPHYSICAL APPROACH

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The presence of Neogene fault systems can have a significant impact on hydraulic connectivity of aquifers, juxtaposing otherwise disconnected aquifers, enhancing recharge and/or discharge or acting as barriers to flow and consequently compartmentalising groundwater resources. Previously, regional airborne electromagnetics (AEM) transects allied with groundwater investigations have pointed to the potential for localised compartmentalisation of the Daly River Basin groundwater systems. However, existing data is sparse, and equivocal.

In this context, the main aim of the Daly River Basin Project is to determine if compartmentalisation of the aquifers is a significant factor and thus should be explicitly considered in groundwater modelling and water allocation planning. The objectives of the project main goals of the project are to: (1) map Neogene faults through the use of airborne electromagnetic (AEM) and morphotectonic mapping, and (2) assess the permeability and transmissivity of mapped fault zones and their role in potential groundwater system compartmentalisation. Data acquisition includes 3325 line-km of new AEM and airborne magnetics, ground (ground magnetic resonance (GMR)), and borehole geophysics, drilling, groundwater sampling and hydrochemical analysis, geomorphic and morphotectonics mapping. Hydrogeophysical, geomorphic and hydrogeological data will also be used to better understand groundwater-surface

water connectivity and the potential for managed aquifer recharge schemes to replenish extracted groundwater resources. The outcomes of this project will inform decisions on water allocations and underpin effective and efficient groundwater use. This paper specifically reports on the ability of AEM and morphotectonics mapping to identify Neogene fault systems in the Daly River Basin.

P093. DEVELOPING REGIONAL-SCALE HYDROGEOLOGICAL FRAMEWORKS FOR REMOTE PARTS OF AUSTRALIA – THE ROLE OF DIGITAL TERRAIN DATA COUPLED WITH FINE-SCALE GEOPHYSICAL AND GEOLOGICAL DATA

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Securing water resources in central Australia for isolated communities and environment is a challenge for both State Governments and industry. The G-FLOWS projects of the Goyder Institute for Water have developed a scalable approach to help better understand water resources of arid inland regions of Australia. It employs digital terrain data and a terrain index - MrVBF to delimit contemporary valleys or low points in the landscape. This index is designed to identify areas where alluvial/colluvial material might be deposited at a range of scales based on the observations that valley bottoms are low and flat relative to their surroundings and that large valley bottoms are flatter than smaller ones. This index has been tested with airborne electromagnetic and airborne magnetics data datasets in data poor, arid parts of South Australia where spatial associations between surface topography and materials, and observed subsurface character were identified. A hydrogeological framework model was then developed with five hydrogeological units defined, categorising the landscape as comprising alluvial aquifers with buried palaeovalley systems, alluvial/colluvial aquifers, colluvial aquifers, aquifers in saprolite and weathered fractured rock, and fractured rock aquifers in fresh rocks. The hydrogeological framework model has also been tested in other areas, and can be scaled depending on the resolution of available terrain data, but also an understanding of the basement geology. The framework can help target locations and determine approaches for finer-scale groundwater resource assessments by Government or industry, and in future can be modified and applied to other areas in Australia as needed.

P094. STRUCTURAL ANALYSES AIDING IDENTIFICATION OF WATER CONDUCTIVE FRACTURE ZONES IN CRYSTALLINE ROCKS

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Development of hydraulic conductive zones in crystalline rock can result from a wide range of geological conditions, which include primary structures, post crystalline tectonics, fluid solution and movement within a developing and eroding regolith.

Crystalline rock areas mostly have low water resource potential due to inherent extremely low storage and water conductive properties. Therefore, fracture zones of high hydraulic conductivity have an important role in developing groundwater resources in these areas.

Mechanisms for development of open tension or pull-apart fractures in brittle rocks are similar to those involving development of mineralised veins. The same structural analytical techniques can be applied.

Crystalline rock fracture zones can be amenable to rapid recharge through rainfall runoff. They are also significant in that they provide a mechanism for underdrainage through 'delayed yield' of surrounding or enclosing low conductive rocks such as saprock/saprolite, pelite and phyllite.

In addition to brittle rocks, open tension fracture zones of enhanced hydraulic conductivity may also occur in more fissile pelitic rocks such as slate and phyllite. These zones are often associated with crestal zones of folds and along saddles in cross-folds and in strike deviations produced by conjugate shears.

The development of conjugate joint sets in a region also provides a significant basis for this type of fracture analyses.

This presentation provides examples of water supplies developed from crystalline rock structures in a range of geological and earth environments.

P095. MAGNETOTELLURIC, BASIN STRUCTURE AND HYDRODYNAMIC; SOUTH WEST OF WESTERN AUSTRALIA

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An MT transect was collected over a hypersaline aquifer along a west-east profile almost perpendicular to the Darling fault and Indian Ocean coast in a rural/semi-rural area proximal to Harvey, Western Australia. AMT/MT data were recorded during periods between 10 h and 24 h simultaneously at multiple stations. Some stations were influenced by power line high noise, and remote reference processing was applied to improve data quality. First 1D forward modelling was completed to get a sense of conductivity distribution, then 2D inversions was completed using Mare2DEM. Clear and significant splitting in TE and TM mode apparent resistivity and phase occurred at low frequencies (less than 0.1 Hz) for all stations. The mode splitting could be related to the proximity of the MT transect to the narrow deep Perth Basin near the Darling fault, combined with the presence of the Indian Ocean several kilometres to the West. The 2D inversion result shows some thick sand formations containing high salinity where resistivity appears to be strongly connected to reduction in porosity with depth.

P096. APPLICATION OF MAGNETIC RESONANCE DATA FOR GROUNDWATER PROSPECTIVITY IN THE FITZROY BASIN, WESTERN AUSTRALIA

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In northern Australia, groundwater investigations in remote areas face challenges including the cost and difficulty in obtaining

POSTER ABSTRACTS

drilling permit due to lengthy heritage and environmental approvals processes. Non-invasive geophysical techniques, including airborne electromagnetics (AEM), Ground Magnetic Resonance (GMR) and borehole Nuclear Magnetic Resonance (NMR), are particularly attractive in these circumstances, as key hydrogeological parameters including depth to water table, porosity and transmissivity can be obtained with limited clearance approvals required.

In the Fitzroy Basin of Western Australia, both surface and borehole MR have been applied to groundwater prospectivity assessment of the Cenozoic sediments, and the Palaeozoic and Mesozoic sandstone aquifers. Eight GMR sites were acquired across the basin, which include Mowanjum, Willare – lower Fitzroy, Mount Anderson, and May – Lennard River areas. These sites were selected based on interpretation of the AEM data.

The GMR results with good resolution to 100 m depth were compared against borehole NMR and lithostratigraphic information, and found to be consistent. Both sets of MR data support that the Palaeozoic (Grant Group and Poole Sandstone) are excellent aquifers. At other sites, the lack of water content in some of the water profiles indicates the presence of aquitards such as Blina Shale and Jarlemai Siltstone.

GMR data indicates that the floodplain alluvium of the intermittent Fitzroy River contains little 'mobile', or free-draining, water (~3 vol %) at the end of the dry season. The water table at the site was ~30 m depth, most likely beneath the alluvium in the Mesozoic sedimentary rock.

P097. UTILISATION OF AEM METHODS FOR COST-EFFECTIVE MAPPING OF SHALLOW NEOGENE INTRA-PLATE FAULT SYSTEMS IN EASTERN AUSTRALIAN COAL SEAM GAS BASINS

Ken Lawrie[1], *Donna Cathro*[1*], *Neil Symington*[1], *Niels B. Christensen*[2], *Chris Harris-Pascal*[1], *KokPiang Tan*[1], *Andrew McPherson*[1] *and Laura Gow*[1]
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Neogene fault systems are increasingly recognised as an important control on hydraulic connectivity in some of Australia's energy rich basins. However, accurate delineation of these faults systems is challenging and expensive. In this context, the main objective of the Exploring for the Future (EFTF) Surat-Galilee Basin (Phase 1) Project is to test novel methods for more cost-effective mapping of Neogene fault systems in the Coal Seam Gas (CSG) basins of eastern Australia. Methods assessed in this project include morphotectonic mapping using temporal remote sensing data and high-resolution terrain mapping techniques, airborne electromagnetics (AEM), and the use of earthquake databases to inform active tectonic and geomechanical analysis.

The project is funded by Geoscience Australia (GA) as part of its EFTF Program, and is focussed on exemplar areas in the Surat and Galilee Basins where Neogene fault activity has been interpreted on high-resolution 2D and 3D seismic reflection surveys. This paper reports on the use of airborne electromagnetics (AEM) for detecting near-surface (<50–150 m) Neogene faults in both basins. Approximately 4500 line km of AEM data were acquired in a number of smaller acquisition blocks where Neogene faults had previously been identified. The AEM inversion results are compared with interpretation of seismic reflection data, morphotectonic mapping, and other hydrogeological and tectonic/geomechanical data. The utility of AEM to map the broader hydrogeological system in these basins, including groundwater-surface water connectivity (springs and rivers), is also assessed.

SECTION 5
BIOGRAPHIES

Australian Society of Exploration Geophysicists

PESA Petroleum Exploration Society of Australia

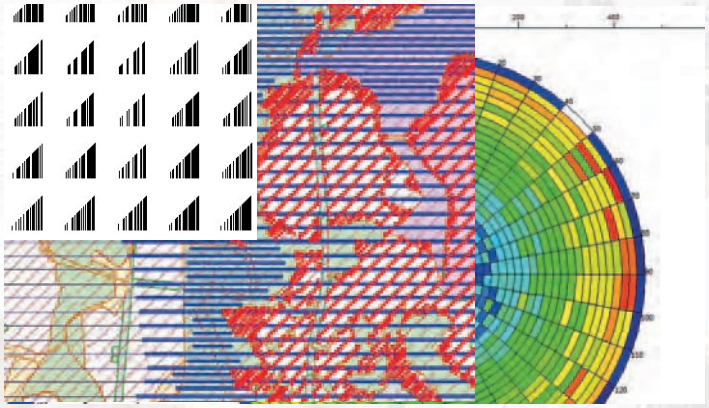
AUSTRALIAN INSTITUTE OF GEOSCIENTISTS

Company Overview

Velseis is widely regarded as Australia's most experienced seismic contractor, leading the industry in high resolution seismic data acquisition, processing and interpretation.

Operating throughout Australia as well as Internationally, Velseis provides a full suite of integrated seismic services across the entire resource sector including the oil and gas, minerals, coal, and coal seam gas industries.

The Company draws upon 35 years of practical and logistical know-how, along with high-level geophysical expertise, to consistently deliver quality results safely and with exceptional efficiency.



Seismic Source Capability

Explosives

Velseis has over 35 years' experience in high-resolution Dynamite surveys. Shot hole drilling services are provided by our Seisdrill division, which has six truck-mounted Bourne 1000R drilling rigs, specifically suited to shot hole drilling. We are licensed to purchase and handle explosives, our pre-loaders are highly experienced, and our QHSE protocols are comprehensive.

Velseis

Integrated Seismic Technologies

Seismic Survey Design

Using industry leading 3D design software, along with internally developed proprietary technology, we provide a comprehensive 2D and 3D design service which accommodates the technical, logistical and economic considerations of our clients.

Seismic Data Acquisition

With a diverse range of seismic source and recording hardware options along with experienced field personnel, Velseis can provide customised field crews suitable for most projects.

R&D Design Drilling Acquisition Processing Interpretation

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Certified System Health & Safety AS/NZS 4801 SAI GLOBAL
Certified System Quality ISO 9001 SAI GLOBAL

Vibroseis

IVI Envirovibe (15,000lb) buggies

- Manoeuvrable
- Environmentally friendly (low impact)
- Easily transported

Inova Univib (26,000lb) buggies

- Manoeuvrable
- Environmentally friendly
- Adjustable hold-down for peak force variability

AHV-IV 380 Renegade (80,000lb)

Velseis has recently expanded its Vibroseis fleet to include INOVA's 80,000 lb Renegade buggies. The Renegade 380 is currently the largest vibrator in Australia and when compared with INOVA's standard 60,000lb vibrator, exhibits superior low frequency sweep characteristics, enhanced broadband capability and deeper stratigraphic imagery.

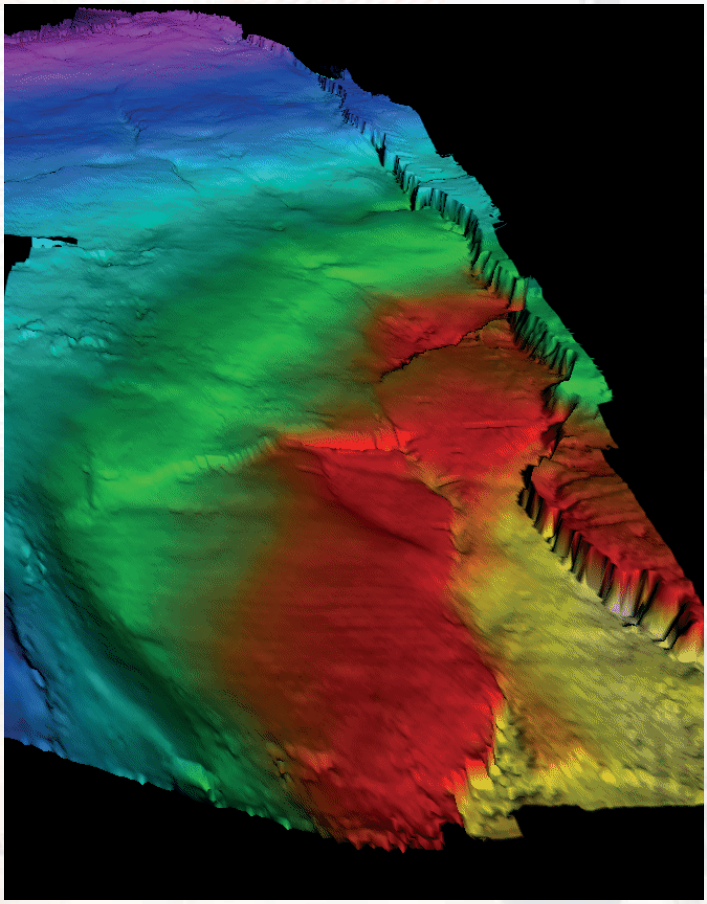
"Renegade Reaches Australian Shores"

Mini-SOSIE

In areas with particular environmental or access restrictions, Mini-SOSIE provides a seismic data acquisition method which is a geophysically viable alternative to Vibroseis. Utilising a Wacker Neuson compactor as an impactive energy source and smaller field crews, this technique is well suited to smaller projects with shallower targets. Mini-SOSIE is also effective as an alternative energy source for areas of a 3D Vibroseis survey where access is not possible for Vibroseis buggies due to environmental, topographical or cultural restrictions.

Recording Hardware

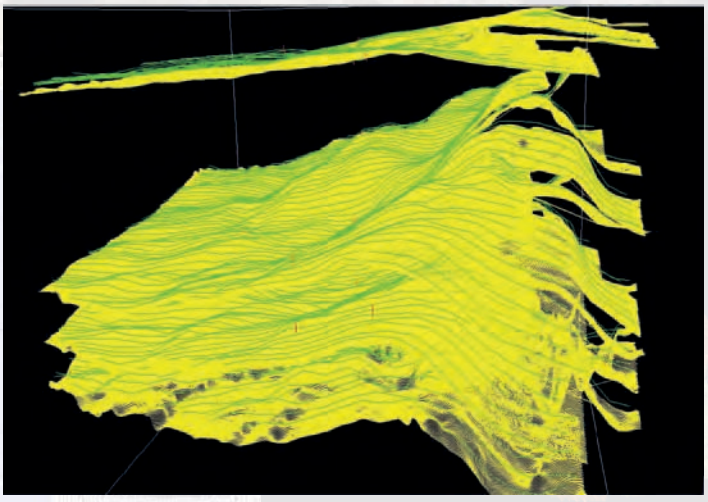
- 10,000 channels of Sercel 428/408 Telemetry recording hardware
- 6,000 channels of Sercel UNITE RAU eX-3 (wireless) recording equipment
- Up to 40,000 channels of Nodal recording equipment



Seismic Data Processing

Velseis Processing has provided quality seismic data processing and interpretation services to the oil & gas, coal, and mineral industries for over 25 years. We draw on a history of thousands of projects, and a staff of nearly 400 years' experience to extract valuable insights into the subsurface for our customers. Major oil & gas companies have consistently ranked our services as among the best available, and we have long been acknowledged as worldwide industry leaders in high resolution imaging for coal and minerals.

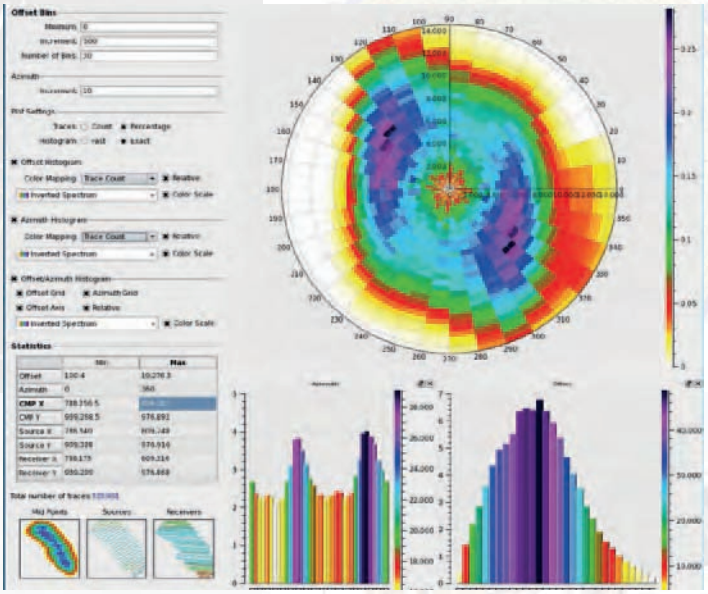
Our processing and interpretation services have been utilized by Australian Coal and Coal Seam Gas Industries for the past 15 years, and are of significant importance to the economics and safety of mining operations. Velseis work closely with mine planning staff to provide detailed stratigraphic and geotechnical analysis, highlighting faults and other stratigraphic anomalies. The information is used by mine staff for mine design, to prepare for drilling, and to help predict changing roof, floor and seam conditions.

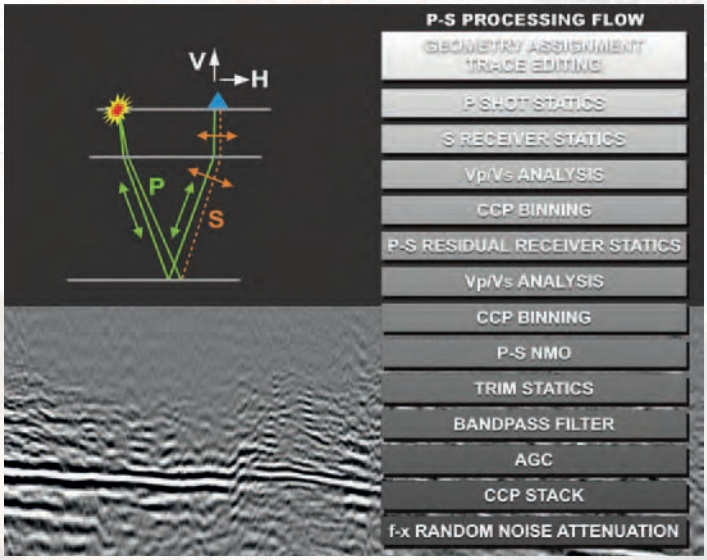


Velseis processing capabilities have rapidly expanded in past few years. With a significant and scalable computing processing facility, along with a world class suite of proprietary and licensed technology, Velseis is processing large 2D, 3D,

and 4D seismic surveys both domestically and internationally. Whether it be land, marine, or transition zone environments, our people and technology are configured to take on the most challenging of projects. Our comprehensive technology catalogue includes solutions for:

- Tomo-statics
- Cross spread noise attenuation
- COV binning
- De-Ghosting
- SRME
- Shallow Water De-multiple
- 5D Interpolation
- Azimuthally Aware Tomography
- HTI correction
- VTI/TTI Pre-Stack Time and Depth Imaging
- RTM
- FWI





Research And Development

Since its inception, Velseis has based its operations on sound geophysical principles and technical innovation. The company maintains an active R&D division, which carries out targeted research in applied seismology. Current research activities include embedded acquisition systems, multi-component seismology, and optimisation of high-resolution data processing.

R&D publications are available at:
http://www.velseis.com/research/recent_publications

Health And Safety

At Velseis, we strive to provide our clients with geophysical information of the highest possible quality. To achieve this aim, our operational procedures are based on rigorous geophysical procedures, and are carried out with strict quality control. This focus on technical excellence runs parallel to a stringent commitment to health, safety and the environment.

Furthermore, we aim to achieve technical products of the highest possible quality, to maintain an incident-free workplace, and to conduct our business with no adverse effects to people, to property, or to the natural environment.

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Certified System Quality ISO 9001 SAI GLOBAL

Jared Abraham is a principal geophysicist with Aqua Geo Frameworks, LLC in Mitchell, Nebraska. Over the past 25 years, his research has focussed on the application of geophysical techniques for mapping water, energy, mineral resources, and engineering and environmental problems. His research interests include the use of airborne geophysical survey techniques to construct 3-D geological and hydrological framework models. Jared received his Masters in Science in geophysics from the Colorado School of Mines in 1999. He received his Baccalaureate in Science in geology from Mesa State College in 1994.
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Cameron Adams is a PhD Student at the Centre for Exploration Targeting (CET), School of Earth Sciences, University of Western Australia. Cam has been awarded a MRIWA postgraduate research scholarship and an ASEG Research Foundation grant for his PhD project titled 'Understanding of the petrophysical properties of altered rocks: implications for geophysical exploration'.
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Shakil Ahmed is a research scientist specialising in the modelling of digital rock physics, numerical reservoir simulation, flow through micro-pore structures, rock-fluid interaction, computational fluid dynamics and multi-phase flow. He has led and been involved in a number of projects. He has been asked to review more than 40 papers over the last five years for many renowned journals. Dr Ahmed is involved with the ARC as an assessor. He is affiliated with the IEAust, SPE, EAGE, ARMA, the Institute of Engineers, Bangladesh (IEB) and the Bangladesh Society of Mechanical Engineers (BSME).
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Zubair Ahmed is a PhD candidate from Department of Exploration Geophysics, Curtin University of Technology, Western Australia. His research area includes rock physics characterisation of unconsolidated sand using laboratory ultrasonic measurement and micro-CT image analysis. His study primarily focusses on effective elastic properties of granular medium using contact based models. Before commencing postgrad study, he worked on seismic data acquisition as a field QC for a national petroleum exploration company. He was also involved with 3D seismic data interpretation team on different petroleum fields to characterise reservoir potentials and new locations for drill wells using inversion and attribute analysis.
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Alan Aitken has over 10 years of research experience in geophysics. Topics of research interest include solid earth geophysics, cryosphere geophysics and environmental geophysics.
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Ruken Alac is a PhD candidate at the University of Sydney. She received her MEngSc in surveying and geospatial engineering from University of New South Wales and BS in geophysical engineering from Istanbul Technical University. She also holds Master of Science and Technology in Spatial Information from University of New South Wales. Her current research interests include modeling, data processing, optimisation problems and data mining. She is currently working with EarthByte Group and the Basin GENESIS Hub.
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Nikolce Aleksieski is a scientist on the rise and has been in the industry over the past few years. His prior employment as a supervisor for contaminated land remediation has given him insight into issues associated with mining. His academic background is in geology and geophysics with a postgraduate degree in environmental and sustainability with a research dissertation on impacts to groundwater relating to coal seam gas and shale gas mining. His overarching goal is to promote sustainable mining in Australia.
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Carl Altmann is currently an exploration geologist for Origin Energy in Brisbane, Australia. He received his BSc degree in geology, geophysics and environmental geoscience from Adelaide University and his Honours degree in petroleum geoscience from the Australian School of Petroleum. Carl is a member of AAPG and SPE.
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Jade Anderson has a research background in U–Pb geochronology, metamorphism and Proterozoic Australia tectonics.
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David Annetts has been with CSIRO since 2007. A forward-modeller by inclination, he has researched the application of frequency and time-domain electromagnetic prospecting methods to marine CSEM, CO2 sequestration, uranium and groundwater exploration, and maintains interest in CSIRO's Bayesian Lithological Inversion initiative.
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Mehdi Asgharzadeh is a geophysicist with more than 14 years combined industry work and academic research experiences in exploration geophysics. He has completed an engineering degree in mining exploration (2000), a MSc degree in petroleum geosciences (2004) and a PhD in exploration seismic (2014). He has worked with National Iranian Oil Co. and Schlumberger Australia as a geophysicist and as a researcher with Curtin University.
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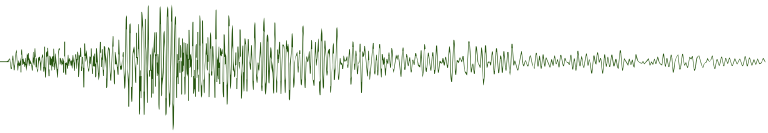

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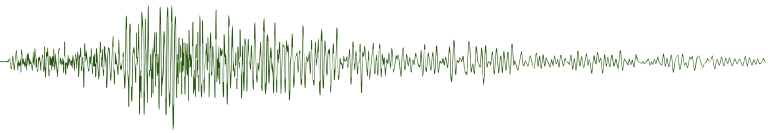

microstructure studies (the Elle platform), integration of geology and geophysics in 2 and 3D (the WA_In3D project), and the tectonics and metallogenesis of the West African Craton (WAXI).
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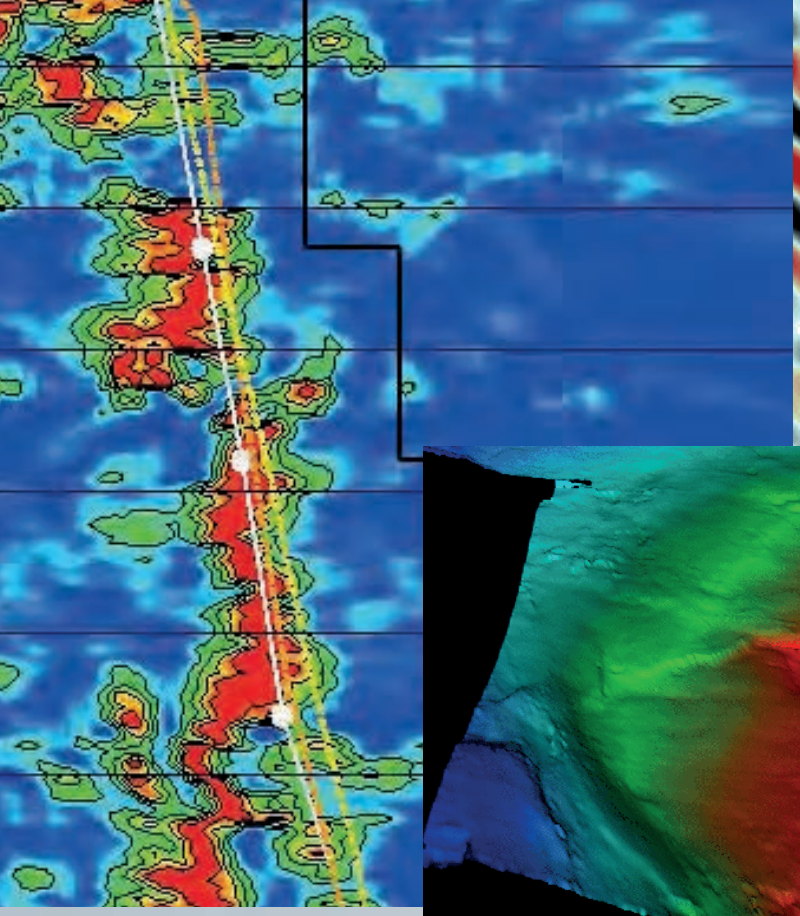

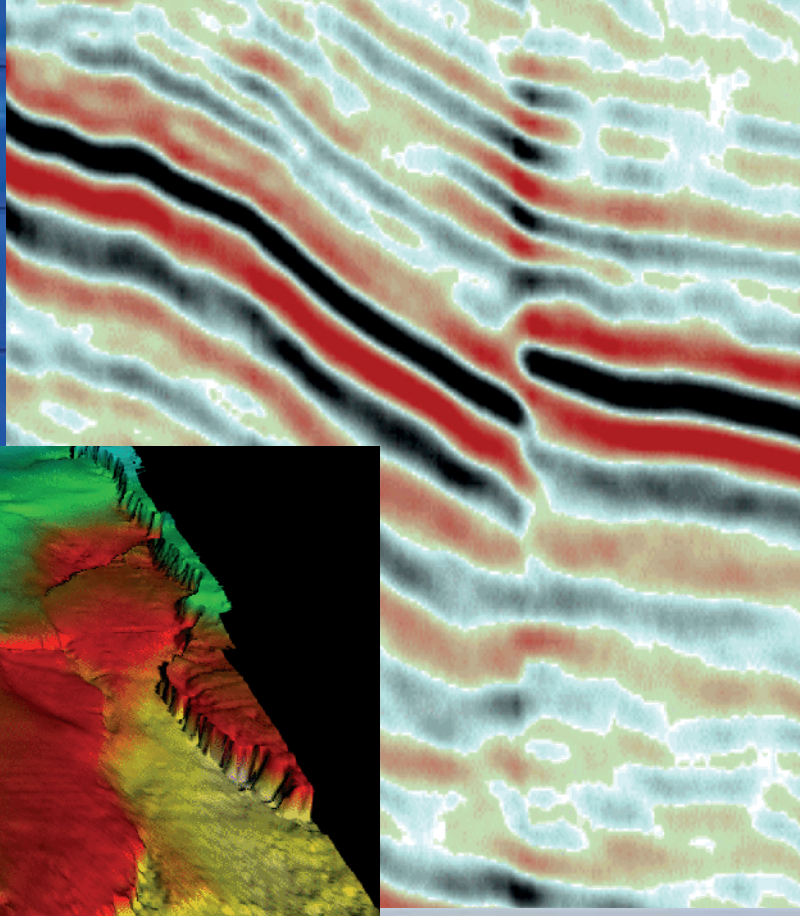

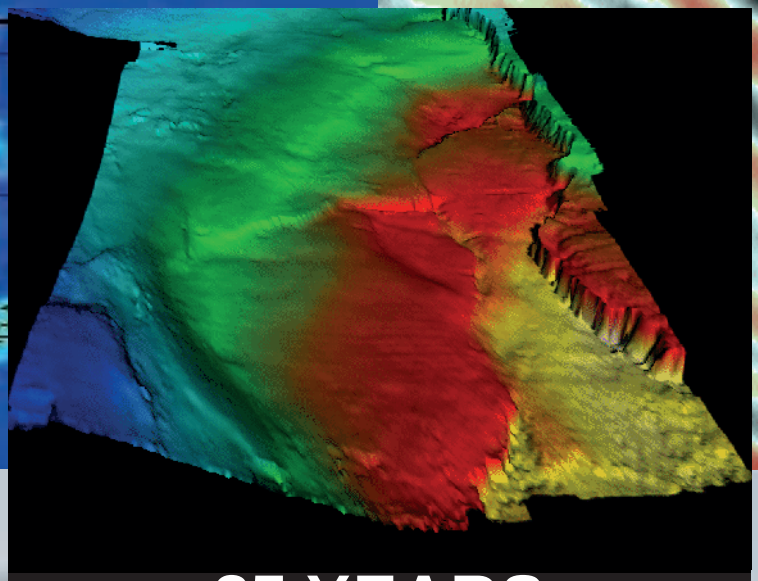

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e-research group, pursuing open innovation involving the development of open-source software as well as regional and global digital data sets. One of the fundamental aims of the EarthByte Group is geodata synthesis through space and time, assimilating the wealth of disparate geological and geophysical data into a four-dimensional Earth model, connecting solid Earth to surface processes. He directs the ARC Basin Genesis Hub as well as the Sydney Informatics Hub.
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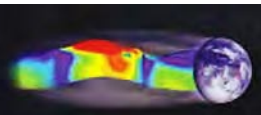

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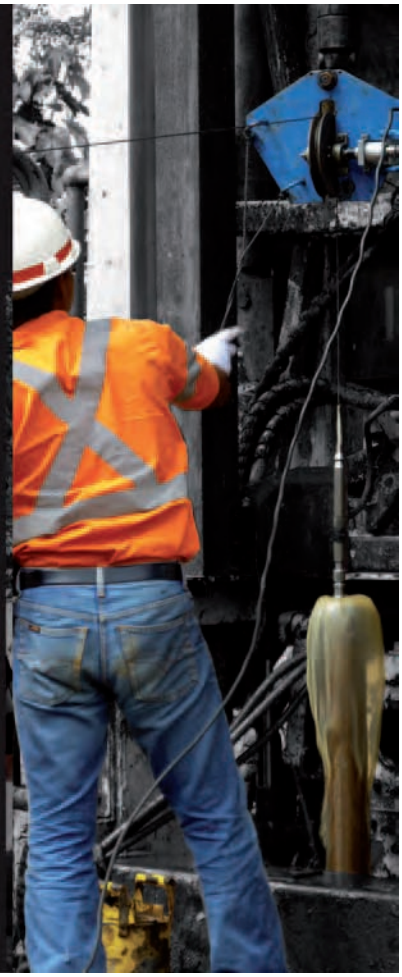

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5–7	Third EAGE Workshop on Naturally Fractured Reservoirs Calibration Challenges https://events.eage.org/2018/	Dubai	UAE
18–21	Australasian Exploration Geoscience Conference http://www.aegc2018.com.au/	Sydney	Australia
March	**2018**		
1–2	GeoTHERM – expo and congress 2018 http://www.geotherm-germany.com/	Offenburg	Germany
20–23	OTC Asia http://2018.otcasia.org/	Kuala Lumpur	Malaysia
April	**2018**		
8–11	Fifth Australian Regolith Geoscientists Association Conference http://www.regolith.org.au/conference2018.html	Wallaroo	Australia
8–13	EGU https://www.egu2018.eu/	Vienna	Austria
11–12	EAGE-HAGI 1st Asia Pacific Meeting on Near Surface Geoscience and Engineering http://events.eage.org/en/2018/EAGE%20HAGI%20Near%20Surface%20Geoscience%20and%20Engineering%202018	Yogyakarta	Indonesia
24–27	CPS/SEG Beijing 2018 International Geophysical Conference and Exposition http://seg.org/events/IGC18	Beijing	China
May	**2018**		
20–23	AAPG 2018 Annual Convention and Exhibition http://www.aapg.org/events/conferences/ace	Salt Lake City	USA
June	**2018**		
10–13	The 8th International Conference on Environmental and Engineering Geophysics (ICEEG)	Hangzhou	China
10–16	16th Castle Meeting - New Trends on Paleo, Rock and Environmental Magnetism http://castle2018.igf.edu.pl	Chęciny	Poland
11–14	80th EAGE Conference & Exhibition 2018 http://www.eage.org/	Copenhagen	Denmark
18–21	GPR 2018 https://www.gpr2018.hsr.ch/	Rapperswil	Switzerland
22–24	Global Symposium on Millimeter Waves (GSMM) 2018 http://www.gsmm2018.org	Boulder	USA
August	**2018**		
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
23–25	SPE Annual Meeting	Dallas	USA
October	**2018**		
14–18	AGC Convention http://www.agc.org.au	Adelaide	Australia
14–19	SEG Annual Meeting	Anaheim	USA
November	**2018**		
12–14	13th SEGJ International Symposium http://www.segj.org/is/13th/	Tokyo	Japan

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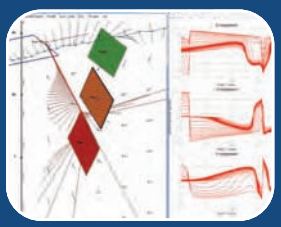

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