Australian Society of
Exploration Geophysicists

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PREVIEW

NEWS AND COMMENTARY

FEATURES

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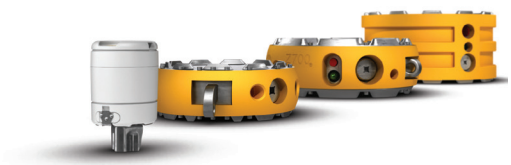

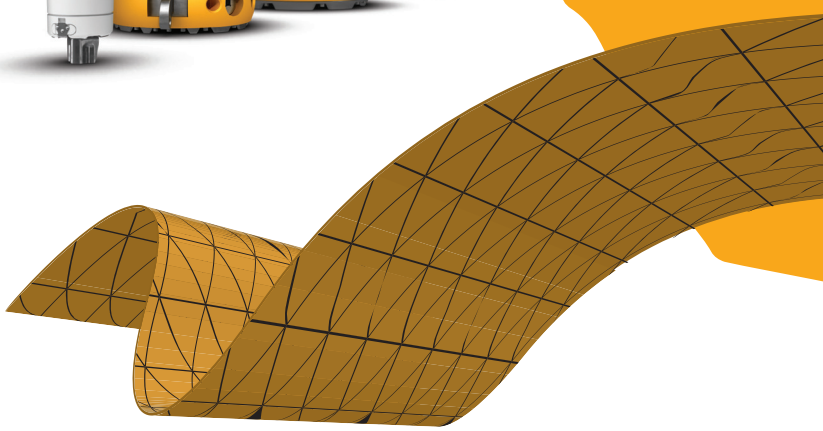

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PREVIEW

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FRONT COVER

The cover image shows Jie Yu, who has recently completed a Bachelor of Science with Honours in Geophysics at the University of Tasmania, collecting data for her Honours Project in the Mt Lindsay-Lynch Hill area.

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Lisa Worrall

As promised, this is a bumper issue of *Preview*. It is also an issue that is unashamedly focused on research students. We invited all students who completed research projects in geophysics at an Australian university in 2014 to submit their title, abstract and short bio for publication in *Preview*. Forty-four students from 10 universities responded – a good indication of the strength of the discipline. The topics addressed by the students were diverse and I can almost guarantee that there will be something to pique the interest of every reader!

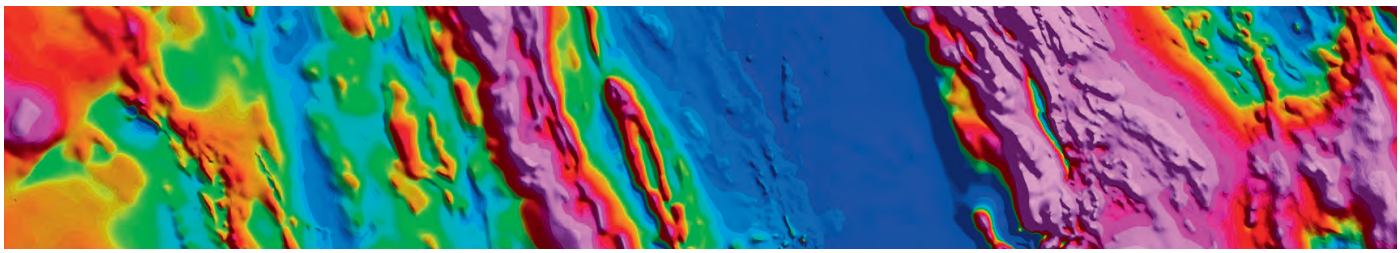
One student of geophysics, Jack Muir (Honours, ANU), has distinguished himself by winning the prestigious John Monash scholarship to study science in the United States of America. The scholarship, which is worth $180 000 over 3 years, allows Jack to choose the university he would like to attend in the USA. His options include notable schools such as the California Institute of Technology, Princeton University and Harvard University. Jack's achievement caught the attention of the media http://www.abc.net.au/news/2014-11-29/canberra-student-wins-scholarship-to-study-science-in-us/5928200 and has raised the profile of geophysics in Canberra.

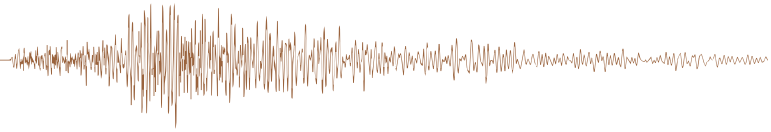
In this issue we also celebrate the 25th anniversary of the establishment of the ASEG Research Foundation. This foundation, which was the brainchild of Bob Smith, has supported the work of many students. We take a close look at the career trajectory of a sample of those students, many of whom will be an inspiration to those of you who are just starting out.

There are, of course, a number of other treats in store, most particularly Don Emerson's article on the history of the lodestone. Don notes that the ancients believed that ingestion of small quantities of lodestone restored one's youth in the manner of 'vipers wine'. According to Don, vipers wine is a ghastly decoction brewed from vipers, aloes and balsam – amongst other things. Methinks that lodestone pills would preferable. Don Emerson has promised to follow this article with another on the history of lapis lazuli and to say something about the petro physical properties of this historically rare and precious commodity. I understand that he is already out and about obtaining samples so lock up those illuminated manuscripts!

The next issue of *Preview* will include the ASEG–PESA 2015 conference handbook and will appear in your conference satchel. The Perth conference promises to be a marvellous outing for all geophysicists. The ASEG Publications team will be there in force – in the hopeful expectation of garnering exciting copy – and we look forward to receiving your feedback on both *Preview* and *Exploration Geophysics*. In the interim, the Publications team wishes you a safe and happy festive season.

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





Letter to the Editor

Hi Lisa

I read the current issue of *Preview* (**172**) with interest, and noted in your editorial a lamentation that 'the CSIRO team of geophysicists has largely been disbanded'. Given that it was a comment made in the context of government sponsored research and development, it could be taken that CSIRO has given away geophysics as an active area of research. Nothing could be further from the truth, and it would be remiss of us not to counter such perspectives.

In fact you only have to look at recent material presented in the previous issue of *Preview* **171**, **'**Understanding magnetism in the Giles Complex, Musgrave Block, SA' by James Austin, Dean Hillan, Phil Schmidt and Clive Foss, to get a flavour for some of the research we are engaged in. The Magnetics and Gravity Research Team undertakes studies to advance the use of magnetic field data in mineral exploration and development programs and have been very active in that area in the past 5 years. These studies span theoretical advances (for instance in magnetic moment analysis and self-demagnetisation), development of new technology (down-hole tensor magnetic gradiometry), and creation of software (for instance linked, web-delivered Australian databases of magnetic field anomalies due to remanent magnetisation, rock magnetic properties and palaeomagnetic studies). The research group, which includes geophysicists in the Mineral Resources and Manufacturing Flagships, cooperates internationally to target research problems, provides solutions and training to industry, government and academic geoscientists, and also undertakes sponsored research selected to ensure our relevance to the exploration industry. Their work is internationally recognised, and combines young researchers with more experienced ones.

Elsewhere CSIRO continues an active research program in minerals geophysics with some innovative work being undertaken in the above mentioned Flagships on borehole geophysical methods. CSIRO has been active in this area for several decades, with some of that work delivering into the research agenda of the DETCRC (including the development of a gamma neutron activation tool, which provides in situ 'assays' of some key elements in rocks surrounding the drillhole). In the manufacturing sector, CSIRO has continued an active research agenda having developed and delivered LandTEM (SQUID-based TEM systems) in collaboration with industry, in work led by Cathy Foley and Keith Leslie. Subsequent developments involving that group include the down-hole tensor magnetic gradiometry technologies mentioned above.

In the EM and seismic space CSIRO has more than eight geophysicists working on a range of problems linked to CO_2 sequestration, geothermal, oil and gas reservoirs, and coal mine characterisation, inversion, NMR and EM for aquifer and groundwater characterisation, regolith and geological mapping etc. A key focus for their research agenda is exploration through cover. I haven't mentioned that CSIRO also houses one of the foremost geomechanics and rock physics laboratories in the world, led by Ben Clennell and Dave Dewhurst. The Petrophysics laboratory facilities are used to determine and interpret the physical properties of rocks to enable the characterisation of the production performance of petroleum reservoirs.

Geophysics is alive and well in CSIRO and the 'team' of geophysicists is growing, not disbanding. We at CSIRO consider geophysics as a priority area for future R&D and as a collective we are very optimistic about contributing significantly to the technology developments and applications across a range of areas, just as many would expect of an organisation such as ours.

I will finish by making comment on Greg Street's assertion, made in the same issue of *Preview*, that 'Cost cutting at CSIRO has left so few geophysicists, one wonders if they can be really effective in research. This situation is compounded by cost recovery which forces CSIRO to compete for projects with the private sector'. As a collective we regard this, at best, as being ignorant of the realities and, at worse, disingenuous. CSIRO has a large contingent of geophysicists, sure not as many as we would like, but we believe we are being ***very effective*** in our research. I would go further and venture to suggest that as an organisation we are blessed with probably one of the largest contingents of scientists in this disciplinary area in Australia. As regards the comment on 'cost recovery' – again I suggest such comments are naive. Our cost base is well in excess of many consultants, one reason why we cannot compete when jobs go to tender. We are not 'forced to compete' because if we did, we'd be bankrupt tomorrow. CSIRO has a range of skill sets available for research. It is by doing the research well and demonstrating this that we attract support from external agencies and industry. It is really that simple.

Best regards

Tim

Tim Munday
tim.munday@csiro.au

Travels and travails

It has been a busy period since my last piece in *Preview*. In September I attended the EAGE Near Surface Conference in Athens. It was a small but well run event and the hospitality in Athens was first class. Following the EAGE meeting I represented the ASEG in Denver, USA, at the annual SEG meeting. Like many before me I found the SEG a massive event with a maze of exhibitors in a vast convention centre. Also, like many before me, I found that the meeting was dominated by the oil and gas sector and that for many in the SEG, geophysics equals seismic reflection. The SEG groups minerals geophysics with engineering, environmental and archaeological geophysics in the 'Near Surface Geophysics' basket. There were less than five exhibitors relevant to minerals geophysicists and probably only one or two of relevance to engineering and environmental geophysicists.

For those who have not been to the SEG this was an 'off' year for minerals. Every second year they have a greater minerals focus and thus SEG 2016 in New Orleans may be better for those in the minerals sector. Having said all that, if you are a seismic geophysicist then the SEG conference provides a wonderful range of papers, exhibits and demonstrations that are unavailable anywhere else in the world.

You may ask why the ASEG president attends the SEG. This was a question I had on my mind before travelling to Denver. Firstly, I might say that the trip from Perth across the Pacific going east was horrendous. I did not recover from jetlag until well after I got back and most of my week in Denver was a bit of a haze, as I woke every morning at around 2 am. As ASEG President I had a number of duties between Monday and Wednesday including:

- Manning the ASEG booth.
- Delivering an address to the Asia-Pacific luncheon.
- Attending a meeting to prepare for Exploration 2017 in Toronto.
- Attending a Minerals Group meeting.
- Attending the annual President's reception.
- Meeting with SEG Japan and SEG Korea about our continuing relationship, particularly in regards to publication of Exploration Geophysics.
- Meeting with the President of the Mongolian Geophysical Society.
- Meeting with the Near Surface Group – including a discussion about the Near Surface Conference in Hawaii in 2015.
- Meeting with SEG President, President Elect and executive staff to discuss the SEG role in Australia and especially the provision of the DISC and DL series.
- Promoting the Perth ASEG–PESA conference.
- Bringing student membership of the ASEG to the attention of students at all the universities represented in the exhibition.
- Bringing our overseas members up-to-date with what is happening in the ASEG.

Was it all worth the trip? From a personal perspective it was probably not worth the trip because there were not enough papers and exhibits of interest to me. From the ASEG perspective, however, I believe it was worth sending the President to the conference because we continue to get DISC and DL lecturers from SEG, it is a great place to promote the ASEG, and our expatriate and overseas members like to have the opportunity to catch up with what's happening in Australia.

I now look forward to ASEG 2015 in Perth. ASEG conferences are such a great way to catch up with old mates and make new friends. The conference committee has put together a great program. The North Americans were particularly impressed by the inclusion of geologists, which makes the conference relevant to all explorers. I hope to see you there.

By this time you should have received your annual renewal notice and noted a small increase in membership fees to reflect the increase in the Australian Consumer Price Index. Your membership runs out for 2014 on 31 December and I urge you to take advantage of the generous discount in 2015 membership fees for those paying by the end of 2014.

The Federal Executive has put a lot of effort into making the membership renewal process easier in 2015. Some of the difficulties that members experienced in 2014 were caused by the outmoded membership database. Our new secretariat recommended a professional database software called Currinda and you might encounter this program in your renewal.

This has not been a good year for geophysicists, particularly those involved in the minerals sector. Those of you still employed might spare a thought for our student and underemployed members during the festive season. Can you talk your employer into taking a student for vacation work? As education becomes more expensive students need vacation work to carry them through the year and any job relevant to geophysics has to be better than waiting on tables. Can you offer contract or short term work to those currently on 'gardening leave' to help them survive the downturn?

The Annual General Meeting will be held in Sydney in April 2015. We are seeking new people to take on committee roles in the ASEG. So, consider stepping forward or dobbing in a mate. We particularly need volunteers for roles on the Education Committee. This group (which is a group of one run by Wendy Watkins) runs the OzStep program and has a role in bringing SEG and EAGE lecturers to Australia as well as liaising with the secondary science teachers groups in the east (TESEP) and in Western Australia (STAWA).

There are many other roles to be filled and I encourage you to volunteer, particularly if you have ideas about where the society should go in the future.

Greg Street
ASEG President
president@aseg.org.au

The ASEG President snapped at the races with eminent geophysicist Kim Cook.

Meet your 2014–2015 ASEG Federal Executive

Directors

President

The President of the ASEG is one of the four Directors of the Society as recognised by Australian Securities and Investment Commission (ASIC), and has legal obligations to ASIC under the *Corporations Act 2001* for the proper running of the Society. The President oversees the general running of the ASEG Federal Executive (FedEx), chairs FedEx meetings, General Meetings and the ASEG council meeting held at the ASEG conference. In addition, the President represents the society at the ASEG annual conference and at international meetings.

A candidate for President is expected to serve for a minimum of 3 years; the first as President Elect learning the ropes, then a year as President and finally a year as Past President acting as a mentor to the President and President Elect. There is no requirement to resign after 3 years if one still has energy and enthusiasm for the job and the support of the FedEx. The 3 year term allows the President to take on projects and see them through to completion, therefore it is not uncommon for the Past President to be running with projects they started, or which were started during their term as President. Both the President Elect and President are Directors of the Society and responsible to the members as well as ASIC.

Greg Street 2014–2015
president@aseg.org.au

President Elect

The President Elect's role is to support the President and act on their behalf when required, and also to work with the standing committees when the opportunity arises. The President Elect has 12 months to become familiar with the issues facing the Society so they will be able to implement plans the following year.

Phil Schmidt has been the Chair of the Society's Publications Committee since 2005. He is due to stand down as Chair of that Committee in 2015.

Phil Schmidt 2014 – present
presidentelect@aseg.org.au

Secretary

The ASEG has a professional Secretariat that undertakes many of the traditional roles of an Honorary Secretary. This has allowed the ASEG's Secretary to focus on improvement of old policies, and the development of new policies that describe how the Federal Executive puts into practice the Society's Constitution. The Secretary organises FedEx events such as the Annual General Meeting and meetings of Council. They also maintain the Society's Strategic Plan. The Secretary is elected each year and is a Director of the ASEG.

Barry Drummond 2012 – present
fedsec@aseg.org.au

Treasurer

The Federal Treasurer is elected at the Annual General Meeting as a Director of the Society. This role requires the Treasurer to be responsible for all of the Society's accounts and finances (federal and state) and to be accountable to the relevant regulations under ASIC. The Treasurer is also the Chair of the Finance Committee, which advises the FedEx on longer term financial matters.

Theo Aravanis 2014 – present
treasurer@aseg.org.au

Non-Directors

AGC Representative

Kim Frankcombe 2012 – present
kfankcombe@iinet.net.au

The Australian Geoscience Council (AGC) is a body representing the Geoscience Learned Societies. As well as the ASEG it includes the AIG, AusIMM, PESA, GSA, IAH, AGIA and AAG. Representation and voting power is determined by each society's size. Its main role is in lobbying and focusing geoscience agendas for the benefit of its members. Following the very successful IGC conference in Brisbane, the AGC now also has funds to apply to education as well as other worthwhile projects that may benefit Australian geoscientists in general.

Conference Advisory Committee Representative

The ASEG will have at least one Conference Organising Committee (COC) active at any time, although there are generally two and often more when smaller symposia-style events are included. Behind the Organising Committees are a group of past Conference Chairs collectively called the Conference Advisory Committee (CAC). Their role is to mentor the COC and to act as the Society's corporate memory and as a panel of experts in advising the FedEx. Kim Frankcombe is the Executive's representative on the CAC.

Kim Frankcombe 2011 – present
kfankcombe@iinet.net.au

Continuing Education Committee Chair

The Continuing Education Committee aims to help meet the needs for the ongoing education of members and to help to promote geophysics as a career. This is achieved by arranging for visiting lecturers from overseas societies to present at State Branch meetings, and by providing 1-day courses e.g. SEG Distinguished Instructor Short Courses, EAEG Education Tours and the ASEG OZSTEP courses. The aim is to deliver one minerals and one petroleum course per year.

In the future more educational material will be presented online and the Society is developing a strategy to facilitate this.

Wendy Watkins 2013 – present
continuingeducation@aseg.org.au

Immediate Past President

The position of Immediate Past President is filled by the President of the previous year. The role of Immediate Past President is to provide continuity in the activities of the ASEG FedEx. The Immediate Past President is expected to advise the current President about the status of standing projects and issues, past resolutions and contacts in foreign societies. They advise the Directors from their experience.

Koya Suto 2014 – present
pastpresident@aseg.org.au

International Affairs Committee Chair

ASEG has ten associated societies: SEG, EAGE, SEG Japan, Korean SEG, Engineering and Environmental Geophysical Society (EEGS), SAGA (South Africa), SPE India, Chinese SEG, SBGf (Brazil) and Mongolian SEG. The responsibility of the International Affairs Committee includes communicating with these societies on conferences and other activities, and organising meetings with them. As the President often represents ASEG at meetings with the associate societies, the Chair of the International Affairs Committee reports directly to the President.

Koya Suto 2014 – present
pastpresident@aseg.org.au

Membership Committee Chair

The Membership Committee is responsible for membership matters, which include admission, renewal, promotion and dismissal. They assist the Secretariat in maintaining the membership database and any enquiries that arise. The Membership Chair is a member of the Executive and advises the FedEx of new member applications and membership upgrades and assists the Secretariat in preparing renewal procedures and forms.

Katherine McKenna 2013 – present
membership@aseg.org.au

Publications Committee Chair (Vacant in 2015)

The Publications Committee Chair's role is to coordinate the Publication Committee's efforts to deliver the Society's publications on time and on budget. This requires dealing with the publisher (currently CSIRO Publishing) to address changing Society needs, new technologies and interfacing between the publisher and the Committee. The Publications Committee comprises the Chair, the Publications Officer and the Editors-in-Chief of *Exploration Geophysics* and *Preview*. Phil Schmidt has been the Publications Chair since 2005.

Volunteers interested in becoming the Chair of the Publications Committee should contact secretary@aseg.org.au for more information regarding the role.

Specialists and Working Groups Liaison

Specialist and Working Groups are supported by the ASEG FedEx to assist members interested in the same sub-discipline to network and advance their knowledge through workshops and conference sessions. Coordination between the FedEx and Specialist and Working Groups is undertaken by this position.

Tania Dhu 2013 – present
tania.dhu@nt.gov.au

State Branch Representative

State Branches hold a key role in delivering services to local members. The State Branch Representative liaises between the Branches and the FedEx, communicating relevant issues between the Federal and Branch levels of the Society.

Tania Dhu 2013 – present
branchrep@aseg.org.au

Technical Standards Committee Representative

The Technical Standards Committee was established to co-ordinate uniform data exchange formats such as the GXF, ASEG GDF and most recently the ASEG ESF. It also acts as the Society's interface to external bodies such as GGSSA and IAGSA. It is chaired by Tim Keeping and represented on FedEx by Kim Frankcombe.

Kim Frankcombe 2011 – present
kfankcombe@iinet.net.au

Website Committee (Vacant in 2015)

The Website Committee works with web designers and the Secretariat to design, maintain and keep the web page up to date. They work on strategies to allow for continuous improvement of the web functionality, its services to the members and in helping promote the Society to the greater community.

Volunteers interested in becoming the Chair of the Website Committee in 2015 should contact secretary@aseg.org.au for more information regarding this role.

webmaster@aseg.org.au

Welcome to new members

The ASEG extends a warm welcome to new Members approved by the Federal Executive at it's meetings in October and November.

First name	Last name	Organisation	State	Country	Membership type
James	Goodwin	Geoscience Australia	ACT		Active
Laszlo	Katona	Geological Survey of South Australia	SA		Active
Gary	Reed	Geological Survey of South Australia	SA		Active
Stephan	Thiel	Geological Survey of South Australia	SA		Active
Paul	Walshe		SA		Active
Will	Yount	Schlumberger	SA		Active
Mark	Stanley	CGG	VIC		Active
Shane	Mulè	CGG	WA		Active
Andrew	Stevenson	GHD	WA		Active
Otgonbayar	Dorjsuren	Xanadu Mines Mongolia LLC		Mongolia	Active O/S
Alireza	Mardani	SINOPEC		Iran	Active O/S
Lynsey	Brett	Rio Tinto	WA		Active
Graeme	Eastwood	GX Technology Australia Pty Ltd	WA		Active
U Geun	Jang	The University of Western Australia	WA	Australia	Active
Nikhil	Prakash	Rio Tinto	WA	Australia	Active
Michael	Alexander	Integrated Geophysics Corp.	TEXAS	USA	Active O/S
Mazin	Farouki	Petroleum Geo-Services		Singapore	Associate
Julien	Bourget	University of Western Australia	WA		Associate
Alastair	Smart	Omnitron TechnologiesP/L	VIC		Associate
Nooreddin	Alavi		WA		Associate
Adouley	Guirou	First Quantum Minerals		Mali	Associate
Sarah	Bembrick	University of Sydney	NSW		Student
Andrew	Takonis	University of New South Wales	NSW		Student
Jean-Daniel	Nicolas	Macquarie University	NSW		Student
Thedius	Godwin	Macquarie University	NSW		Student
Stephanie	Kovach	Macquarie University	NSW		Student
Ida	Hooshyari Far	Curtin University	WA		Student
Abdulaziz	Alasbali	Curtin University	WA		Student
Lachlan	Hennessy	RMIT University	VIC		Student
Joseph	Hamad	RMIT University	VIC		Student
Wen Jun	Lau	Macquarie University	NSW		Student
Aaron Joseph	Girard	UWA	WA		Student
Will	McAdam	University of Tasmania	TAS		Student
Bronson	Rogers	University of Tasmania	TAS		Student
Benjamin	Witten	The University of Western Australia	WA		Student
Muhammad	Hossain	Curtin University	WA		Student

Magnetic Field Sensors for Exploration

Three-Axis Magnetic Field Sensors

- Measuring ranges from ±70μT to ±1000μT
- Noise levels <6pTrms/√Hz at 1Hz
- Bandwidth to 3kHz; wide bandwidth version to 12kHz
- Range of data acquisition units

MS3 Magnetic Susceptibility System

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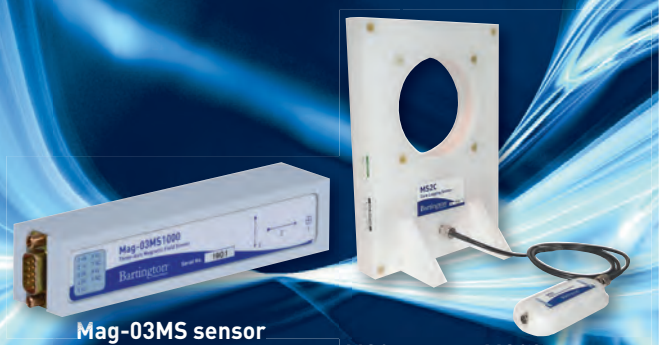
- Noise levels down to $2x10^{-6}$ SI
- Measuring range up to 25 SI



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Notice of Annual General Meeting

The 2015 Annual General Meeting (AGM) of the Australian Society of Exploration Geophysicists (ASEG) will be held in Sydney on Wednesday 15 April 2015. The meeting will be hosted by the NSW Branch at the Rugby Club (http://www.rugbyclub.com.au/). The address is: Rugby Place, Off Pitt Street, Sydney, NSW 2000.

Drinks will be available from 5.30 pm and the meeting will begin at 6.00 pm.

The business of the AGM will include:

- To confirm the minutes of the 2014 AGM;
- 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 Society's Constitution and to law;
- To report the ballot results for the election of the new office holders for the Federal Executive;
- To confirm the appointment of auditors for the 2015 financial year.

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 of the Federal Executive are listed in *Preview*; please contact one of them if you wish to know more about volunteering for your society.

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

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

These officers are elected annually by a general ballot of Members. Phil Schmidt was elected as President Elect in 2014 and as such will stand for the position of President in 2015.

Members wishing to nominate for one of these positions should note that 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 following officers are also recognised in the Society's Constitution and serve on the Federal Executive:

(i) Vice President,
(ii) the Immediate Past President (unless otherwise a member of the Federal Executive),
(iii) the Chairman of the Publications Committee,
(iv) the Chairman of the Membership Committee,
(v) the Chairman 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:

Barry Drummond
ASEG Secretary
Care of the ASEG Secretariat
PO Box 576, Crows Nest, NSW 1585
Tel: (02) 9431 8622
Fax: (02) 9431 8677
Email: fedsec@aseg.org.au

Nominations must be received via post, fax or email **no later than COB Wednesday 18 March 2015**. 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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ASEG News

Queensland

In October we welcomed the SEG near-surface honorary lecturer **Dr Koichi Hayashi** presenting 'Integrated Geophysical Methods Applied to Geotechnical and Geohazard Engineering: From Qualitative to Quantitative Analysis and Interpretation'. The audience was entertained by his sense of humour and interesting presentation. In November we are hosting an OZSTEP workshop 'Interpreting seismic amplitudes' presented by **Dennis Cooke**. The Queensland branch is also looking forward to our annual student night which will showcase the work of three recent Queensland graduates including **Nicholas Josephs** 'Ground penetrating radar and an Honours case study on the eastern coast of Queensland', **Andrew Pacey** 'Predictive deconvolution for coal seismology' and **Daniel Reyes** 'Geophysical indicators of CSG sweet spots'.

Dr Koichi Hayashi presenting to the Queensland Branch of the ASEG.

We invite anyone who is visiting Brisbane to attend our technical meetings and are currently looking for speakers for 2015.

Fiona Duncan (Queensland Branch President)

South Australia and Northern Territory

Recent events for the SA/NT Branch have included our annual Industry Night, the Melbourne Cup Luncheon and the SEG Near Surface Lecture, presented by **Dr Koichi Hayashi**. His talk, 'Integrated geophysical methods applied to geotechnical and geohazard engineering: from qualitative to quantitative analysis and interpretation' was well attended by a diverse audience, mostly interested in hearing of geophysical methods being used outside of the resources industry. This talk was also notable for drawing the largest audience of engineers seen in recent history at an SA ASEG technical evening.

All our technical events are made possible by our very generous group of sponsors for 2014, including Beach Energy, the Department of State Development, Geokinetics, Ikon Science, Minotaur Exploration, Petrosys, Santos, Schlumberger, Statoil and Zonge. We hope to have them all back in 2015, with a few new faces too.

The Industry Night in October showcased a diverse group of companies, with presenters from Minotaur Exploration, Santos, Schlumberger and Statoil giving the local branch members an update of their activities. The Beach-Energy sponsored ASEG Melbourne Cup Luncheon was also a great success, despite the best efforts of a poorly timed fire alarm drill during the Calcutta Sweep proceedings.

By the time you have read this, events for 2014 will likely have wound up, and the Committee will be starting to look into events calendar for 2015, starting with the AGM in March, when everyone is back from ASEG–PESA 2015 in Perth. We welcome any interested members to the local Committee, and any commitment, large or small, is appreciated.

As ever, new members and other interested persons are always welcome to local events. For further details, please contact Luke at luke.gardiner@beachenergy.com.au or 08 8338 2833.

Luke Gardiner (SA and NT Branch President)

Tasmania

Dr Brian Minty's OzSTEP radiometrics workshop held on 30 September was both well received and well attended. A solid majority of the 20 participants were not primarily from geophysical backgrounds. This is an excellent sign of broader recognition of the potential of the technique for lithological and alteration mapping, especially in Australia with its extensive coverage of high quality public data sets. In a testament to Brian's presentation skill and expertise, the whole audience remained thoroughly engaged throughout the day, despite widely varying prior knowledge. All came away having learned a great deal and glimpsed some exciting ongoing developments.

Dr Koichi Hayashi from Geometrics in California gave the 2014 SEG Near Surface Honorary Lecture to the Tasmanian branch on 6 October. University Earth Sciences staff, students and members of the local geotechnical community all appreciated Koichi's presentation on how the integration of geophysical techniques can deliver information of direct use to engineers engaged in major construction and natural disaster mitigation. Thanks go to the SEG and sponsor Shell for giving us this sort of access to world class expertise, and also to the School of Earth Sciences and ARC Centre of Excellence in Ore Deposits at the University of Tasmania for hosting these ASEG branch events.

October also saw several geophysics Honours students give their final presentations. **Alistair Harvey** 'Geophysical interpretation of the Eastern Surat Basin basement' sponsored by QCG, supervised by **Michael Roach**, **Jie Yu** 'A geophysical investigation of the Mt Lindsay-Lynch Hill area, western Tasmania' sponsored by Mineral Resources Tasmania and Venture Minerals, supervised by **Michael Roach** and **Mark Duffett**, and **Ashby Cooper** 'Crustal structure of the Bass Strait region from combined passive seismic methods' sponsored by the Australian Research Council in partnership with Mineral Resources Tasmania, Geoscience Victoria and FrOGTECH, supervised by **Anya Reading** and **Nick Direen**, all gave talks of a very high standard.

Mark Duffett (Tasmanian Branch President)

Victoria

On Wednesday 8 October the ASEG Victoria Branch hosted an evening technical meeting at the Kelvin Club with the SEG 2014 Near Surface Honorary Lecture 'Integrated geophysical methods applied to geotechnical and geohazard engineering: from qualitative to quantitative analysis and interpretation', by **Dr Koichi Hayashi** from Geometrics. The evening was well attended with the additional influx of members from the Australian Geomechanical Society.

On Thursday 23 October we hosted the Annual Student Night, where local geoscience students presented their current research. First place went deservedly to **Teagan Blaikie**, School of Geosciences, Monash University for her work on 'Interpreting the subsurface architecture of maar volcanoes using geologically constrained 3D gravity inversions'. **Janenie Mohgan** from Monash University, presenting 'Ground Penetrating Radar (GPR) used as a geophysical method for subsurface utility mapping and lateritic bauxite exploration', shared second place with **Robin Armit** from Monash University presenting 'High-heat geodynamic setting during the Palaeozoic evolution of the Mount Painter Province, SA, Australia: evidence from integrated field structural geology and joint potential-field inversions'.

Dr Koichi Hayashi presenting to the Victorian Branch of the ASEG (and what seems to be a number of billiard tables).

On Wednesday 10 December it will once again be time celebrate the festive season at our Annual ASEG–PESA–SPE Societies Christmas Lunch at the Victoria Hotel in Melbourne's CBD.

We look forward to seeing many ASEG Victoria Branch members at the meetings in the coming months.

Asbjorn Norlund Christensen (Victorian Branch President)

Western Australia

It has been a fantastic spring season for WA with very many events such as the OzSTEP Workshop on Radiometrics, a Tech Night to celebrate the release of the new geophysical text book, a visit by the SEG Honorary Lecturer, a workshop on Magnetotellurics (MT), the ASEG–PESA Golf Classic and a students' presentation night.

On 22 September the OzSTEP one-day workshop on 'Gamma-ray spectrometric method for mineral exploration and environmental mapping' was held at Technology Park Function Centre, Bentley. This four-session workshop led by **Dr Brian Minty** was attended by 20 geophysicists/geologists.

Dr Brain Minty presenting to the WA Branch of the ASEG.

On Thursday, 25 September the WA Branch gathered to celebrate the release of the text book 'Geophysics for the mineral exploration geoscientist' co-authored by **Michael Dentith** and **Stephen Mudge** and published by

Cambridge University Press. **Geoff Pettifer** of GHD made an excellent review presentation on the wider relevance of this new mineral geophysics text book to groundwater, geotechnical, hydrocarbon and environmental investigations. About 40 people attended this special Tech Night.

On Friday 10 October SEG Honorary Lecturer **Dr Koichi Hayashi** from Geometrics, California spoke on 'Integrated geophysical methods applied to geotechnical and geo-hazard engineering: from qualitative to quantitative analysis and interpretation'. The lecture introduced several case studies from different countries around the world.

A week long workshop on magetotellurics (MT) was conducted at University of Western Australia in late October. This popular MT-Workshop was conducted by **Professor Alan Jones** of Dublin Institute for Advanced Studies, Dublin. Module One of the workshop covered 'An introductory short course for geoscientists' while Module Two helped the participants with practical data analysis and 1D inversion.

The 27th Annual **ASEG–PESA Golf Classic** was conducted on Friday 7 November at the Araluen Resort, WA, and was well attended by both ASEG and PESA members.

The Tech Night on Wednesday 12 November was exclusively for Honours and Masters students who had just completed their research projects. This year we had five candidates. Their names, affiliations and research topics are listed below:

1. **Matthew Kovacevic** (Curtin University) spoke on 'Seismic characterisation and tectonic significance of listric fault systems in the Ceduna sub basin'.
2. **Mahesh Raghvani** (Curtin University) spoke on 'Using seismic tomography to map shallow structures on land seismic'.
3. **Vanessa Carolia Gutierrez Acevedo** (Curtin University) spoke on 'Cooperative evaluation of post-stack inversion techniques over the Maitland Reservoir and adjacent prospects'.
4. **Alexander Costall** (Curtin University) spoke on 'Feasibility of Ground Penetrating Radar for Delineation of the Saline Water Interface along Perth's Coastal Margin'.
5. **Sandy Jones** (Curtin University) spoke on 'Evaluation of an electromagnetically driven seismic source'.

From left: Matthew Kovacevic, Mahesh Raghvani, Vanessa Carolia Gutierrez Acevedo, Alexander Costall and Sandy Jones.

The audience at the WA ASEG Branch Tech Night 2014.

A large number of ASEG–PESA members attended this special Tech Night and the Best Presenter award was given to Matthew Kovacevic.

The WA branch of the ASEG is offering awards to eligible students currently studying geophysics or a related scientific discipline. The aim of the program is to promote and encourage geophysics-related research and education in WA.

Applications were invited from eligible students currently studying geophysics or a related scientific discipline at universities in WA. This year there were many applicants and a thorough review process was undertaken, following the ASEG guidelines, in search of 'the best'.

Benjamin Witten, PhD student at University of Western Australia (UWA) received the A$2000 award for 2014. His research topic is 'Elastic parameter estimation using image-domain adjoint-state tomographic inversion of passive seismic wavefields'. According to Ben, the research outcome is expected to contribute towards the improvement of velocity estimates that will lead to more accurate appraisal of earthquake properties, which will in turn provide more robust decisions and risk assessments operators of injection wells. Additionally this research could have applications on other scales and fields such as regional or whole earth seismology, non-destruction testing, and security such as within nuclear test ban monitoring.

Ben Witten

Ben Witten graduated with a BSc in Applied Mathematics from Columbia University (2005), and with an MSc in Geophysics from Stanford University (2008). After completing his MSc, he went into industry for 5 years with Spectraseis working on passive seismic research and processing. In early 2014, he returned to academia to begin a PhD at UWA. He was awarded a UWA International Postgraduate Research Scholarship, an Australian Postgraduate Award and a UWA Safety-net-top-up Scholarship. Ben has contributed to various aspects of geophysics working on active and passive seismic projects, as well as near-surface studies and archaeological geophysics investigations. He has (co)-authored six peer-reviewed journal publications, 17 extended abstracts and submitted three patents. Ben is active in the geophysical community, having reviewed articles for various journals and conference abstracts. He was also the SEG Student Chapter vice-president while at Stanford, and currently holds the same position within the UWA SEG Student Chapter. He has contributed to the geophysical work within the WA community and promotes its value for cultural and heritage purposes.

John Joseph on behalf of Kathlene Oliver (WA Branch President)

Australian Capital Territory

ASEG ACT student branch member **Jack Muir** has been awarded a scholarship by the General Sir John Monash foundation for 2015. The foundation assists future Australian leaders in completing overseas postgraduate study. Between 12 and 15 scholarships are awarded each year, to the value of $60 000 p.a. for up to 3 years. Jack has recently completed his Honours year at the ANU, and hopes to continue his research by developing new statistical methods to solve problems in seismic tomography. Jack intends to complete a PhD at the California Institute of Technology, and eventually return to the Australian geophysics community. We wish Jack well with his studies.

Geoscience Australia hosted **Professor Alan Jones**, Head of Geophysics at the Dublin Institute of Advanced Studies, on 17 November. Professor Jones presented 'Modelling the lithosphere constrained by topography, surface heat flow, geoid, gravity, seismology and magnetotellurics within a self-consistent petrological-geophysical framework', which was based on his presentation at the International Conference on Continental Dynamics earlier in 2014. The local branch organised afternoon tea and dinner with Alan during his visit.

The ACT branch held an ASEG promotional event on 26 November at Geoscience Australia where four talks were presented to an audience including various specialities of earth science, students, engineers and education professionals. Speakers included: **Richard Blewett** 'Progress in deep seismic reflection transects across Australia', **Ian Roach** 'AEM and its application to potash exploration in Australian salt lakes', **Tony Meixner** 'Stavely geophysical acquisition – mapping cover thickness prior to drilling' and **Sanjay Govindan**, Student Scholarship Winner speaking about his research.

During the promotional event ACT local branch gifts were handed out. Gifts were given to: **Tim Jones** for his work organising the Federal Executive AGM here in April as well as his student contributions; **Phil Wynne** for his support of the local branch activities, particularly with the scholarship awards and set up of events; **Guy Holmes** for his fantastic work in *Preview*; **Tania Dhu** for representing the local branches at the Federal level; and **Carina Kemp** for her work with the Federal Executive as well as her work here at the local level. We also thanked every ASEG member who works hard to ensure we have a society that promotes the science of geophysics, throughout Australia, fosters fellowship and co-operation between geophysicists, encourages closer understanding and co-operation with other earth scientists and assists in the design and teaching of courses in geophysics – THANK YOU.

Christmas for the ACT branch will be a combined ASEG–PESA 'back to the 1920s' with a themed Christmas Party at Kamberra Winery on Friday 5 December 2014. Tickets are $50 for members. Contact **Millie Crowe** for more details.

The ACT branch of the ASEG wishes you a Merry Christmas and happy and safe holidays.

Marina Costelloe (ACT Branch President) and Millie Crowe (ACT Branch Secretary)

New South Wales

In September, **Brian Minty** from Minty Geophysics gave his OzSTEP workshop on the basics of radiometrics. After a day of enlightening the workshop attendees, Brian then gave a talk in the evening on 'Developments in airborne gamma-ray spectrometry'. Brian spoke about aspects of radiometrics that currently have his interest, such as how to reduce noise in multichannel airborne gamma-ray spectra, as well as the automatic detection of radioelement anomalies and on the 3D inversion of airborne gamma-ray spectrometric data to elemental concentrations on the ground. Many questions and discussion followed his presentation.

In October, we held our student night and the following students spoke. All talks were well presented and much discussion followed over beers and wine.

Rhiannon Garrett: 'Numerical modelling of salt tectonics: understanding the impact of salt's thermal conductivity on temperature distribution' (Sydney University)

Benjamin Patterson: 'Geophysical investigation of the Woodend base metal occurrences' (Macquarie University)

An invitation to attend NSW Branch meetings is extended to interstate and international visitors who happen to be in town at that time. Meetings are held on the third Wednesday of each month from 5.30 pm at the Rugby Club in the Sydney CBD. Meeting notices, addresses and relevant contact details can be found at the NSW Branch website.

Mark Lackie (NSW Branch President)

Date	Branch	Event	Presenter	Time	Venue
2015					
15–18 Feb	WA	ASEG-PESA Conference			Perth Convention Exhibition Centre (http://www.conference.aseg.org.au/).
18 Mar	NSW	Branch Meeting and technical presentation	TBA	1730 till late	Rugby Club, Rugby Place, Off Pitt Street, Sydney (http://www.rugbyclub.com.au/).
15 Apr	NSW	ASEG AGM and technical presentation	TBA	1730 till late	Rugby Club, Rugby Place, Off Pitt Street, Sydney (http://www.rugbyclub.com.au/).

TBA, to be advised (please contact your state branch secretary for more information).

Australian Society of Exploration Geophysicists

RESEARCH FOUNDATION

All geophysics students at Honours level and above

You are invited to apply for ASEG RF grants for 2015

Closing date 27 February 2015

Donations to the ASEG Research Foundation are always very welcome and are tax deductible

Contact ASEG if you wish to make a donation

Awards are made for:

- BSc(Hons) Max. $5000 (1 year)
- MSC Max. $5000 per annum (2 years)
- PhD Max. $10 000 per annum (3 years)

Application form and information at:
http://www.aseg.org.au/research-foundation

Awards are to project specific applications, and reporting and reconciliation is the responsibility of the supervisor

Any field related to Exploration Geophysics considered
e.g. Petroleum, Mining, Environmental, Engineering

Applications must be electronic and on the application form

Email to Doug Roberts (Secretary ASEG RF): dcrgeo@tpg.com.au

ASEG Research Foundation

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

Strategy
To promote research in Applied Geophysics, by providing research grants at the BSc(Hons), MSc and PhD levels (or equivalent).

Management
The ASEG RF Committee comprises ASEG members from mining, petroleum and academic backgrounds, who serve on an honorary basis, and who share the administrative costs to spare Research Foundation funds from operating charges. The funds are used in support of the project, for example, for travel costs, rental of equipment, and similar purposes. Funds must be accounted for and, if not used, are returned to the ASEG Research Foundation.

History articles in *Preview*

An early project of high priority for the History Committee was the compilation of all the items of historical interest in past issues of *Preview*. In addition to feature articles and anniversary articles (many by our prolific historian, Doug Morrison), obituaries were included as they invariably contain historical information.

The first compilation, starting with the first digitised issue of *Preview* (August 1988) and finishing with the issue for October 2013, is appended below. In the digital version of this article, which is available on line, each item is directly linked to the appropriate issue of *Preview*. The list consists of 70 items from 113 issues, with some issues having more than one item. The list will be up-dated periodically.

Roger Henderson and Anne-Marie Anderson-Mayes
history@aseg.org.au

Issue no.	Starting page	Title	Type
53	35	A fortunate life in seismic - Part I (an interview with Bob Sheriff)	Interview
54	30	A fortunate life in seismic - Part II (an interview with Bob Sheriff)	Interview
54	12	Reg Sprigg	Obituary
61	35	William (Bill) Stuart	Obituary
87	8	Eric Blazey 1906-2000 (by Bill Langron)	Obituary
87	8	Dave Dekker 1951-2000 (by Sharyn Dawson)	Obituary
89	12	Geoff Dickson 1938-2000 (by Peter Dalhous)	Obituary
95	15	Adelmo Agostini 1941-2001 (by Steve Webster)	Obituary
96	11	Wilfred Parkinson 1919-2001 (by Charles Barton & Max Banks)	Obituary
97	12	Samuel Carey 1911-2002 (by Patrick Quilty)	Obituary
98	23	Geological Survey of Victoria celebrates 150 years of achievement	Article
99	16	Fifty Years Of Potential Field Modelling (David A. Pratt)	Article
100	11	Norm Uren retires	Article
100	12	Stanley Ward	Obituary
100	6	The History of Preview	Article
107	10	Hugh Doyle 1927-2003 (by John Glover)	Obituary
108	9	Rodney Tuson 1941-2003 (by Bob Richardson)	Obituary
109	14	Geophysical Anniversaries - Doug Morrison	Article
110	15	Geophysical Anniveraries - The magnetic shoal near Bezout Island (Doug Morrison)	Feature
111	18	Geophysical Anniversaries - 140 years ago - Neumeyer (Doug Morrison)	Article
111	11	James Dooley 1919-2004 (by Barry Drummond)	Obituary
111	13	Bernie Milton 1920-2004 (by Nick Dunston, Reg Nelson & Dave Cockshell)	Obituary
112	28	Geophysical Anniversaries - 175 years ago - R W Fox (Doug Morrison)	Article
113	18	Geophysical Anniversaries - 101 years ago on the island of Mauritius (Doug Morrison)	Feature
114	23	Geophysics at Newmont - a history of innovation and development (Part I, 1946-1975)	Feature
114	21	Geophysical Anniversaries - 70 years ago -'Southern Cross' (Doug Morrison)	Feature
115	16	90 years ago - some pioneering field trips (Part I) (Doug Morrison)	Feature
115	19	Geophysics at Newmont - a history of innovation and development (Part II, 1975-2005)	Feature
116	20	90 years ago - some pioneering field trips (Part II) (Doug Morrison)	Feature
116	12	Willem Verhoeff 1930-2005 (by Norm Uren)	Obituary
116	13	Keiiti Aki 1930-2005 (by Dave Denham, Koya Suto & John McDonald)	Obituary
117	17	90 years ago - some pioneering field trips (Part III) (Doug Morrison)	Feature
118	19	Farewell to WMC (Lisa Vella)	Feature
119	29	Some old books - late 19th C (Doug Morrison)	Feature
120	18	Paul Passalsky: a young man's legacy to geophysics (Doug Morrison)	Feature
120	9	Anita Heath 1955-2005 (by Craig Dempsey)	Obituary
121	21	Neumayer: pioneer exploration geophysicist (Part 1) (Doug Morrison)	Feature
122	12	Neumayer: pioneer exploration geophysicist (Part 2) (Doug Morrison)	Feature
123	17	Neumayer: pioneer exploration geophysicist (Part 3) (Doug Morrison)	Feature
123	14	Edward Burnside 1919-2006 (by Ian Pontifx, Keith Yates & Chris Haslam)	Obituary

Continued

Issue no.	Starting page	Title	Type
124	32	Neumayer: pioneer exploration geophysicist (Part 4) (Doug Morrison)	Feature
124	10	Desmond Rowston 1923-2006 (by Stewart Gunson)	Obituary
125	34	Neumayer: pioneer exploration geophysicist (Part 5 - final) (Doug Morrison)	Feature
126	39	Jack Rayner and the Imperial Geophysical Experimental Survey (John Rayner)	Feature
126	9	Anton Hales 1911-2006 (by Ted Lilley)	Obituary
126	14	Satoru Ohya 1932-2006 (by Koya Suto)	Obituary
127	33	Jack Rayner in America, 1945 (John Rayney)	Feature
128	34	Jack Rayner and AGGSNA (John Rayner)	Feature
129	36	Geophysicists at war: mines, magnetism and memories - Part 1 (John Rayner)	Feature
129	8	Lawrence Drake 1931-2007 (by Keeva Vozoff, Jim Tayton & Edward Bowen)	Obituary
130	32	Geophysicist at war: mines, magnetism and memories - Part 2 (John Rayner)	Feature
137	35	Paleomagnetism 1958 revisited: a Golden Anniversary (Ted Lilley)	Article
142	8	Tony Barringer 1925-2009 (by Roger Henderson)	Obituary
145	12	Turhan Taner 1928-2010 (by Roy and Judy Farrell)	Obituary
145	11	Ken Seedsman 1929-2010 (by Keith Johns)	Obituary
148	45	My first shot (seismic refraction) (Peter Gunn)	Article
148	10	Shanti Rajagopalan 1960-2010 (by David Boyd)	Obituary
150	9	History of Preview - 25 years and 150 issues (Ann-Marie Anderson Mayes)	Article
150	33	History of seismic resolution (John Denham & Les Denham)	Feature
150	6	Remembering Grahame Sands	Memorial Tribute
150	7	Craig Hoffman 1961-2010 (by Mike Harch & Kelly Keates)	Obituary
152	11	Duncan Crone 1929-2011 (by Roger Henderson)	Obituary
152	11	Len Collett 1922-2011 (by Roger Henderson)	Obituary
154	7	Harold O Seigel 1924-2011 (by Chris Nind et al)	Obituary
157	13	Stewart Gunson 1925-2012 (by Norm Uren)	Obituary
158	11	George Keller 1927-2012 (by Roger Henderson & Charles Stoyer)	Obituary
160	9	Peter Elliott 1954-2012 (by Kim Frankcombe)	Obituary
161	8	Jodie Gillespie 1972-2012	Obituary
163	21	Geophysical instruments in the National Historical Collection (Denis Shephard)	Feature
164	22	Three magnetometers from Australia's Historical Collection (Denis Shephard)	Feature
166	39	The first official recommendation to establish exploration geophysics in institutions in Australia (Roger Henderson)	Feature

Vale Don Gray (1931–2014)

Don Gray, the founder of the Australian Landsat Station, passed away on Tuesday 4 November 2014. Don Gray is a significant figure as it was through his vision and leadership that the Australian Government invested in the Australian Landsat Station in 1979. In subsequent years this facility grew and was renamed the Australian Centre for Remote Sensing, widely known as ACRES, before becoming part of Geoscience Australia through the amalgamation of AUSLIG and AGSO in 2001.

Don Gray's contribution and achievements have left Australia with a tremendous legacy; a ground station in Alice Springs that is still operational and acquiring Landsat 7 & 8 imagery today (operated by OSS), and over 35 years of Landsat observations (under NEMO's stewardship). This archive has provided an incredible Australian continental baseline dataset that spans through space and time and has become the foundation of the Australian Geoscience Data Cube.

Alla Metlenko
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Vale Trevor Jones (1949–2014)

Trevor Jones passed away on Tuesday 5 November. Trevor had a distinguished career first as a seismologist, then as a seismic hazard specialist, a multi-hazard risk analyst and finally as a technical advisor to government.

Trevor played a central role in breathing life to the establishment of Geoscience Australia's geohazard capability. Trevor's passion for work was contagious and the future state he imagined created excitement among his peers. Trevor was a true mentor to his staff and a champion for bringing science to policy making across government. Trevor's leadership resulted in milestones such as the National Risk Assessment Guidelines, the now 'Risk Assessment, Measurement and Mitigation Sub-Committee' and the 'National Situational Awareness Tool' which recently received AGD's highest honour, winning the Secretary's Award.

Trevor helped improved methods for earthquake hazard assessment in urban areas by assessing techniques for determining shallow sediment structure particularly in Perth. Trevor contributed to the science and practice of geophysics resulting in wide recognition within the geophysics community.

Trevor's legacy and his vision continue to inspire many across government. He is remembered in particular for his warmth, enthusiasm and resilience in an at times challenging bureaucratic environment. He will be deeply missed.

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King Coal sends mixed messages

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With coal as a keystone in the Abbott government's energy mix we are getting mixed messages on how the carbon emissions are going to be reduced.

On 4 November the Prime Minister was quoted as saying: 'For now and for the foreseeable future, the foundation of Australia's energy needs will be coal. The foundation of the world's energy needs will be coal.'

At the same time the planet's atmospheric carbon dioxide concentration continues to rise and exceeded 400 ppm between May and July 2014. This level is the highest it has been in the last 800 000 years. It is a third higher than it was at the turn of the 19th and 20th centuries and is still increasing at approximately 2 ppm/year.

Consequently, if we are to continue to burn coal there should be ways of reducing its impact on CO_2 levels in the atmosphere. The carbon capture and storage method has been actively developed in Australia. The plan is to capture the CO_2 at the coal fired power station and store the gas underground, hopefully in liquid form. A CO_2 Co-operative Research Centre was established in 2004 to find suitable storage sites in Australia and develop appropriate technologies. Unfortunately, rather than encourage this research the government, in the May Budget, cut $459 million over 3 years, leaving $192 million to continue existing projects for the next 7 years. One might have thought that this research would have been top priority but the slash and burn appears to continue without any prioritisation.

Instead the government is investing in DICE. According to an ABC transcript from 20 July 2014, DICE – or Direct Injection Carbon Engine – is based on a modified diesel engine running on a mix of coal and water. It has just received $9 million in funding for stage one trials, including $1 million from the Victorian and Commonwealth governments. According to John White, chairman of the DICE Network and co-founder of Ignite, Ministers Hunt and Macfarlane 'are very interested in DICE, because it offers the opportunity of reducing CO_2 emissions for electricity from brown coal by 50 per cent, and it offers the opportunity to reduce CO_2 emissions from black coals by around 30 per cent'. At present, however, DICE technology exists only as a prototype single-cylinder diesel 16 kw, 3.9-litre engine in a lab at the CSIRO in Newcastle. It's clear that the technology, which the government hopes will be rolling out in 3–5 years, is a long way from commercial viability. How this technology reduces greenhouse gases significantly is not yet clear, but I guess the proponents will be hoping for a share of the Direct Action funds to advance the technology.

In the meantime the government and the Labor party have not been able to come to an agreement over the Renewable Energy Target, and at the time of writing the solar and wind power generators are projecting a huge loss of investment and jobs as a result of the uncertainty. Ironically, it turns out that in the ACT, which has the lowest electricity prices in the country, 64 per cent of the ACT's electricity consumption was met with accredited 'GreenPower' through ActewAGL purchasing 383 734 kWh in 2012–13 against the supplied total consumption of 595 227 kWh (ACTEW AGL Annual Report).

So for me, I would go for wind, solar and nuclear – coal would only be in the mix if carbon capture and storage can be applied. We must reduce the pollution from coal fired power stations if our planet is to provide an acceptable climate for humans. But that's just my view.

Growth in coal-fired power generation on the cards

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Prime Minister Abbott's comment on coal being the foundation of world energy needs has been underscored by the recent US–China CO_2 emissions agreement, whereby China's total emissions will continue to increase until 2030, with 80% of its energy being supplied by fossil fuels. The comments are further supported by proposals by two Indian companies to build major coal mines in the Galilee Basin, Qld. As Indian Prime Minister Narendra Modi said recently, Australia is 'a major partner' in his new government's drive to educate Indian youth, put a roof over the heads of the nation's poor and connect electricity to every household. I suggest that China and India are not sending mixed messages; rather, the messages are unequivocal, and Mr Abbott is stating the obvious. It is not in Australia's interests, nor is it our right, to suggest these countries should do otherwise.

It follows that CO_2 levels in the atmosphere are going to increase, probably on the IPCCs RCP8.5 'business as usual' scenario regardless of what action we in Australia may take (that does not necessarily imply that the consequences of such emissions will follow the RCP8.5 projections of global temperature and sea-level increase; observational evidence is increasingly at variance with climate model predictions, but that can be a debate for another day). Should we now redouble efforts in carbon capture and storage technology? I doubt it, since the pipeline distribution and injection technology on any effective scale would demand infrastructure at least equal to pipeline infrastructure for all our existing oil and gas distribution, and arguably the requirement would be several-fold larger given the tonnages of coal being oxidised to CO_2.

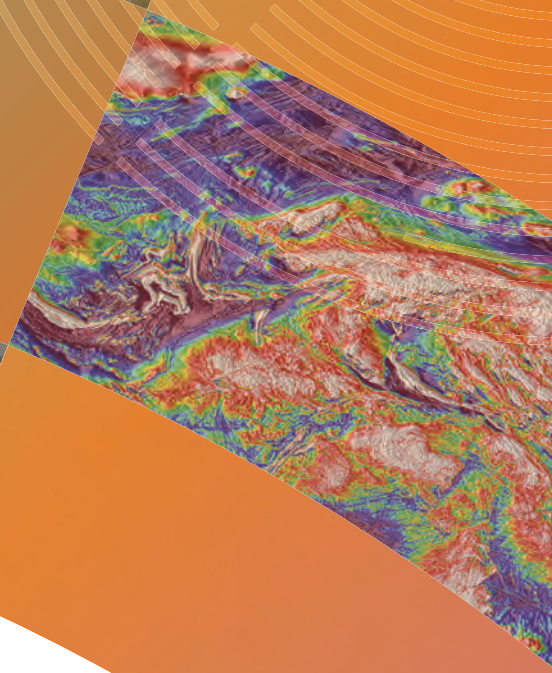
I don't regard wind and solar energies as scaleable to a large fraction of our total energy demands (the Chinese target is 20% by 2030) since every unit of solar and wind capacity must be matched by a duplicate investment in fossil fuel technology to ensure continuity in energy supplies. Whether limitation of development of solar and wind technology genuinely represents a 'huge loss in investment and jobs' I leave the economists to argue, but given the large subsidies of public money required for such projects to be viable, I question the assumptions. We slashed subsidies for the

textile clothing and footwear industries decades ago, and we are ending subsidies to our car-manufacturing industries, for reasons both major political parties endorse. Our economy is stronger if we lose inefficient industry and generate new industry capable of competing in a real world. The disastrous lesson of Spanish investment in renewable energies since 2000 is that for every 'green' job created by subsidies, 2.2 jobs are lost in other industries (higher energy prices and redirection of capital put other industries out of business).

None of this argument is intended to suggest we ignore increasing CO_2 emissions, which probably have played a part, along with natural cycles, in warming the Earth since the Little Ice Age. Natural cycles have been little studied in climate science and until they are better understood we will not be successful in modelling effects of the rising CO_2 emissions that will surely accompany the development of China, India and other non-western nations.

I am, however, in furious agreement with David Denham's call for nuclear power. A fission reactor on Spencer's gulf would provide a triple synergy. It would provide energy to SA and in particular the major mining developments to the north, it would power a desalination plant pumping water into the dry hinterland to up agricultural output (our Chinese friends want to eat as well as build houses and factories), and it would provide a boost in employment and technology in a state that is seeking to reinvent itself after closure of last-century's car and ship-building construction sites. And by the way, while we think about our first nuclear power station, China has 22 nuclear power stations in operation, and a further 26 under construction.

The Premier Exploration Geophysical Conference in the Southern Hemisphere



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KEYNOTES

- **Minerals:** Eric Anderson, Peter Betts, Richard Hillis, Scott Halley, Jon Hronsky, David Isles, Mark Jessel, Richard Lane, Musa Mansi, Keith Martin, Gavin Selfe, John Vann, Ken Witherly
- **Near-Surface:** Alireza Malehmir, Laura Valentina Socco, Rosemary Knight, Fiona Hook
- **Petroleum:** Tariq Alkhalifah, Per Avseth, Dennis Cooke, Peter Duncan, Michael Glinsky, Felix Herrmann, Ian Jones, Simon Lang, Nick Moldoveanu, Henry Posamentier

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- Case studies that showcase the process of discovery through geophysical endeavours.

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- Explorational Rock Physics and Seismic Reservoir Prediction.
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Update from the Ground Geophysical Survey Safety Association Ltd (GGSSA)

Members of the Ground Geophysical Survey Safety Association (GGSSA) are invited to attend the inaugural AGM and Technical Meeting, which will be held in conjunction with the ASEG Conference in Perth on Friday 13 February 2015.

GGSSA was formed in 2011 with the purpose of promoting safe and effective ground geophysical survey practices and to serve as a centre for exchange of safety information. The formation of the Association was in response to NSW Government concerns about electrical ground surveys and compliance with the Australian Standards AS/NZ3000 and AS3007. Specifically, the concerns centred on electrical protection, isolation and insulation.

The goal of the association is NOT to be a regulatory body, but rather an association that facilitates the design and practice of safe procedures for ground geophysical surveys. Membership of GGSSA opened following the 2013 ASEG conference in Melbourne. Since that time the association has attracted 35 members (14 active and 21 associate) from Australia and overseas. Active members are defined as any commercial or industrial enterprise engaged in ground geophysical surveys. Associate members are any enterprise including education faculties, government departments, manufacturers, consultants or exploration companies with an interest in the objectives of GGSSA. GGSSA values the support of the following five sponsors: Rio Tinto, MMG, Hudbay Minerals, Fortescue Metals Group and AngloGold Ashanti.

GGSSA has developed industry guidelines for electrical geophysical surveys, which require active members to:

- Implement safe operating procedures compliant with the requirements documented in the guidelines
- Implement equipment maintenance schedules and maintain records of service history
- Implement appropriate training programs and assessment for personnel working on electrical geophysical surveys
- Ensure transmitters are fitted with safety features outlined in the guidelines
- Conduct regular compliance audits (both internal and external).

In the future, the focus of GGSSA will, in part, be directed by members. As an example, the association has released a *Working with Lightning Guidance Note* in response to one member request. The GGSSA Technical Committee, made up of representatives from the various members, is currently working on further guidance notes for members, covering fatigue management, manual handling and vehicles and driving.

The direction of GGSSA will also be driven by data. Active members are requested to submit monthly safety statistics on a quarterly basis to an independent group contracted by GGSSA. It is expected that over time meaningful trends will emerge. The member information will be analysed with the highest levels of discretion so as to determine where hazards are actually occurring and to understand the incident types that may occur, without breaching confidentiality. For example, when are incidents more likely to occur; during mobilisation and demobilisation or while surveying, during winter or summer operations?

The benefit to members will be two-fold. Firstly, the results will allow them to compare their risk pattern with that of all members. Secondly, GGSSA will be able to direct its Technical Committee to areas within the guidelines that require modification and also prioritise the release of guidance notes to mitigate the risks identified.

Details regarding the inaugural AGM and Technical Meeting (agenda, time and location) will be available early next year. For further information about GGSSA, including a full list of benefits to members, or to log your interest in attending the AGM in Perth, please visit our website www.ggssa.org or email exco@ggssa.org.

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New areas released for petroleum exploration and greenhouse gas storage

In October 2014, the National Offshore Petroleum Titles Administrator invited bids for 18 offshore areas for petroleum exploration and three areas for greenhouse gas storage. Most areas are situated off shore Western Australia.

Table 1. Four areas available for cash-bidding on 5 February 2015

Area	Basin	Sub-basin	Figure number
W14-20	Northern Carnarvon	Rankin Platform	1
W14-21	Northern Carnarvon	Barrow	2
W14 22	Northern Carnarvon	Exmouth Plateau	3
W14 23	Browse	Caswell	4

Table 2. Fourteen areas available for cash-bidding on 2 April 2015

Area	Basin	Sub-basin	Figure number
AC14-1	Bonaparte	Vulcan	5
W14-1	Bonaparte	Petrel	6
W14-6	Northern Carnarvon	Rankin Platform	1
W14-8, W14-9, W14-10, W14-11, W14-12, W14-13, W14-17, W14-18 and W14-22	Northern Carnarvon	Exmouth Plateau	3
W14-19	Bight	Eyre	7
Re-release areas			
W14-3 and W14-4	Browse	Caswell	4

Table 1 shows the four areas available for cash bidding at the auction on 5 February 2015. Table 2 shows the areas available for bidding by 2 April 2015. Bidding for the three greenhouse gas storage areas, all in the Gippsland basin, closed on 27 November 2014. Detailed information about the location of all areas can be obtained at http://www.petroleum-acreage.gov.au/.

The price of Brent Crude dropped sharply from around $110 to $80/bbl in the period June–November 2014. This price change is unlikely to encourage more exploration so it will be interesting to see how many bids are made for the areas that have just been released.

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Update on Geophysical Survey Progress from the Geological Surveys of Western Australia, South Australia, Northern Territory, Queensland, New South Wales, Victoria and WA Department of Water (information current on 17 November 2014)

Tables 1–3 show the continuing acquisition by the States and the Northern Territory of new airborne magnetic, radiometric, gravity and AEM data over the Australian continent. All surveys are being managed by Geoscience Australia (GA). Further information 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
Coompana	GSSA	GA	TBA	Not before 31 Jan 2015	249 600	400 m 80 m E–W	The proposed survey (Figure 1) may cover all or part of Noorina, Wyola, Cook, Coompana, Nullarbor, Ooldea, Maurice, Wells and Birksgate standard 1 : 250 000 standard map sheets The Quotation Request closed on 19 Nov 2014 and responses are being assessed by GA and GSSA				
Dunmarra	NTGS	GA	GPX Surveys	28 Jun 2014	103 985	400 m 80 m N–S	36 280	100% complete at 10 Oct 2014	Raw data were supplied to GA on 24 Oct 2014 Final processed data were received for assessment in Nov 2014	PV 170 – Jun 2014 p. 24	TBA

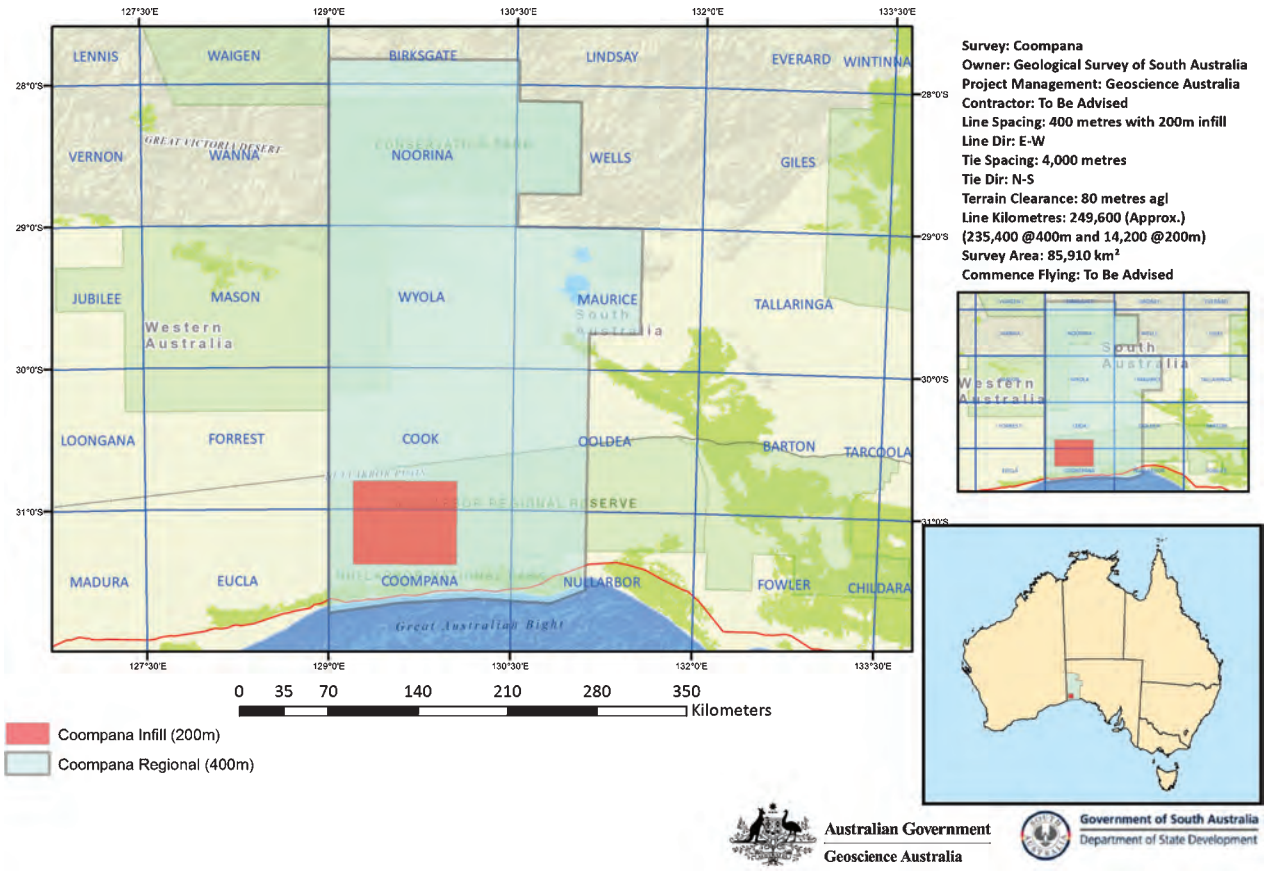

Figure 1. *PACE 2020 – Coompana SA Airborne Magnetic and Radiometric Survey 2014–2015.*

Table 2. Gravity surveys

Survey name	Client	Project management	Contractor	Start survey	No. of stations	Station spacing (km)	Area (km²)	End survey	Final data to GA	Locality diagram (*Preview*)	GADDS release
Sir Samuel – Throssel	GSWA	GA	IMT	19 Jun 2014	11 702	2.5 km regular grid	73 800	100% complete at 7 Sep 2014	Final data expected to be released via GADDS before the end of 2014	PV 171 – Aug 2014 p. 39	TBA
West Amadeus	NTGS	GA	Atlas	29 Jun 2014	8127	4 km regular with areas of 0.5, 1 and 2 km infill	45 050	100% complete at 11 Aug 2014	Final data expected to be released via GADDS before the end of 2014	PV 171 – Aug 2014 p. 39	TBA
Southern Thomson	GA/ GSNSW/ GSQ	GA	Atlas	17 Jul 2014	3660	8 traverses at 333 m station spacing	TBA	100% complete at 17 Sep 2014	Final data expected to be released via GADDS before the end of 2014	PV 170 – Jun 2014 p. 24	TBA
Gippsland	GSV	GA	Atlas	30 Jun 2014	1440	12 traverses at 500 m station spacing	8358	100% complete to 21 Jul 2014	Final data expected to be released via GADDS before the end of 2014	PV 170 – Jun 2014 p. 25	TBA
North McArthur Basin	NT	GA	Atlas	16 Sep 2014	7175	4 km regular grid with areas of 2 km infill; 1 area of traverses spaced 4 km apart with a station spacing of 1 km	71 030	100% complete at 4 Nov 2014	Preliminary final data were supplied to GA at the end of Nov 2014	PV 171 – Aug 2014 p. 39	The survey covers all or part of Arnhem Bay, Gove, Mt Evelyn, Mt Marumba, Blue Mud Bay, Katherine, Urapunga and Roper River standard 1 : 250 000 standard map sheets

Table 3. AEM surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Spacing AGL Dir	Area (km²)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
Swan/Scott Coastal Plain and Albany/ Esperance	WA Dept of Water	GA	CGG Aviation (Australia)	25 Mar 2013	8607	300/ 600 m	TBA	100% complete to 15 May 2014	Final data to GA 20 Jan 2014	PV 163 – Apr 2013 p. 17	The data were released by GA on 3 Oct 2014 via http://www.ga.gov.au/search/index.html#/
Southern Thomson Orogen	GA/ GSNSW/ GSQ	GA	Geotech Airborne Ltd	8 Apr 2014	4198 (3327 in survey and 871 in traverses)	5 km E–W	16 270	100% complete at 5 May 2014	Additional work (traverses) over the Paroo and Darling Rivers to examine the potential for new groundwater resources was completed on 5 Jun 2014	PV 168 – Feb 2014 p. 24	The final point-located data were accepted by GA in Nov 2014

TBA, to be advised.

2014 roundup of geophysical activity at the Geological Survey of South Australia

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2014 has been a busy year for the geophysicists in the Geological Survey of South Australia (GSSA). Some of the major projects are briefly described here.

- A gravity survey was undertaken in the Musgrave Ranges, on the Alcurra, Agnes Creek and Tieyon 1 : 100 000 mapsheets. This semi-regional survey filled in some of the holes in the coverage in that area of the state, and brought to light some new gravity anomalies. Details of this gravity survey can be found in RB2014/018 (Government of South Australia publication).
- Radiometric streaming is a technique used to level airborne radiometric surveys. With the completion of the Marree magnetics and radiometrics survey, the GSSA geophysicists have undertaken radiometric streaming in the Marree and Warinna area to provide optimum leveled data.
- A new report compiling all the Australian Fundamental Gravity Network sites in South Australia has been written, containing the latest observations at all sites in South Australia. 70 Australian Fundamental Gravity Network sites in South Australia remain usable, and 75 have been destroyed. More details can be found in RB2014/013 (Government of South Australia publication).
- The geophysicists are currently working on a geophysical database, containing information on all mineral geophysical surveys undertaken in South Australia. While the database is still in early stages, once complete it will greatly reduce the time taken in locating individual surveys, simplify customer requests, and provide the team with a stable environment to store the data. Petrophysical data are also being stored in a database and can be accessed directly through SARIG. The data can be found by following links to drillhole information.
- For its next major regional survey, the GSSA is planning to re-fly much of the aeromagnetics and radiometrics in the far west of the state, including the Coompana anomaly. Look out for this data next year!
- Recent changes to the South Australia Mining Act include the introduction of a sunset clause for geoscientific data. The latest releases of geophysical data are announced bimonthly in the MESA journal, and are made available online at that time.
- Recently, Stephan Thiel has joined the team bringing in expertise in the magnetotelluric method. Stephan previously worked at the University of Adelaide and is still working on the Australia Wide MT survey.
- Our vacation student programme commences shortly, and we look forward to working with a student geophysicist to help with data delivery.
- Finally, we've undertaken detailed ground magnetic and gravity surveys investigating palaeochannels and magnetic remanent anomalies north of Yunta in SA. We'll be presenting the results at the ASEG conference in Perth 2015, and we look forward to seeing you there!

Updated 40 m magnetic compilation map for Western Australia

In September 2014 the Geological Survey of Western Australia (GSWA) released an updated 40 m resolution magnetic anomaly grid for onshore Western Australia. The new grid is a compilation of more than 1100 individual survey grids made from aeromagnetic datasets registered in GSWA's MAGIX database and the national Geophysical Archive Data Delivery System (GADDS) hosted by Geoscience Australia.

In 2009, as part of the state government's five-year Exploration Incentive Scheme, GSWA embarked on an accelerated program of airborne magnetic and radiometric surveys to acquire data at a line spacing of between 200 m and 400 m over the approximately 30% of the area of Western Australia that still had only 'first-generation' coverage with a survey line spacing of 1600 m.

By 2013, with the support of Geoscience Australia, this phase of the project was completed with the acquisition of almost 3.5 million line kilometres of new magnetic and gamma-ray spectrometric data. Western Australia was able to boast of complete 'second-generation' coverage of the state with publicly available data with a line spacing of 500 m or better. An updated state composition TMI grid was released with a cell size of about 80 m – optimal for the representation of data at a line spacing of 300 m – 400 m.

In 2013 and 2014, GSWA commenced a new program of more detailed surveys with a line-spacing of 100 m over selected areas of the state. The first area to be surveyed at this resolution was in the Goldfields, increasing quite substantially the area of Western Australia that is covered by regional data at a line spacing of 300 m or less.

However, Western Australia's very active mineral exploration sector means that GSWA also holds data from many detailed surveys submitted by exploration companies in accordance with the requirements of the WA Mining Act. Data submitted under these conditions are released to the public after a specified period of confidentiality. Currently the

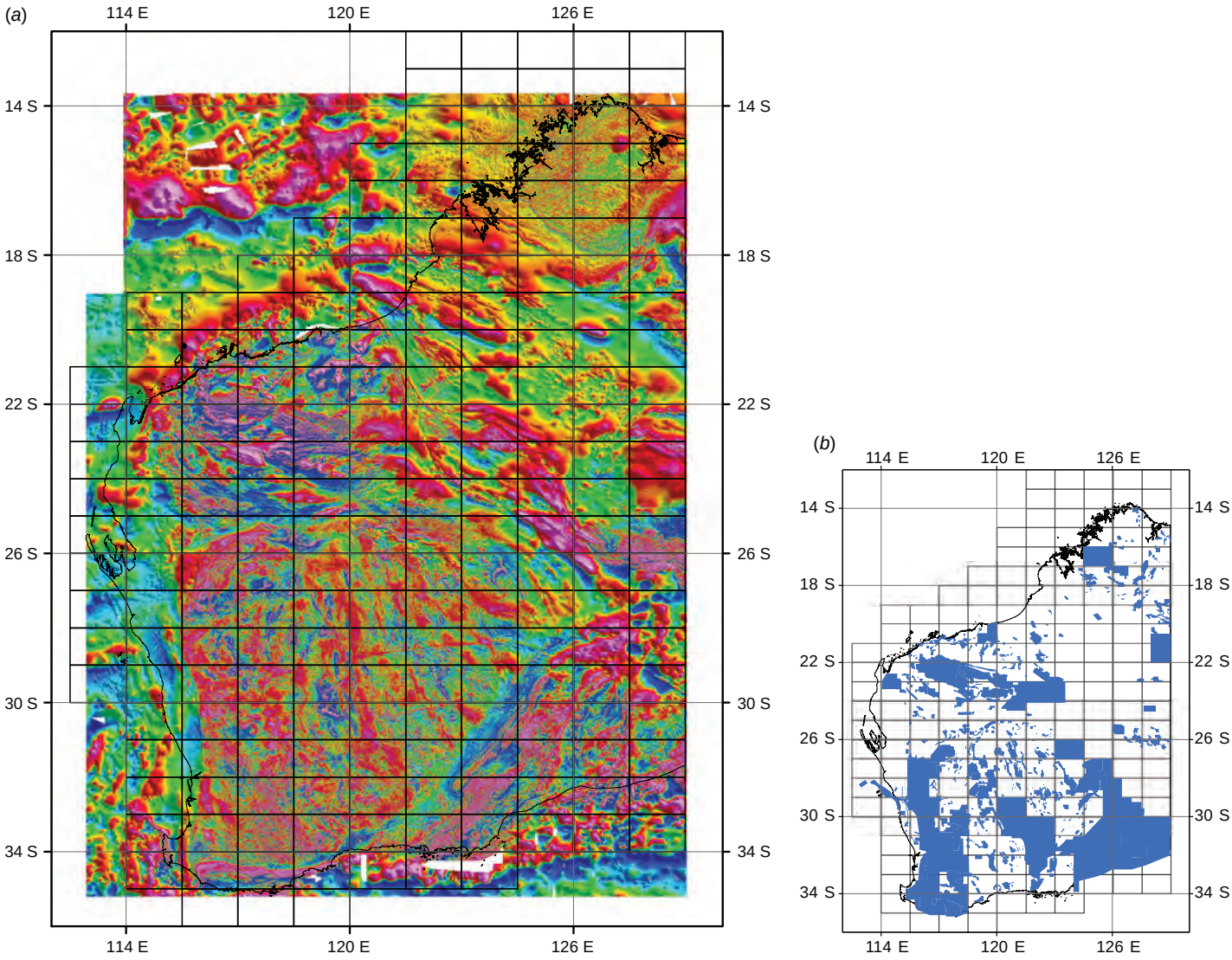

Figure 1. *(a) Image of 40 m compilation TMI grid of Western Australia. (b) Publicly available aeromagnetic survey coverage of Western Australia with line spacing of 300 m or less.*

MAGIX database holds approximately 11 million line-km of company datasets, many of which are available for inclusion in the state compilation.

With the combination of non-confidential higher-resolution company and regional datasets, a significant area of Western Australia, particularly in the south-western half of the state, is now covered by aeromagnetic data at a line spacing of 300 m or less.

To adequately represent these data densities, a grid of resolution higher than 80 m is required. A grid cell size of 40 m represents an adequate compromise between data resolution and manageable file size.

In 2013, GSWA produced the first state compilation with a cell size of 0.000416 degrees, approximately 40 m. The magnetic grid of Australia V5 2010 (Milligan *et al.*, 2010) with a cell size of 0.000833 degrees was used as the base reference for the new compilation. This is the same reference that was used for the earlier 80 m state compilations.

The latest release of the 40 m grid in September is a new compilation that includes the recently completed Goldfields 100 m surveys as well as all available company data to date. The merged grid was created using Intrepid Geophysics' GridMerge program installed on the iVEC supercomputer Fornax (iVEC is an unincorporated joint venture between CSIRO, Curtin University, Edith Cowan University, Murdoch University and The University of Western Australia and is supported by the Western Australian and Federal Governments).

Compared to the 80 m grid compilation, the 40 m grid contains improved detail in areas of survey line spacing of 300 m or less – shown in the shaded areas in Figure 1b. In other areas there will be no difference in frequency content from that of the 80 m grid; however, image pixelation will be less apparent at larger viewing scales.

The latest 40 m grid in ER Mapper format is available for download from the GSWA website http://www.dmp.wa.gov.au/16942.aspx, as is a geo-referenced image in JP2 format. Images for individual 1 : 250 000 map sheets based on the same dataset can also be downloaded.

The iVEC supercomputing facilities are now being used by GSWA for all the state grid compilations, resulting in faster turnaround as well as the potential to make higher resolution grids. GSWA shortly expects to release a state 20 m compilation grid to display detail in areas of surveys with lines spaced at 100 m or less. A 20 m grid compilation has already been released for the area of the Goldfields 100 m surveys.

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Milligan, P. R., Franklin, R., Minty, B. R. S., Richardson, L. M. and Percival, P. J., 2010, *Magnetic Anomaly Grid of Australia (Fifth Edition)*: Geoscience Australia, Canberra.

For more information and advice contact John Brett, Department of Mines and Petroleum, Government of Western Australia (john.brett@dmp.wa.gov.au).

National search for earth science superstars off and running

The national search conducted by Australian Science Innovations for talented students to represent Australia at the 2015 International Earth Science Olympiads is off to a flying start, with 380 students registering to sit the inaugural Earth and Environmental Science Olympiad (EESO) exam.

Joining the well-established Olympiad competitions in biology, chemistry and physics, the Australian Earth and Environmental Science Olympiad will select and train talented secondary students in preparation to compete at the International Earth Science Olympiad (IESO). The first stage in the process is the national exam, where Year 10 and 11 students test their knowledge of geology, geophysics, meteorology, oceanography, astronomy and environmental sciences. The inaugural exam was held in August, with those who performed well in the exam invited to attend an intensive summer school at ANU where their theory and practical skills will be developed further.

According to the EESO Program Director, Greg McNamara, the exam was a challenge to write:

> *In order to select a cohort of 12 excellent candidates to attend the first EESO summer school the exam needed to identify truly outstanding students from an exceptional group while also asking questions within the framework of the Australian curriculum and the IESO syllabus. In addition we needed to ensure the questions were scientifically and pedagogically sound. I would like to think we were successful and acknowledge the able assistance provided by critical friends, experts in the 'spheres' of geology, atmosphere, hydrosphere and astronomy.*

The Executive Director of Australian Science Innovations, Lillian Lesueur, reported that:

> *all students who sat the exam should be proud of their efforts as it is clear they all put in a great effort to succeed. The most outstanding candidates, who have now been invited to summer school, come from a variety of city and rural backgrounds and we are looking forward to working with this group over January.*

The exam has provided a number of learnings that will inform future exams as well as the content and structure of the 2015 summer school. It is clear from the variety of questions successfully attempted by students that not all students have the same underpinning content knowledge and that the variations are both school and state based. Whilst not a surprise, it has provided the EESO program staff with an empirical benchmark from which to plan their training.

Generally, students demonstrated a good understanding of contemporary environmental issues but tended to interpret all environmental processes through an anthropogenic lens rather than considering the possibility of overarching natural processes. The exam also revealed widespread misconceptions in the areas of stellar evolution and the formation of solar systems with students frequently confusing these processes with those operating during the Big Bang. There was also a general lack of depth in basic content knowledge pertaining to solid Earth geology, mapping and stratigraphic relationships.

The experience that Greg McNamara and the program's Deputy Program Director, Dr Bronte Nicholls, recently had at the 2014 IESO in Spain confirms that the Earth Systems Science approach adopted in formulating the EESO exam and summer school plans are well aligned with the IESO and will provide a good basis for taking a team of four students to the 2015 IESO. The inaugural Australian Earth and Environmental Science Olympiad is sponsored in part by the Australian Geoscience Council (AGC) and the ASEG is a member of the AGC.

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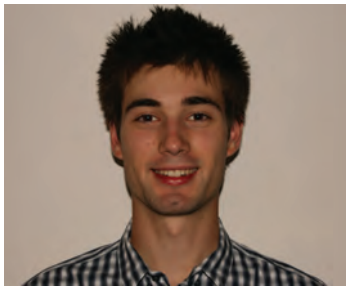
Student projects in geophysics completed in 2014

Honours projects

Michael Dello-Iacovo: *Heat flow in southern Australia: source and implications for geothermal energy.* University of Adelaide.



The South Australian Heat Flow Anomaly is a broad region (>400 km wide) in Proterozoic South Australia defined by drill holes with anomalously high heat flow estimates yielding a mean of 92 ± 10 mW m^{-2}, compared to a global Proterozoic mean of 49-54 mW m^{-2}.This study conclusively determined the primary source of this anomalous heat flow. Thermal conductivities of 145 drill core samples were measured using an optical thermal conductivity scanner. These were utilised with thermal conductivity and temperature profiles provided by Petratherm and the Department of State Development to make five new heat flow estimates in the Curnamona and Mount Painter provinces using the product and thermal resistance methods. Measured surface heat flows fall between 84.352 and 128.051 mW m^{-2}. Significant lateral variations in surface heat flow support previous work suggesting shallow crustal radiogenic heat generation, primarily in Mesoproterozoic high heat producing granites. Analysis of existing deep seismic data has revealed a significantly cooler and thicker lithosphere in Proterozoic South Australia compared with regions dominated by mantle heat flow such as southeastern Australia. Geotherms have been computed for steady-state regimes to demonstrate that the surface heat flow evident in the South Australian Heat Flow Anomaly is consistent with elevated upper crustal source. Thick, thermally insulating sedimentary cover in the Curnamona and Mount Painter provinces and high temperatures at shallow depths are encouraging for geothermal energy exploration, and geothermal prospectivity for these provinces was examined. Lateral thermal conductivity variations of stratigraphies in the Curnamona Province have been assessed, revealing that more data must be collected to use thermal conductivity from neighbouring boreholes as a proxy for heat flow estimates.

Michael is passionate about using his geoscience knowledge and collaborating with others to solve global energy and climate issues. He is particularly interested in geothermal energy, solar and natural gas. He completed his Bachelor of Science (Honours) in geophysics in November 2014, and will commence work with Santos Ltd in 2015 as a graduate geophysicist.

Henry Johnson: *Geographically constraining the South Australian Heat Flow Anomaly.* University of Adelaide.

The South Australian Heat Flow Anomaly is a large contiguous region of anomalously high heat flow (>90 mW m^{-2}) in otherwise tectonically quiescent Proterozoic lithosphere. The broad anomaly (>400 km) is nearly 40 mW m^{-2} greater than the global average for terranes of similar tectonic age, but is poorly constrained geographically due to relatively few and poorly distributed heat flow data. This study reports four new heat flow determinations, located to improve the spatial sampling. The product method and thermal resistance were used to calculate heat flow. Data were obtained from drillhole core samples that traverse the anomaly. The samples were then scanned for thermal conductivity using a Thermal Conductivity Scanner. Temperature logs of the drillhole were used to determine the thermal gradient with depth. The product of thermal conductivity and thermal gradient determines surface heat flow. The spatial extent will become better defined with each new heat flow datum. Reliability of the pre-existing data source of the anomalously high heat flow was ascertained by evaluating bias in previous data measurements, recent tectonic and magmatic activity. Using existing data and measurements made in this study, evidence for and against a primarily deep mantle and shallow crustal radiogenic source was examined.

Henry's career aspiration is to enter the geophysical exploration industry as, from his Honours project, he has found that finding something new that no one has seen before is both challenging and exciting. Coming from a rural background he finds himself wanting to be in the great outdoors, which compliments his aspiration agreeably. After furthering his professional experience he would like to gain further knowledge overseas.

Angus Keane: *Carbonated mantle: modelling the effect of carbonated melts on mantle melting and conductivity.* University of Adelaide.

The effect of carbonated melts is observed to have significant deepening of the solidus and high conductivity as a function of CO_2 concentration in the melt. In this study these two effects are parameterised and a model is presented that determines mantle melt fraction and bulk hydration from conductivity observations, using the melting models of McKenzie and Bickle (1988), Katz *et al.* (2003) and Hirschmann (2010). This model is applied to conductivity data of Key *et al.* (2013) and (Wannamaker *et al.* 2008) for the East Pacific Rise and the Basin and Range, Colorado, respectively. Our interpretations of melting and hydration, are in agreement with those posed by Key *et al.* (2013) and Wannamaker *et al.* (2008).

Oliver Putland: *Magnetotelluric well stimulation monitoring.* University of Adelaide.

Hydraulic stimulation tactics allow for the economical extraction of tight-

gas plays by increasing the hydraulic conductivity of impermeable formations. The rise of shale-gas exploration and production has seen the implementation of horizontal drilling to pump pressurised fluids into a formation, reactivating palaeo-fracture networks from induced pressure instability. The fracture networks stimulate: reduction in pore pressure, increasing pore connectivity and provides new paths for hydrocarbon migration. Deep geophysical monitoring is required to analyse the geological impacts from hydraulic fracturing (fracking), they also aid to increase well success rates. Microseismic surveying is currently the primary technique employed to monitor these induced effects, however passive seismic monitoring is not directly sensitive to the physical properties of formation fluids.

This report describes early-stage evaluation of magnetotelluric monitoring of hydrogeological changes induced from a hydraulic fracturing at 3000 m depths. This study presents the findings from phase tensor dimensionality studies and inverse modelling in two dimensions of a twelve-hour recording time interval prior and post injection. The regional low resistivity of the sedimentary basin stratigraphy constrains the changes in the magnetotelluric responses associated with fluid injection to lie within the dead-band (1–10 s); thus signal-to-noise ratios are low and changes are difficult to uniquely detect.

An incongruent path through university – software engineering, marine biology, botany to geophysics – allowed Oliver to find his true interests, for that he is forever grateful. Take some time to get to know him and you will find that he has quite simple tastes – a book, coffee and some sun make for a perfect day.

Michael Stepan: *Magnetotelluric imaging of a Palaeozoic Andean margin subduction zone in western Victoria.* University of Adelaide.

The geological setting for the accretion of the Lachlan and Delamerian Orogens in southeastern Australia is controversial, with two different models proposed. The Lachlan Orogen resulted from either subducting oceanic crust and wedge accretion, or shortening and compression between two continental blocks. Broadband magnetotelluric (MT) data recorded over the transition between the Delamerian and Lachlan Orogens impose new constraints on the formation of south eastern Australia. The east–west MT survey extended for approximately 120 km, recording at 44 stations. A 2D inversion of the data in the bandwidth of 0.05–2000 s yielded a resistivity model to a depth of 150 km, with resistivity ranging from 1 to 10 000 Ωm. The upper crust was most resistive (>10 000 Ωm), and transitioned to a relatively flat conductor of 50–100 Ωm at <20 km. The upper mantle is resistive (>1000 Ωm) and uniform below this layer. The Escondida, Moyston and Avoca Faults are imaged as low resistivity pathways (100–200 Ωm) extending to the surface. Faults may be anomalously conductive from alteration to serpentinite, and other trace mineralisation such as graphite. The Lachlan Orogen likely formed from west dipping subduction of mafic to ultramafic oceanic crust. This crust was altered to serpentinite, with magnetite coating grain boundaries. Imaged conductive bodies show where shearing caused interconnectivity of the magnetite.

In 2014 Michael was a BSc Honours student in geophysics at the University of Adelaide. Next year he will be working for Santos in a graduate role in their Adelaide office. His interest lies primarily in exploration, particularly seismic and offshore. He would one day like to live and work overseas, ideally in Europe or north Africa.

Sanjay Govindan: *The nature of pore space at a weathered/fresh rock interface and its effect on the resistivity signature (special topic).* Australian National University.

We have conducted a DC resistivity survey over a 500 m section of a gold mine in Majors Creek. Inversion and forward modelling of the data produced a true resistivity model of the near sub-surface. With additional information supplied by Unity Mining, we are able to correlate alteration styles and the weathering profile over a depth of 60 m to the true resistivity model calculated from field measurements. The next stage, which is currently under way, is to collect porosity and connectivity data, both in thin section and CT form. Imaging samples from the drill core supplied by Unity Mining we are able to gain a snapshot of host rock characteristics over the entire 60 m depth. Five samples from the host rock were collected and are currently undergoing preparation for scanning and imaging. This will allow a potential relationship to be established between pore space and connectivity to the resistivity values experienced in the field. The future outlook for this topic is to conduct a similar study over transported regolith and compare and contrast the difference. It is hoped that resistivity and regolith characteristics can be better understood to assist in defining the boundary between transported and *in-situ* regolith.

Originally from Sydney Sanjay came to Canberra to pursue an earth science and mechanical engineering degree and has enjoyed his four years there immensely. The Research School of Earth Science is highly engaging and involved with its students, pushing students to interact with researchers and learn through applying research processes. Sanjay's 4 years at the school has led him to visit some spectacular country throughout Australia, make a range of new friends and to get involved in the researched based learning that he is highly passionate about. Currently transitioning into honours he is keen to pursue research into CT scanning techniques and hopefully to apply them to the challenges at the Earth Science School. In his spare time he is always very keen take the mountain bike out to Stromlo, go climbing at Kambah pools, or go for a hike or run through the bush. In 2014 he was awarded the ACT ASEG Branch Student Conference Travel Award

Jack Muir: *Bayesian inference of deep earth structure via a joint inversion of normal mode and body wave data.* Australian National University.

In this thesis, we present a hierarchical Bayesian joint inversion of the P-wave velocity perturbations in the lowermost 300 km of the mantle and the topographic perturbations of the core mantle boundary. We use a novel dataset, free of the effects of the inner core, consisting of PcP – P, PKPab – PKPbc and P4KP – PcP differential travel times. We employed a hybrid hierarchical Hamiltonian Monte Carlo/Gibbs sampler, to our knowledge thus far unused in global seismology, to generate the posterior parameter distributions arising from Bayesian analysis, using Monte Carlo simulation. After confirming the efficacy of our sampler on a synthetic dataset, we invert for the lowermost mantle and core mantle boundary. After including corrections to the differential travel time data to account for upper mantle structure, we find a root mean square P-wave velocity perturbation in the lowermost mantle of 1.26% and a root mean square topographic perturbation of the core mantle boundary of 6.04 km, with a predominantly north/south hemispherical character to the resultant maps of the perturbations.

ASEG ACT branch member Jack Muir was awarded the ASEG ACT Branch Student Scholarship in 2014. Jack has recently completed a Bachelor of Philosophy (Science) at the Australian National University, with a thesis in seismic tomography. He has been elected as a General Sir John Monash scholar for 2015, and intends to study for a PhD in geophysics in the United States next year.

Alexander Costall: *Feasibility of ground penetrating radar for delineation of the saline water interface along Perth's coastal margin.* Curtin University.

The feasibility of applying Ground Penetrating Radar (GPR) to the investigation and delineation of saline water on Perth's coastal margins has been evaluated by this paper. The research concluded that the technique can be applied to the detection and quantitative analysis of the water table at coastal boundaries; estimations to the variation in moisture content, including variability of infiltration rates along profile lines, and dilution of the saline water interface have been observed. As such, GPR is a fast, readily accessible alternative to the drilling of new monitoring wells, particularly in urban environments. Radar antennae with central frequencies of 50 and 250 MHz were used with a MALA ProEx radar system and in conjunction with a Real-Time Kinematic Global Positioning System (RTK GPS) to accurately and precisely investigate a region of Perth's coast. The area included four lines of approximately 300 m length, running pseudo-parallel in an easterly direction from the beach to the nearby road which allowed for the generation of a 3D fence diagram, as well as a general characterisation of the area from GPR data. To investigate the effect of rainfall on the research area, a second 250 MHz survey was conducted after a period during which Perth's high rainfall season had saturated the area. Analysis of the water table reflections, comparison of event times and instantaneous frequency changes show that a qualitative analysis of the water infiltration can be concluded by GPR surveying; however the saline water wedge is not easily identified. The changes identified are due to the effect of water on electromagnetic wave propagation. The degree to which the media has been saturated is able to be estimated by the travel time delays to known reflection interfaces, and the Topp relationship. From average EM propagation velocity changes of 0.2 m/ns, an estimated 3.6% increase in water saturation has been observed in the study area, equating to 36 mm/m approximate additional water content. The presence of the Tamala Limestone inhibits investigation with the 250 MHz antenna as the signal appears to be scattered, while the unshielded nature of the 50 MHz antenna became an issue with overwhelming airwave noise from wire fences along the tracks, additionally, it's inherently lower resolution resulted in hindrances to the technique over this area.

Mathew Fleay: *True amplitude processing and imaging of IGO 3D high-resolution seismic survey for Nickel, Kambalda, WA.* Curtin University.

Sandy Jones: *Analysis of a small electromagnetically driven seismic sources.* Curtin University.

This project aims to determine the effectiveness of a portable vibrating seismic source. Starting with the raw hardware, we built software code in order to create a designable sweep signal for vibroseis. The next step was to design and build the amplification system that will drive the source. Following the building of the amplification system, we aimed to design and build a testing rig that will allow measurement of the direct force output of our system. The final step in the program was to conduct some field testing, firstly to iron out issues with interfacing to a new system, and secondly, to test against a known source (sledgehammer). Unfortunately, despite the best efforts of the author and supervision team, the load cell sensors for the force testing system were behaving in an unexpected manner, and as a result, data from an absolute force test are not available at this time.

The tested hardware shows definite promise, the output frequency response and energy output seems positive compared to the hammer source. There are definite areas for improvement to the source before it could be considered as a commercial entity. The most important of these is a well-engineered weight loading system, which will enable solid ground coupling, and eliminate any 'impact' type events. Secondly, an effective transport system is need to efficiently transport the source between shot points.

It is recommended to apply some further research into this source, or similar sources. The idea of a one to two man operation of a small scale high definition seismic system is still a very attractive one. The next stage of research could involve a full reflection survey over a known area, using 10 Hz geophones, and some well-engineered solutions to the problems listed above.

Sandy Jones is an honours graduate geophysicist from Curtin University in

2014. Sandy is looking forward to a rewarding career as a geophysicist, has a keen eye for innovation, and a passion for the technological advancement that is a key aspect of the geophysics industry. Sandy runs a small business providing professional musical services in Perth, based on his extensive experience in the music and hospitality industries. You can reach him at sandyjonesgeophysics@gmail.com. Or check LinkedIn here: https://www.linkedin.com/pub/sandy-jones/35/7b2/892.

Matt Kovacevic: *Seismic characterisation and tectonic significance of listric fault systems in the Ceduna sub basin.* Curtin University.

The Ceduna sub-basin is considered by many to be a major potential petroleum province. Deposition is dominated by Late Albian to Maastrichtian deltaic sequences, which have been deformed through gravitationally induced listric extensional faulting. Previous studies of listric fault systems within the Ceduna sub-basin have focused on regional 2D seismic, with a line spacing of 4 km. The high resolution Trim 3D survey, covering an area of 1200 km^2 on the south western edge of the system, allows the evolution of fault systems to be studied in much greater detail. Faulting initiated in the Cenomanian White Pointer sequence and demonstrates a regional northwest southeast trend; however the interpretation of the Trim 3D survey has also resulted in the identification of previously unrecognised north south trending faults. After a period of quiescence in the Coniacian, renewed faulting occurred throughout the Santonian until the Maastrichtian. Faults developing during this time nucleated above previous northwest southeast trending faults, and displacement profiles indicate an upward propagation of growth through to the Maastrichtian. North south trending faults were not reactivated. The structural evolution of the Ceduna delta system has important implications for potential petroleum systems; fault reactivation may have compromised seal integrity within the White Pointer sequence.

Matt Kovacevic is an Honours Student in the School of Exploration Geophysics at Curtin University. He is graduating at the end of 2014 at which point he will join the Chevron Australia Graduate Program as an Earth Scientist.

Mahesh Raghvani: *Using seismic tomography to map shallow structures ion land seismic.* Curtin University.

One of the frequent drawbacks of seismic reflection, in its current implementation in a hard rock environment, is its inability to adequately image the top 200 m of the subsurface with conventional acquisition geometry. This depth range generally contains structures of interest such as shears, faults and fractures that typically control mineralisation. Although, the tomographic approach for delineating the near surface velocity field is commonly used in hydrocarbon exploration, it has scarcely been used in a hard rock context. For this reason, this project aimed to test the effectiveness of using travel time tomography for enhancing shallow structures in hard rock seismic.

The investigation was carried out on a high resolution 2D dataset, which was acquired in Western Australia and exhibits this shallow imaging problem. First arrivals were used to conduct travel time tomography on two different software packages using separate algorithms. The subsequent velocity models produced were used for time migration and depth conversion. These results were then critically analysed in order to make comparisons on the effectiveness of tomographic inversions.

The two models obtained from the different inversions showed strong similarities and similar distributions of velocity. The velocity models indicated an undulating low velocity upper layer, which highly varied in both thickness (10–70 m) and velocity (700–7200 m/s). Having used these velocities for time migration, localised areas in the time sections experienced significant improvements in both the continuity and resolution of the reflectors.

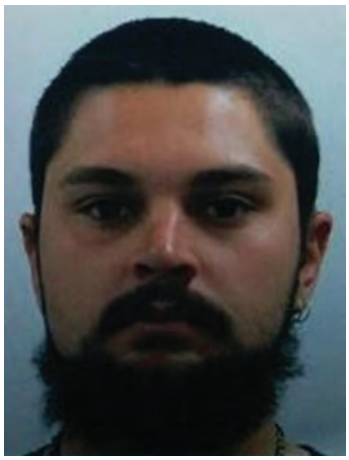
Comparative analysis between the tomographic velocities and the sonic log showed a strong correlation, indicating that tomography produced accurate and realistic velocities. The conventionally used single velocity function, in time to depth conversion, was found to have excessively high velocities in the upper 150 m when compared to the sonic log. Most importantly, a comparison between the two velocities (single velocity function and tomographic velocities) for depth conversion confirmed that to a large extent, limited shallow imaging is caused by inaccurate time to depth conversion. Utilising tomographic velocities for depth conversion showed that reflectors and structures were better imaged up to the top of the fresh rock. Small improvements observed in the time sections translated to large increases in interpretability after using tomographic velocities for depth conversion. Results from this investigation indicate significant potential for improving shallow imaging when travel time tomography is implemented in hard rock processing.

Benjamin Williams: *Qualitative and quantitative ranking of different seismic acquisition geometries over the Northwest Shelf using synthetic data.* Curtin University

Abstract withheld for reasons of confidentiality.

Ben Williams received his BSc in geophysics in 2013 and is currently finishing his Honours degree from Curtin University. He has worked with Barrick Gold Corporation, and more recently with Woodside Energy as both an Intern and Geophysics Analyst. He is set to start as a graduate geophysicist with Woodside in 2015. He is a member of ASEG and PESA.

Ry Zawadzki: *Test and development of a hybrid fluxgate-induction coil sensor for TEM measurement.* Curtin University.



A large part of Australia's mining industry includes the extraction of metalliferous sulphides. Time domain electromagnetic methods have proven to be the most effective geophysical method for base metal exploration, due to the conductive to semi-conductive nature of the ore deposits. As ore bodies come increasingly deeper and smaller to find, there is a need for higher power EM field transmitters, better signal processing, better receiver noise levels and bandwidth increase. Induction sensors and fluxgate magnetometers are currently industry standard TEM sensors for base metal exploration. They have complementary characteristics where one works well at low frequencies and the other at high frequencies. With this in mind, the idea of a new type of TEM sensor combining both the induction coil and fluxgate magnetometer into a single sensor sparked interest in TEM exploration industry.

A new type of TEM sensor was developed. The sensor was a hybrid of both a parallel time's deference fluxgate and induction coil sensor. Both exploited using a feedback circuit through an innovative integrated circuit created by Texas Instruments. The final result exhibited a working, highly linear, low drift sensor at DC-6 kHz fields. The idea of induction bypass at high frequencies has worked. A flat bandwidth of approximately 6 kHz was achieved. However, quantification of higher frequency sensitivity requires further testing and modifications. The hybrid is small and can be made fairly rugged for field use. This would allow for moving loop crews to access to one small (>5 kg) sensor operating off a 5 V power supply. Extensive noise level and frequency response testing has yet to be carried out at the conclusion of this thesis due to time limitation. However the prospect of this sensor providing a high bandwidth response with good high and low frequency noise levels warrants further investigation.

Ry was born in Hobart Tasmania and moved to Western Australia at the age of 14. An interest in electronics and physics led him to pursue a high school education in physics. He completed his Bachelor's degree in geophysics in 2012. In 2013 he worked as a geophysicist with Independence Group (IGO). Primarily his role was to ensure the highest quality data was collected in both surface and downhole electromagnetic surveys and that all remote camp requirements were achieved, maintaining all field equipment and completing field repairs where necessary. This maintenance covered a wide range of equipment from basic car and generator servicing through to more technical aspects of receiver and transmitter maintenance as well as completing data QA/QC procedures to ensure all collected data was of the highest quality and contained all relevant information. Ry's honours year in 2014 allowed him to pursue the development of a new type of magnetic field sensor. In his spare time he likes submission grappling/wrestling. The sport allows him to dissociate from his work/study after a long day while still keeping physical and mentally active. He is currently looking for employment to pursue his interest in geophysical innovation and practice.

Justine Carstairs: *Geophysical constraints on structural modelling in the onshore Gippsland Basin.* University of Melbourne.

The offshore Gippsland basin has been well studied since the discovery of giant oil and gas reserves, yet the onshore area remains, by comparison, poorly understood. This study aimed to produce a 3D model of the onshore stratigraphy, to accurately describe the subsurface structures, and to distribute the model with physical properties such as porosity. By integrating all available datasets, and inverting the model using new gravity data acquired by both the Geological Survey of Victoria and students at The University of Melbourne, I attempted to resolve in particular the Basement-Strzelecki interface, a difficult task given their physical similarities. Petrophysical data has been newly acquired for Yallourn North-1 using a Geotek Multi-Scanner Core Logger, and this data is added to existing well log information to geostatistically distribute porosity and density through the model. It is hoped that increasing our understanding of the regional geology – particularly the geometry of deep structures – will allow further development in fields as diverse as tight gas production, geothermal energy, and geological carbon storage and aquifer studies.

Nicole Filling: *Tectonic evolution of the Archaean metasediments of western St Ives Goldfield; implications from structural and stratigraphic observations (Kalgoorlie Terrane, Western Australia).* Monash University.

Gold exploration in the Kalgoorlie Terrane, Yilgarn Craton, Western Australia, has historically been biased towards the prominent greenstone belts. This has resulted in limited exploration of the overlying sedimentary sequences, comparative to the earlier greenstone sequence. The recent discovery of gold within these sediments at St Ives Goldfield has prompted a shift in exploration towards these younger units, specifically the Speedway Corridor on the western flanks of the exposed greenstone sequences. This region is poly-deformed and consists of complex structures. There is a need to better understand both the structures and the stratigraphy of importance of further exploration.

This study addresses discrepancies in the current structural and stratigraphic models of the southern Speedway Corridor using observations from drill core and field mapping, reconciled with high resolution geophysical surveys. Lithological observations were combined with petrographic analysis to characterize the predominant sedimentary sequences. The first of these two sequences is the Black Flag Group, a sub-aqueous feldspar-rich sequence, consisting of a

syn-sedimentary andesitic unit, reworked volcaniclastic debris flows and turbidite units. In comparison the Merougil beds consist of subaerial, quartz-rich sediments interpreted as a braided river deposit. Petrophysics analysis was conducted to determine the magnetic susceptibility of the identified lithofacies. Structural analysis illustrated the complicated relationship between faulting and folding throughout the area. Geophysical surveys were processed and analysed to produce and interpretive geological map of the area, with structural and lithological data providing constraints. From this geophysical investigation the southern Speedway Corridor was interpreted to consist of two synclines that have been juxtaposed together by a gently east dipping thrust fault. Some structures interpreted correlate with deformation events associated with gold deposition in the St Ives Goldfield, providing possible targets for future exploration within the regions, especially within the underexplored sedimentary sequences.

Nicole completed a Bachelor of Science Advanced at Monash University, majoring in Geology. Nicole has just completed honours (October 2014) focussing on structural geology, geophysics and sedimentology in the Kambalda Domain of Western Australia.

Janenie Moghan: *Ground penetrating radar (GPR) used as a geophysical method for subsurface utility mapping and lateritic bauxite exploration.* Monash University.

The operation of ground penetrating radar (GPR) is based on the propagation of electromagnetic waves to probe subsurface materials. Once raw GPR datasets are acquired, it is key that suitable data processing functions and parameters are used to ensure the data is processed and interpreted as accurately as possible. GPR was used to detect buried utilities at a street intersection in Port Melbourne (Australia) and for bauxite exploration at a lateritic bauxite exploration site in Sanxai (Laos). The datasets from these two localities were collected at 400 MHz, and 30 and 80 MHz respectively. Data processing methods for these two applications were studied and compared to identify similarities and differences in the processing functions used. Several key comparisons were able to be made but overall, the utility mapping dataset was found to be simpler and required less processing efforts than the bauxite exploration dataset.

It is important to note that the performance of GPR varies and is highly influenced by subsurface properties. This can sometimes be a disadvantage, especially if ground conditions are unfavourable. Factors such as high soil conductivities, shallow water tables, inadequate signal penetration and inefficient coupling of electromagnetic radiation into the ground may limit the success of GPR surveys. The processing GPR datasets are often subject to individual bias, which can lead to inaccurate or inconsistent interpretations.

Janenie is currently completing her Bachelor of Science (Honours) in Geophysics at Monash University, Australia. In 2013, Janenie graduated from The University of Melbourne with a Bachelor of Science in Geology. She is actively involved in The Australasian Institute of Mining and Metallurgy (The AusIMM) and has undertaken a number of leadership roles such as Treasurer (2012/2013) and President (2013/2014) of The AusIMM Melbourne Student Chapter. Janenie completed work experience with Rio Tinto Exploration between August 2013 and June 2014. She has a passion for travelling and aspires to work as a geophysicist with an Australian or international mining organisation.

Wang Liang: *Characterizing unwanted laboratory signals and noise in B field EM sensors.* RMIT.

The amplitudes of desired signals, unwanted signals and internal noise are the main factors that determine how useful an individual electromagnetic a sensor is in geophysics. Because many unwanted electromagnetic signal sources are widespread in the urban environment, sensitive sensors may be difficult to test in the laboratory, or to use in urban or mine environments. The aim of this project was to characterise the general electromagnetic noise variability at RMIT.

To explore temporal variations, experiments were conducted on weekdays, weekends and public holidays. Each major experiment lasted at least five consecutive days to investigate multiple component amplitude distributions with time. Electromagnetic spectra of weekdays and weekends were compared and it was shown that:

• Tram and other types of public transport created low-frequency signals sub 5 Hz. The magnetic sensor response is dominated by responses from electrical equipment, this equipment including computers, air conditioners and lights. The higher the floor in the building, the lower was the noise that detected by a sensor. In other words, the basement of RMIT University is the 'noisiest' location and level 12 is the 'quietest' location for electromagnetic interference. The Geophysics lab is on level 6, and during working hours unwanted signals are 4 to 5 orders of magnitude greater than sensor noise levels. At every location noise detected after midnight, on a weekend or a public holiday is lower than that detected on the weekdays.

Wang Liang is a Chinese national who completed Honours in Physics at RMIT in 2014. As well his geophysics degree, Wang previously completed a Master's degree in Medical Physics.

Andrew Pacey (Grad Diploma Mineral Resources): *Predictive deconvolution for coal seismology.* University of Queensland.

One of the oldest algorithms in seismic reflection, predictive deconvolution, is based on the assumption that reflecting interfaces are randomly distributed. This assumption is often violated, with coal systems providing an important example of the problem.

The formation of non-white reflectivity is demonstrated with reference to quantitative geological observations of periodicity in sedimentary facies. Novel deconvolution techniques, which

allow for non-random reflectivity, are evaluated, with particular reference to coal seismology.

Daniel Reyes: *Geophysical indicators of CSG sweet spots.* University of Queensland.

Recent research suggests that the gas-storage potential in coal seams may be causally related to P and S-wave velocities, and density. The possibility of surface detection of variable CSG potential has been evaluated, via numerical modelling of multi-component AVO effects in reflection packages from coal seams of realistic dimensions.

Nick Josephs: *Ground penetrating radar and an Honours case study on the eastern coast of Queensland.* Queensland University of Technology.

The purpose of this project was to find evidence of the most recent high-stand sea-level in the Holocene through mapping of the sub-surface using ground penetrating radar (GPR). It is the hypothesis of this project that Holocene sea-level change has influenced the landscape evolution on the Capricorn Coast of Central Queensland and that previous mid-Holocene high stand sea levels have created accommodation space inland from the modern day shore-line. This accommodation space and the deposited sedimentary successions provide evidence for the palaeo-depositional environment, which includes estuarine, barrier systems and palaeo-beach deposits. A difference in dielectric constant between sedimentary features associated with the mid-Holocene high stand and more recent sediments will result in a radar reflector that can be imaged with GPR. Identification of such a reflector as the formation top of mid-Holocene high stand can be achieved through correlation with other physical observations such as boreholes and outcrops.

Using GPR imaging one prominent reflector was found across all sites using the 200 MHz antennae and a second continuous reflector was found using the deeper penetrating 50 MHz antenna. The first reflector was identified as the local water-table and the second showed point reflectors over a strong planar reflector interpreted as being a palaeo-beach environment. The radargram facies and features are exhibited as specific geomorphology in the modern day coastline to the east of the sites. Data also indicate that the velocity of the sediment between sites is constant and fairly homogenous confirming similar sedimentary composition over the area and contributing to the steady Quaternary tectonics hypothesis for this region on the eastern coast of Australia. This study conclusively shows that an ancient beach was found approximately 2.5 m above present local sea-level at 180 m back from the seashore. Due to the tectonic stability of the area, this study provides evidence that sea-level has previously reached up to 3 metres higher compared to present day.

Nick completed a BBiomedSc at QUT in 2007, then worked in an electro-chemical sensing lab until a field and lab technician opportunity presented itself in 2011 at Sigra Pty Ltd; a Civil and Mining Engineering company. Nick's love of geology pushed him to come back to study in 2012 where he finished his BSc (Geology and Geoscience) and has recently completed his BSc (Honours) in the area of Geophysics at QUT.

Ashby Cooper: *The crustal structure of the Bass Strait region from combined passive seismic methods.* University of Tasmania.

The receiver function method is sensitive to deep crustal and upper mantle (5–50 km) seismic velocity variations, and provides an insight into the structure and evolution of the crust beneath the seismometer. Application of the method is particularly appropriate in less explained regions, or as a reconnaissance in regions of contrasting adjacent terranes. Receiver function analysis of teleseismic earthquake events was conducted using twenty-four broadband seismometers distributed around Bass Strait. This was motivated by the need to understand the enigmatic relationship between terranes in Tasmania and Victoria, as well as the poorly understood and undercover association between the tectonic elements across Bass Strait. Using the Neighbourhood inversion Algorithm, a seismic velocity model of the crust was inferred for each location. Well-fitting models are characterised by a synthetic receiver function that matches the variations in the observed receiver function. In the case where more than one structure is a good fit to the waveform, this is shown in the output of the inversion procedure. New determinations of crustal structure were made that significantly improve the constraints on the Moho depth for Bass Strait and surrounding areas. The results from this study suggest a shallow (20–27 km) Moho with a gradational transition beneath west Bass Strait and a deeper (30–40 km) Moho with a sharp transition beneath east Bass Strait. A low velocity zone in the upper mantle beneath King Island is consistent with mafic underplating and subsequent detachment of cooled and fractionated material. The sharp Moho beneath east Bass Strait is not typical of the orogenic terranes in the southeast of mainland Australia. Further implications of the new structural findings are discussed in the light of theories concerning the tectonic evolution of southeast Australia.

Ashby is a geophysics student at the University of Tasmania and part-time adventurer. He has wanted to be a geologist since primary school and over his time at university has developed a passion for global tectonics. He looks forward to learning more about all areas of geology and to getting outside and discovering more about our planet.

Alistair Harvey: *Depth to basement below the Bowen and Surat Basins, Chinchilla, Queensland.* University of Tasmania

The Jurassic-Cretaceous Surat Basin in the Darling Downs region of southern-central Queensland is currently the focus of major coal seam gas (CSG) exploration. The economics of CSG extraction are in part determined by the structure of the basin, which controls the depth to coal resources and permeable pathways for gas extraction. In the Darling Downs region, around the town of Chinchilla, the Surat Basin overlies Palaeozoic basement rocks of the New England Orogen in the east, and the Permian Bowen Basin in the west. Depth to basement varies significantly, from outcrop to the northeast of the region to greater than 10 km in the Taroom Trough to the west. This study provides a detailed depth to basement surface centred on tenements held by QGC near the town of Chinchilla, using public access potential field, well and seismic data.

The basement surface was created predominantly by synthesis of potential field forward modelling guided by wells and 2D seismic. Time horizons picked on 2D seismic data for several prominent reflector packages were interpolated and converted to depth horizons to help constrain the basement interpretation. Interpretations of seismic data and automated potential field source depth estimation guided forward modelling and potential field inversions. The final basement surface was created by ranking the confidence in individual techniques and datasets to compile a surface that reflected the best constrained model.

Well and seismic data are the best methods for determining basement depth, particularly in the east of the study area where there is good seismic coverage and the basement lies relatively close to the surface. However, the limited distribution of wells and seismic further west, together with the difficulty of identifying basement beneath the Bowen Basin in seismic data, meant that potential field techniques were utilised to infill gaps. Potential field automated depth estimation techniques locate lateral contrasts and produce a range of plausible depths, although considerable filtering of source solutions was required to identify the most probable solutions. Inversions of magnetic and gravity data provided few additional constraints on the basement depth surface. Difficulties with synthesizing the individual datasets meant that forward modelling, guided by the seismic and automated depth estimate techniques, was heavily relied upon to produce the final model

Alistair has a double degree in Economics and Science, majoring in Economic Analysis, Economic Geology and Geophysics, and has just completed his Honours year in Geophysics at the University of Tasmania. He has been actively involved in the Tasmanian Student Chapter of the AusIMM as Treasurer in 2012 and has undertaken internships in both the Mining and Energy sectors. He will commence work with Evolution Mining as a Graduate Geoscientist in 2015.

Jie Yu: *A geophysical investigation of the Mt Lindsay-Lynch Hill area, western Tasmania.* University of Tasmania

The Mt Lindsay-Lynch Hill area is characterized by a complex succession of late Proterozoic to Ordovician rocks that has been intruded by Devonian granitic rocks. The study utilizes potential field geophysical methods to reinterpret the three-dimensional geology of this region with particular emphasis on the distribution of Devonian granitic rocks.

New petrophysical data from drill core indicates that the Meredith Granite, Owen Group and Eldon Group may produce negative residual Bouguer anomalies, while positive anomalies are likely associated with denser units like the Success Creek Group, the Crimson Creek Group and Cleveland-Waratah association. Cambrian ultramafic units display significant variation in density, due to the high degree of sepentinistation of the samples. Cambrian ultramafic complexes and mineralized rocks are the strongly magnetic rocks within the study area and account for almost all of the anomalies observed in the TMI data.

Addition of new gravity data on systematic application of automatic terrain correction in the study area has better defined the form of the major anomalies and suggests a steeper southern margin for the Meredith granite than previously interpreted. Constrained inversion of the residual Bouguer gravity data suggests the presence of a previously undocumented subsurface granite body in the east of the study area. Unconstrained magnetic inversions suggest that Cambrian ultramafic units do not continue under the Huskisson syncline in all areas. The zones where Cambrian ultramafic units appear to be discontinuous are spatially associated with the referred subsurface granite body. The discontinuous distribution of Cambrian ultramafic units provides a supporting evidence for a subsurface granite body in this area.

Jie Yu is Chinese and came to Australia to study in 2011. She holds a Bachelor of Science with Honours in Geophysics from University of Tasmania. She is interested in geophysical mapping and mineral exploration.

Masters projects

Sabbath Akhabue: *Analysis of time lapse signal over a depleted gas field.* Curtin University.

Vanessa Gutierrez: *Cooperative evaluation of post-stack inversion techniques over the Maitland Reservoir and adjacent prospects.* Curtin University.

The Maitland Gas field located in the Barrow Sub-basin of the offshore Carnarvon basin shows a distinctive seismic amplitude anomaly at the base Tertiary level, where three wells have intersected gas charged sandstones. The Moon-1 well located approximately 15 km towards the north of the Maitland gas field shows poor reservoir development at the Maitland sand horizon at the base Tertiary level with weak seismic amplitude response. Even though the presence of gas in Maitland Sand shows a general elevated amplitude response, a judgment based only on amplitude will not be enough to characterize the Maitland reservoir. Therefore, impedance estimation over the area is required by performing a poststack inversion. This analysis will allow mapping of the spatial variability of the acoustic impedances related to the Maitland gas charged sand by performing poststack inversion. From that process will be possible to see better sand quality in those areas where the acoustic impedances is lowest. The poststack inversion results will be evaluated by comparing different conventional poststack algorithms, then a comparison with previous study will be performed This will help in the identification of the largest continuous areas of lowest impedance and in the evaluation of their spatial distribution and potential geological boundaries. All of this interpretative work was done on Apache Energy's offices using the Hampson-Russell Inversion software package (Strata) and Insight3.1.0.

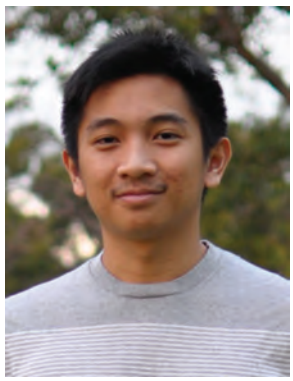
The different inversion results show clearly the reservoir, a low impedance sand. The post-stack inversion gives the best results was the Coloured based algorithm, at the well location this model shows to be the closest to the values of the impedances from well logs. The distribution of the Maitland sand was best represented by the Band Limited inversion, as it matches with geological features observed on seismic data.

Vanessa Gutierrez is from Venezuela, South America. She studied for her Bachelor's degree at the Simon Bolivar University in Caracas, Venezuela. After that, she spent 1 year and 5 months working for a service company. This working experience made her think about going to university to complete a Master's degree in Geophysics. In 2012, she decided to come to Australia to study for a Master's degree in Science (Geophysics) at Curtin University of Technology. After a year, she joined Apache Energy as a vacation student, which allowed her to complete her thesis project during 2014. Vanessa is very interested in continuing to learn whilst working as a geophysicist in Australia.

Zacharia Shitakwa Hoidi: *An investigative study on static correction methods to optimise on processing time and cost.* Curtin University.

Raqatim Seru: *A field test of electrical resistivity changes occurring during flow through a whole core sample.* Curtin University.

Ridha Ramadhan Soedarsono: *Pseudo 3D processing of crooked 2D Seismic profiles.* Curtin University.



Land 2D seismic survey is often restricted due to various terrain issues and ends up as a crooked 2D seismic profile. In complicated 3D geological structures, out of plane events are frequently introduced. These are cross-dip events produced away from the midpoint track which do not correspond to the CMP line. These events may both create false structure as well as distorting true structure.

In case of a severely crooked seismic profile, the midpoint distribution would scatter forming a wide area instead of a single line. Therefore, there is a possibility to treat a crooked profile data as a portion of 3D survey. This project attempts to identify out of plane events by performing a pseudo-3D processing algorithm on the crooked profile data. Subsequently comparison with both conventional 2D processing data and true 3D data is done to see the robustness of the method.

There are issues found with this method. It has a lower stack quality due to lower fold density and, as it also lacks of actual crossline information, it does not represent the accurate crossline interface compared to true 3D data. Nevertheless, result shows the pseudo-3D processing method is capable of identifying out of plane events by presenting less of these events in the final image compared to the conventional 2D processing method. This result is also confirmed by comparison with the true 3D data.

Ridha Ramadhan Soedarsono is a Masters in Geophysics student at Curtin University. He has a Bachelor's degree in Physics from Institut Teknologi Bandung, Indonesia. He is currently interested in seismic data processing.

Alexandre Lemenager: *Assessment of the geothermal attributes of the Northern Permian Sydney Coal Measures.* Macquarie University.

Coal samples from the Northern Sydney Basin coal measures were collected and analysed through a thermal conductivity tester in order to determine individual thermal conductivities of each coal specimen. Thermal conductivities were acquired at temperatures between 20 and 300°C. Petrographic and XRF/ICPMS analysis are underway which will aim to constrain certain parameters such as pore space, grain size, cement mode and signs of alteration in coal samples, as well as determining the bulk composition to be correlated with known thermal conductivities. The majority of samples were acquired through exploration mining companies. Samples of the St Heliers coal seam, part of the Greta coal measures, were obtained through MusCoal based at Muswellbrook; samples of the Lemington and Bayswater seams, part of the Whittingham coal measures, were obtained through the Ravensworth Surface operation exploration mining group; samples of the Big Ben and B3, part of the Tomago coal measures, were obtained through Bloomfield Collieries based at East Maitland;

and lastly the Catherine Hill Bay coal seam samples from the Newcastle coal measures were obtained through a coastal outcrop, southeast of Lake Macquarie. Current results show that the majority of coal samples out of a total of 18 have predictable thermal conductivity gradients between 20 and 300°. There are exceptions, which are due to the presence of quartz veins and apparent silicification, resulting in higher thermal conductivities. Thermal conductivity measurements can be used to predict the potential heat flow of specific coal seams at various temperatures. Low and high temperature calibrations were done to accommodate potential instrumental drift and reduce uncertainties in thermal conductivity measurements, where slight variations in thermal conductivities were observed between stock factory and recent calibrations. Thermal conductivity measurements can be used to predict the potential heat flow of specific coal seams at various temperatures and provide a basis for the understanding of the thermal properties of coal measures in the Hunter Valley region and the role of coal as a thermally insulating structure in potential geothermal systems.

Geology and geophysics have been the main focus of Alexandre's studies at Macquarie University, his Bachelor's Degree and his current Masters project. More specifically, the field of geothermal energy has been a personal field of interest. This interest stemmed from pure curiosity but eventually led to a research project regarding coal measures in the Sydney Basin.

Ben Patterson: *A geophysical investigation of the Woodend base metal occurrences.* Macquarie University.

This report contains the findings of a two week geophysical survey and subsequent data processing, modelling and evaluation of the Woodend base metal occurrences east of Cooma, New South Wales. Three targets were identified within the prospect after the analysis of samples acquired during surface prospecting. Two of the samples returned economic grades of zinc and the third target was the site of an abandoned copper shaft surrounded by malachite stained dump rocks. Analysis of these rocks suggested a promising opportunity for exploration and warranted a geophysical investigation to determine the validity of any possible ore grade deposits. To determine the size and extent of possible subsurface mineralisation a variety of geophysical methods were employed. Industry proven gravity, magnetic, and electromagnetic techniques were deemed the most appropriate in the investigation of the suspected metallic deposits. These methods were also evaluated in terms of their respective ability to resolve the underlying geology of the Woodend prospect. In-depth data processing was undertaken to improve the quality of the various data sets. Each of the data sets was evaluated in terms of their ability to delineate sulphidic mineralisation and the local geology of the Woodend survey area. Although the TEM survey displayed a small anomaly over the abandoned copper shaft, it was ultimately concluded that the methods used in the survey did not identify a massive sulphide deposit but rather detected varying geophysical responses within the local geology.

Ben is currently completing a Master's of Science (Geophysics) at Macquarie University where he also attained his Bachelor of Science majoring in Geophysics and Geology. His focus is on mineral exploration, in particular data modelling and the application and associated challenges of various geophysical techniques. Ben is a student member of the AIG, ASEG and AusIMM.

Tunde Adekoya, Jeffrey Shragge, Mattias Leopold and Gavan McGrath: *Time-lapse geophysical monitoring of the subsurface hydrology at Kings Park.* The University of Western Australia.

Tunde Adekoya

The increasing occurrence of drought stress throughout southwestern Western Australia is postulated to have contributed to the decline of Banksia populations both in Kings Park, Perth, and in the Banksia woodlands in the greater Swan Coastal Plain region. To help quantify these assertions, there is an urgent need to better understand the base levels of soil moisture content – as well as seasonal variations thereof – in these geographical regions. As a baseline study, we applied repeat (i.e. time-lapse) geophysical methods to image the geology and the hydrology at two Kings Park locations with contrasting elevations and depths to groundwater in order to develop a conceptual model of the subsurface hydrology and plant-water use in the Park. We conducted time-lapse (TL) electrical resistivity tomography (ERT) and ground penetrating radar (GPR) methods on a monthly basis and combined with soil analyses and direct soil moisture measurement to refine and constrain the conceptual model.

The two geophysical survey transects were situated within Kings Park roughly 1.3 km apart with the western line situated 40 m higher in elevation than the lower eastern site. Time-lapse ERT and GPR data were acquired at both sites between May and August 2014. Electrodes were left in the ground for the 4-month period to ensure repeatability of measurements and to serve as guides for the repeat GPR acquisition. In addition, at each site we hand-augured test holes to a depth of 3–4 m and collected samples at 20 cm intervals to enable grain-size analysis, soil moisture content and water retention tests. PR2 capacitance probe measurements were also acquired when auguring to enable a moisture content comparison study.

The temporal variations in resistivity profiles from the inverted TL ERT datasets were interpreted in terms of changes in moisture content. These profiles reveal significant calendar variations in the spatial distribution of moisture content. The TL ERT inversions also detected isolated less resistive lithologies and the depths to groundwater. Processed TL GPR data were interpreted to show vertical variations in the vadose zone moisture content. Temporal water content variations were consistent with the rainfall data. However, the TL GPR data could not be used to characterise the spatial variations in the subsurface volumetric water content because the GPR waveforms exhibited

no significant velocity variations and thus low sensitivity to water content changes. We established a highly correlated relationship between dielectric permittivity and water content, which suggests that one may characterise volumetric water content from the dielectric permittivity of the vadose zone. Statistical analysis of the sample grain-size distributions indicate that the particle-size distributions between the two sites do not vary significantly. We examined soil water retention by plotting volumetric water content as a function of pressure, which shows a sharp drop in water content from low-to-high pressures as is typical of sands. The inverted resistivity profiles and observed volumetric water content are strongly correlated ($R^2 = 0.84$) as may be expected from Archie's law. Soil moisture content analysis results including the PR2 probe measurements were plotted as a function of depth, the result shows vertical variations in moisture content with depth. The hydrological tests indicated the properties of the subsurface lithologies confirm the responses of the resistivity measurements.

This research work monitors water variations within the Kings Park and how they are related to the hydrological properties of the subsurface soils. The geophysical investigations indicated that water varies periodically and its availability and variations depends on the frequency of the rainfall. The hydrological tests reveal that the soils are mainly sands with low water retention capacity; however, water retention capacity increases with depth from about 3.5 m (due to an increase in silt/clay content). These observations suggest that during the long dry summer period, water may not be available to plants with shallow roots (plants with roots < 3.5 m deep). Water may therefore be a limiting factor responsible for the decline in Banksia plants.

Tunde Adekoya received a BSc degree in Geology from the University of Ilorin, Nigeria (2000) and MSc degree in Geology with an Applied Geophysics option from the University of Ibadan, Nigeria (2004). Tunde worked for Nigerian Geological Survey Agency between 2007-08 and then as a Field Engineer for Pilbara Wireline Services between 2009-12 conducting downhole geophysical surveys throughout the Midwest and Pilbara regions of Western Australia. In 2012, he commenced a part-time MSc Geosciences degree at the University of Western Australia (UWA) whilst continuing his Field Engineering work. Tunde recently was awarded the 2014 UWA Postgraduate Mentor of the Year Award (Muhammad Rizwan Hussain Award), and is expecting to finish his UWA MSc Geosciences degree in 2014.

PhD projects

Dr Kent Inverarity: *Electrical geophysics of carbonate mound spring complexes of the South-Western Great Artesian Basin.* University of Adelaide.

Artesian mound springs occur along the southwestern edge of the Great Artesian Basin, in northern South Australia, but their underground structure and relationship to faulting is not well understood. This work aims to address that with geophysical surveys over three mound spring systems (Beresford and Warburton Springs, the Bubbler Spring complex, and Freeling Springs), using a range of techniques: self-potential, magnetotellurics, and time-domain electromagnetics.

The self-potential data contain elevated local responses to spring vents and seeps. Spatial correlation suggests that these responses are caused by flow related to springs. Similar responses also occur underneath 'extinct' springs, suggesting shallow subsurface discharge of aquifer waters is still occurring. Little evidence was found for significant downward infiltration from spring tails.

Modelling of time-domain electromagnetic and magnetotelluric data show that the confining Bulldog Shale, which is generally very conductive, contains slightly more resistive areas underneath springs and spring complexes, which may be related to a combination of carbonate buildup in the subsurface and more resistive aquifer water. Magnetotelluric data and modelling suggests that fault zones exist under many of the mound springs, particularly at Beresford and Warburton Springs and the Bubbler Spring complex, with data consistent with models containing parallel vertical fault planes striking NW/SE. The models contain fault zones in the aquifer and immediately underlying basement, suggesting that fluids may be sourced from the aquifer and deeper layers. The fault zone is not sensed in the aquitard, due to the very slight resistivity contrast.

Conduits to specific springs have not been successfully imaged using the techniques employed here, suggesting that the conduits are narrow and present only a slightly fluid resistivity contrast.

Kent Inverarity is working as a Geophysicist / Project Officer in the SA Department of Environment, Water and Natural Resources.

Dr Aixa Rivera-Rios: *Multi-order vector finite element modelling of 3D magnetotelluric data including complex geometry and anisotropy.* University of Adelaide.

This thesis presents the development of a computational algorithm in Fortran, to model 3D magnetotelluric (MT) data using a Multi-order Vector Finite Element Method (MoVFEM) to include complex geometry (such as topography, and subsurface interfaces). All the modules in MoVFEM have been programmed from the beginning, unless specified by referencing the libraries used. The governing equations to be solved are the decoupled electromagnetic (EM) partial differential equations for the secondary electric field, or the secondary magnetic field, with a symmetric conductivity tensor to include anisotropy. The primary fields are the solution of a plane-wave within the air domain. Two boundary conditions are implemented, namely the Generalized Perfect Matched Layers method (GPML) and Dirichlet boundary conditions. Three Dirichlet

boundary schemes are applied, first considering zero EM fields at the boundaries of the computational domain; secondly, considering the boundaries as homogeneous Earth; and finally, considering the boundaries as a layered Earth. Two formulations of GPML are implemented in this algorithm, firstly the original GPML formulation and secondly, the GPML parameters are modified for the MT and Controlled Source Electromagnetic (CSEM) problem. High-order edge-elements are defined based on covariant projections, and mixed-order edge-elements for hexahedra. The vector basis functions are defined for linear elements (12 edge-elements), quadratic elements (36 edge-elements), and Lagrangian elements (54 edge-elements). By this definition, the vector basis will have zero divergence in the case of rectangular elements and relatively small divergence in the case of distorted elements.

The validation of this computational algorithm is performed with a homogeneous Earth, where the analytic solution of the MT problem is known. In the validation, the convergence of the solution is analysed for different grid spacing and for different element-orders with Dirichlet boundary conditions. High-order elements produce accurate solutions with larger spacing than the fine grid needed for linear-order elements. After the convergence analysis, the solution obtained with all the proposed boundary conditions, and edge-element orders are compared for one frequency, and for a frequency range. In the homogeneous Earth, Dirichlet boundary condition presents backward reflections from the boundaries of the computational domain to the centre of the model. Both GPML formulations produce more stable solutions, where no boundary reflections are present. However the MT responses fluctuate within a small range close to the values for the homogeneous Earth. The GPML formulation for MT and CSEM produce more accurate results and stabilize the MT responses over a frequency range. This algorithm is applied to synthetic examples with complex conductivity structures. Some of these synthetic examples have been published previously, thus the results of this algorithm are compared qualitatively. In the case of anisotropy and complex geometry, the proposed synthetic examples have not been published, and a discussion of how the MT responses behave for these Earth examples is presented. This computational algorithm could be extended with the use of an adaptive method, and it could be implemented in an algorithm for 3D inversion of MT data.

Aixa Rivera-Rios is now working for Schlumberger in Houston.

Dr John Wilford: *New regolith mapping approaches for old Australian landscapes.* University of Adelaide.

The regolith, or 'critical zone', forms a discontinuous layer that covers large areas of Earth's terrestrial surface. It is a dynamic zone that forms and changes through time in response to interactions between air, rocks (minerals), water and biota. Knowledge of regolith is critical because of its key role in supporting terrestrial life, through physical, chemical and biological processes that operate at mineral-water interaction scales up to the regional scale through geological and tectonic activity. There are many disciplines or areas of applied integrated research that rely on an improved understanding of regolith formation and information on surface and sub-surface regolith properties at appropriate spatial scales. These areas of study include; agriculture, land use sustainability, hydrology, salinity management, ecology, mineral exploration, natural hazard risk assessment and civil engineering. Furthermore, mapping regolith is critical in understanding the origin and evolution of regolith through space and time. Mapping the regolith and formulation of associated robust process models are in their infancy compared with geological and soil mapping, which have had a long history of development and refinement. Regolith mapping can be seen as a hybrid approach combining elements from the existing mapping disciplines of geology, soil and geomorphology. The regolith-landform approach, used extensively in Australia, is broadly similar to soil-landscape mapping where landforms are used as the principal surrogate to map regolith. Regolith-landform and soil-landscape mapping are inherently empirical and qualitative. However, in the last ten years there has been a move from the qualitative land resource survey (i.e. soil-landscape mapping) approaches to quantitative, digital survey underpinned by statistical methods. These new quantitative approaches are enabling the prediction of specific soil properties with associated estimates of model confidence or uncertainty not possible using traditional approaches.

The aim of the thesis is to demonstrate and assess the application of quantitative soil mapping approaches in predicting regolith properties. Four case studies are presented that illustrate the application of quantitative mapping approaches in predicting regolith across a range of spatial scales and within different landscape settings. These four investigations include: 1. A continent-wide prediction of weathering intensity using a step-wise multiple regression-based model using airborne gamma-ray imagery and terrain relief; 2. A continent-wide prediction of near-surface secondary carbonate using environmental correlation and regolith geochemistry; 3. A regional-scale prediction of soil-regolith thickness over the Mt Lofty Ranges in southern South Australia using environmental correlation, drilling and legacy data, and 4. A regional-scale 3D regolith-landscape evolution model of valley-fill deposits from the Jamestown area in South Australia based on dataset integration, regression analysis and optically stimulated luminescence dating. The investigations are interpreted within a landscape evolutionary framework and future research directions are discussed.

Digital regolith mapping shows considerable potential in predicting regolith properties over different landscape scales. This mapping is also important for understanding the complex interaction of environmental factors that control regolith formation, removal and preservation. Addressing gaps in predictive datasets that describe or reflect properties within the sub-surface (i.e. 5–100 m depth interval) and systematic collection of quantitative regolith attributes such as weathering depth and geochemistry will greatly enhance the future applications of digital regolith mapping in Australia.

John Wilford is currently with Geoscience Australia.

Dr Faisal Abdulkader Alonaizi: *Application of diffracted wave analysis to time-lapse seismic monitoring of CO_2 geosequestration.* Curtin University.

Dr Majed Ahmed Almalki: *Borehole Seismic methods in high permeability sandstones.* Curtin University.

Dr Mehdi Asgharzadeh: *Analysis of seismic anisotropy at the CO2CRC Otway project site.* Curtin University.

Dr Eva Caspari: *Effect of scale and saturation on effective properties of porous rocks for seismic monitoring of CO2 sequestration.* Curtin University.

Dr Sofia Correia Lopes: *Fluid injection in reservoir rocks with x-ray CT scanning*

and active ultrasonic monitoring. Curtin University.

Dr Konstantin Tertyshnikov: *Seismic imaging in hard rock environments.* Curtin University.

Robin Armit: *High-heat geodynamic setting during the Palaeozoic evolution of the Mount Painter Province, SA, Australia: evidence from integrated field structural geology and joint potential-field inversions.* Monash University.

A method for subsurface recognition of blind geological bodies is presented using combined surface constraints and 3-D structural modelling that incorporates constraints from detailed mapping, and potential-field inversion modelling. This method is applied to the Mount Painter Province and demonstrates that addition of low density material is required to reconcile the gravity signature of the region. This method may be an effective way to construct 3-D models in regions of excellent structural control, and can be used to assess the validity of surface structures with 3-D architecture. Combined geological and potential-field constrained inversion modelling of the Mount Painter Province was conducted to assess the validity of the geological models of the region. Magnetic susceptibility constrained stochastic property inversions indicates that the northeast to southwest structural trend of the relatively magnetic meta-sedimentary rocks of the Radium Creek Group in the Mount Painter Inlier is reconcilable with the similar, northeast to southwest trending positive magnetic anomalies in the region.

Radium Creek Group packages are the major contributor of the total magnetic response of the region. However field mapping and the results of initial density constrained stochastic property inversion modelling do not correlate with a large residual negative gravity anomaly central to the region. Further density constrained inversion modelling indicates that an additional large body of relatively low density material is needed within the model space to account for this negative density anomaly. Through sensitivity analysis of multiple geometrical and varied potential-field property inversions, the best-fitting model records a reduction in gravity rms misfit from 21.9 to 1.69 mGal, representing a reduction from 56 to 4.5 per cent in respect to the total dynamic range of 37.5 mGal of the residual anomaly. This best-fitting model incorporates a volumetrically significant source body of interpreted felsic, low density material (1012 m^3) impinging on the central-west of the Mount Painter Inlier and overlying Neoproterozoic sequences, and the emplacement of more mafic affinities in the northeast and east. The spatial association and circular geometry of these granitoid bodies suggests an affinity with the Palaeozoic ~460–440 Ma British Empire Granite that outcrops in the Mount Painter Inlier. The intrusion of this additional material in the Palaeozoic could either be the product of; or contributed to, an increased local geotherm and heat flow in the region during the Palaeozoic.

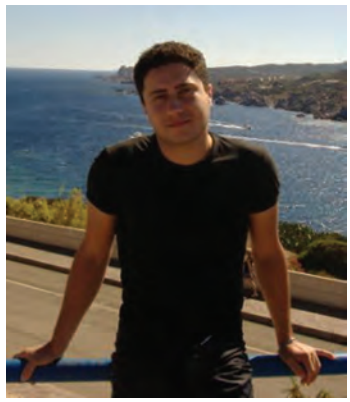
Robin completed his PhD at Monash University studying the geodynamic evolution of the northern and eastern marginal terranes of the Gawler Craton. The research includes the integration of structural geology, geochronology, Hf isotopes and structural geophysics. Robin is also an assistant lecturer in Geophysics at Monash University and a Principal Geologist at PGN Geoscience specialising in geological interpretation mapping from potential-field data.

Teagan Blaikie: *Interpreting the subsurface architecture of maar volcanoes using geologically constrained 3D gravity inversions.* Monash University.

Geophysical modelling techniques are applied to examine and compare the subsurface morphology of maar volcanoes within the Newer Volcanics Province to better understand their eruptive histories and the hazards associated with future eruptions within the province. High-resolution ground gravity and magnetic data were acquired across several maar volcanoes, including the Ecklin maar, Red Rock Volcanic Complex, and Mount Leura Volcanic Complex and the Anakie maar. The depth and geometry of subsurface volcanic structures were determined by interpretation of gridded geophysical data, and constrained 2.5 Dforward and 3 Dinverse modelling techniques. Bouguer gravity lows identified across the volcanic craters reflect lower density lake sediments and pyroclastic debris infilling the underlying maar-diatremes. These anomalies were reproduced during modelling by shallow coalesced diatremes. Short-wavelength positive gravity and magnetic anomalies identified within the centre of the craters suggest complex internal structures. Modelling identified feeder vents, consisting of higher proportions of volcanic debris, intrusive dykes, and ponded magma. Because potential field models are non-unique, sensitivity analyses were undertaken to understand where uncertainty lies in the interpretations, and how the models may vary between the bounds of the constraints. Rather than producing a single 'ideal' model, multiple models consistent with available geologic information are created using different inversion techniques. The modelling technique we present focuses on maar volcanoes, but there are wider implications for imaging the subsurface of other volcanic systems such as kimberlite pipes, scoria cones, tuff rings and calderas.

Teagan Blaikie won the ASEG Victorian Branch student night award for her presentation on her PhD thesis.

Dr Giovanni Spampinato: *Deep Australia.* Monash University.



Geophysical interpretation and 2.5 D potential-field forward modelling suggest that the Thomson Orogen in Queensland represents the interior extensional architecture during the Rodinia break-up that has been subsequently extensively modified by multiple extensional basin forming events and transient episodes of crustal shortening and basin inversions. In this scenario, the Cork Fault separating the Thomson Orogen and the Mount Isa Terrane does not define the zone of break-up as has been previously proposed nor is required to represent the boundary between the Proterozoic crust and the Phanerozoic crust of the Australian continent. This implies that the Thomson Orogen differs from the rest of the Tasmanides and the Thomson and the Lachlan orogens are two fundamentally different terranes.

The ASEG Research Foundation celebrates its 25th anniversary

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Introduction

The Australian Society of Exploration Geophysicists Research Foundation (ASEG RF) has been in existence since 25 September 1989 and to date has supported 115 projects and committed over $1 000 000 to support geophysical students at BSc (Honours), MSc and PhD levels at 13 universities in Australia. The ASEG RF is run by a committee of volunteers from academia, minerals, petroleum, engineering and environmental facets of the exploration geophysical industry. This article describes the origins of the ASEG RF as well as key statistics relating to the foundation's activities. Several recipients of foundation grants tell the story of what the grants have meant to their studies and the paths their careers have taken. Also highlighted are the grant application process and the source of funds and donations as well as committee roles.

Origins of ASEG RF

The birth of the ASEG RF took place over a period of 3 or 4 years following the genesis of the idea in the mind of Bob Smith. Bob canvassed many people's opinions on the original idea and received support from all sides. Additional support was solicited on the squash court. Peter Priest (a colleague of Bob's) was tasked to find the tax implications and effectiveness of such a research institution. Advice on this matter was received from the ATO in April 1987 and guidelines from the CSIRO were provided in May 1987 to assist the ASEG RF in seeking approved research institute (ARI) status.

From December 1987 to February 1988 Bob Smith received several letters of support from key members of the industry, including Keeva Vozoff, Roger Henderson and Jim Cull. In early 1988 the ASEG moved to alter its Articles of Association to allow for the ASEG RF and changes were approved in May 1988. Minutes of the ASEG Executive from 26 October 1988 show that Bob Smith was to be invited to be inaugural Chairman of the Research Foundation. The initial guidelines were developed from the 1987 thoughts of Chairman Bob and are dated 1 August 1988.

During 1989 various activities took place to ensure the legal basis of the ASEG RF, including approval of the altered articles and letters to prominent ASEG members inviting participation. In August 1989 the ASEG Executive approved Peter Priest as Honorary Treasurer of the Foundation. On 22 December 1989 Bob Smith was advised that CSIRO had formally approved the ASEG RF as an ARI. This date could, therefore, be considered the ASEG RF's birthday. Another birthday could be 19 February 1990, when the ATO advised formal approval of ASEG RF as an ARI. The press was informed about the formation of the ASEG RF on 9 March (Figure 1).

On 25 September 1989 the inaugural meeting of the ASEG RF Committee was held. This date is usually considered the official birthday of the ASEG RF, although the first call for grant applications was not made until later in 1990. The meeting was held during the ASEG Conference, at the Hilton Hotel in Melbourne in September 1989. Meetings of the ASEG RF Committee have been held at every ASEG Conference since then. In March 2014 the ASEG RF was approved under the Australian Charities and Not-for-profit Commission, which continued the tax-exempt status of the foundation under a new tax regime.

The ASEG RF Committee established at the first meeting had the following members:

- R. J. Smith (Chair)
- S. Mudge
- N. Hungerford
- J. Denham
- J. Cucuzza

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PRESS RELEASE

The Australian Society of Exploration Geophysicists (ASEG) has formed the ASEG Research Foundation to boost Australian research into exploration geophysics.

Funds are to be raised by donations from individuals, companies and professional societies (eg ASEG) and will be used to support graduate studies in exploration geophysics, primarily at B.Sc. Hons. or M.Sc. level, in Australian tertiary institutions. Mr Bob Smith, Chairman of the Research Foundation, said that this is a level at which funding is difficult to obtain and yet where support is necessary if such research is to continue.

He added that research funds will go directly to support projects in order to maintain applied objectives and hence make them more useful to industry.

The ASEG Research Foundation has recently become an Approved Research Institute, as defined by Income Tax Assessment Act 573A and all donations to the Foundation of $2.00 or more, are now tax deductible.

Some donations have been received already and they will be more actively sought now that tax deductibility is assured.

Mr Smith said, "We anticipate that the leverage obtained in this way will have considerable impact. We aim to attract and keep good students in exploration geophysics and at the same time ensure that they attempt worthwhile and practical research projects of direct interest to industry. Extra funding available through the ASEG Research Foundation should enhance the value of the projects undertaken.

Figure 1. *ASEG press release dated 9 March 1990.*

- P. Gunn
- D. King
- P. Fullagar
- D. Emerson
- S. Hearn
- B. J. Embleton
- E. A. Howell
- D. Boyd
- P. W. Priest

The original Chair was Bob Smith, the Secretary was Joe Cucuzza, and the Honorary Treasurer was Peter Priest. On 4 September 1995 a change took place when Joe Cucuzza became the Chair, Doug Roberts Secretary and Peter Priest Treasurer. Bob Smith continues to serve as a committee member. In 2001 further changes saw Phil Harman become the Chair, Doug Roberts continue as Secretary and Peter Priest as Treasurer. This executive remains in place at present. John Denham has been the Petroleum sub-Committee convenor since inception and Hugh Rutter was Minerals sub-Committee convenor until he sadly passed away earlier this year. In recent years Don Emerson has been the convenor of the Engineering/ Environmental sub-Committee. The full ASEG RF Committee has been very stable with many long-term members. There are still six members from the original list. The ASEG past President is an *ex-officio* member.

Celebrations at the 2013 Conference Dinner. Anti-clockwise from centre: the ASEG Service Medal recipient, Peter Priest; Nick Sheard; Terry Crabb; and Robert Smith.

Currently, however, the committee is searching for new members who are young and enthusiastic. We are looking for volunteers from academia and industry, and from minerals, petroleum and engineering areas.

ASEG RF activities

Table 1 shows the first four projects supported by the ASEG RF in 1991.

Since 1991, 115 projects have been supported by the ASEG RF. The nature of these projects is described in the Figures 2–6.

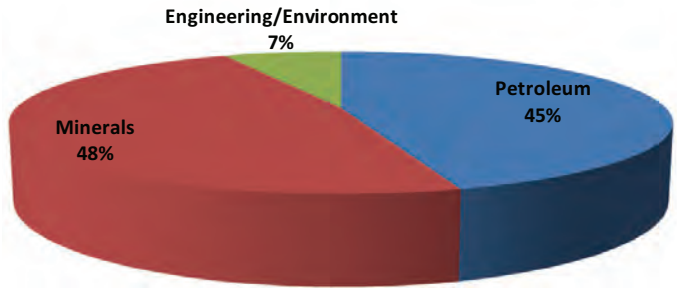

Figure 2. *The percentage of projects supported in each field of geophysics.*

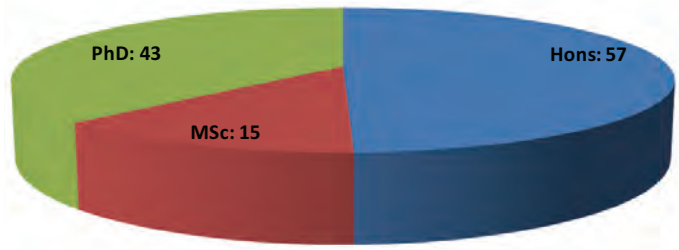

Figure 3. *Number of project supported by degree type.*

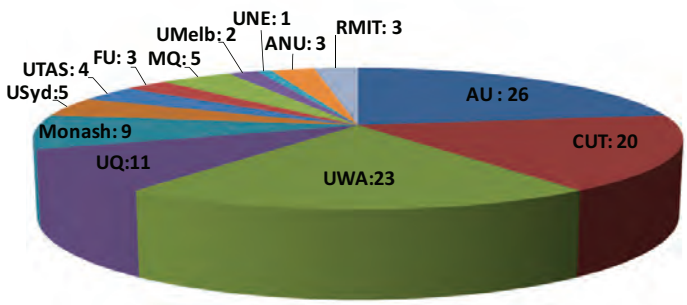

Figure 4. *Number of projects supported by university.*

Table 1. Initial ASEG RF projects

University	Supervisor	Student	Degree	Field	Funding	Years	Topic	Monitor
University of Queensland	Dr S. Hearn	John McMonagle	Hons	P	$4803	1	Combined P wave/S wave seismic reflection for coal	B. Long
University of Western Australia	Dr M. C. Dentith	Kylie Paish/ Michael House	Hons	M	$5000	1	3D structure of the southern greenstone belt WA	G. Street
University of New England	Dr J. M. Stanley	David Boggs	Hons	M	$3987	1	Effects of rock magnetic properties, cultural, and natural HF pulsations and diurnal fluctuations on base station corrections in air mag surveys	S. Mudge
Flinders University	Dr S. A. Greenhalgh	N. Sikes	MSc	P	$3460	1	Imaging of subsurface faults by walkaway VSP waveguiding – physical model experiments	P. Fullagar

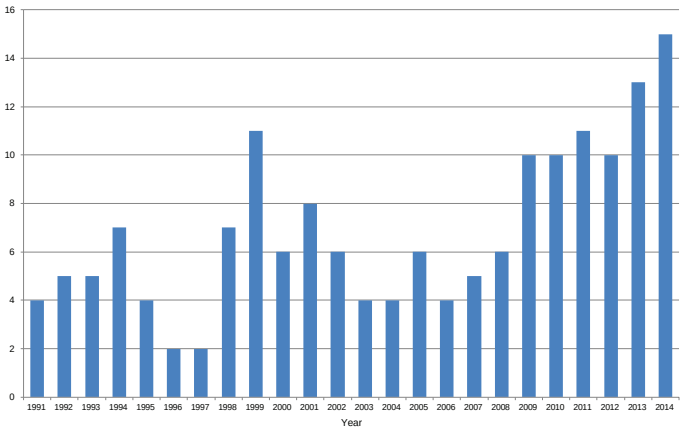

Figure 5. *Number of projects supported each year.*

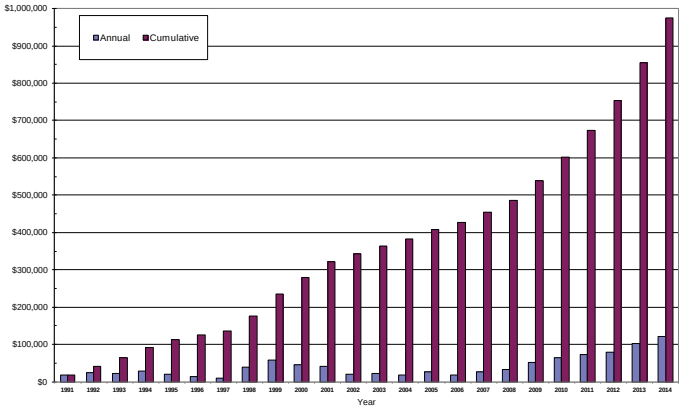

Figure 6. *Funding levels year by year since 1991.*

Past project reminiscences

The ASEG RF Committee asked several past recipients of ASEG RF grants (Table 2) to describe how the grant helped in their studies and also the paths their careers have taken. Many of the students are now well known in the wider ASEG community.

Natasha Hendrick 1993 and 1999

I was first awarded an ASEG RF grant to undertake my Honours year in 1993, in Exploration Geophysics at the University of Queensland. My research project looked at seismic inversion and the impact of assumptions made around spectral extension practices to accommodate missing frequencies in our seismic data. Most importantly, the grant helped fund the University of Queensland geophysics lab, including the computing facilities that I required to conduct my research, and enabled me to attend my first ASEG conference to present my work (and I haven't missed an ASEG conference since!). I am extremely grateful that the grant helped support me through my Honours year so that all of my time could be spent on geophysics (I actually really enjoy my field of work!).

A number of years later, I was privileged to receive an additional grant from the ASEG RF to help cover expenses towards the end of my PhD in multi-component seismic vector processing. A challenging topic … I had out-studied my original PhD scholarship and the awarding of an ASEG grant meant I had the time to finish the research properly. I have applied the learnings from this research in a number of geophysical roles since – including application to onshore, offshore and ocean-floor multi-component seismic data. In 2003 I was awarded the ASEG Laric Hawkins Award (most innovative use of a geophysical technique) for a paper I presented at the ASEG Conference on my PhD research.

Since completing my PhD I have worked in various technical, research, management, training and marketing roles with Digicon Geophysical, MIM Exploration, Velseis, PGS and DownUnder GeoSolutions. My research roles have seen me work with engineers, mathematicians, geologists and geophysicists around the world on broadband seismic solutions, 4D seismic for reservoir monitoring, a multi-component fibre optic seafloor acquisition system, converted-wave imaging, vector processing and finite-difference modelling. These days I'm working as a geophysicist at Santos – providing geophysical support for exploration and development projects, including conventional oil and gas, and shale gas exploration, and managing our Carnarvon and Ceduna Basin Exploration assets.

Table 2. Recipients of ASEG RF grants invited to reminisce about their experience

Year	University	Supervisor	Student	Degree	Field	Funding	Years	Topic
2007	University of Adelaide	Dr Graham Heinson	Michael Hatch	PhD	E	$5037	1	Geophysical interpretation of temporal variations of surface and groundwater hydrology
2002	University of Adelaide	Professor Stewart Greenhalgh	Phillip Heath	Hons	M	$2200	1	A theoretical and numerical study of potential field gradient methods for exploration beneath cover
1999	University of Queensland	Dr Steve Hearn	Natasha Hendrick	PhD	P	$6700	1	Applications of multi-component processing in exploration seismology
1995	University Tasmania	Dr D. E. Leaman/ Dr Michael Roach	Nick Direen	Hons	M	$4790	1	Structure of the Longford Basin, Northern Tasmania
1994	NCPGG	A. Mitchell	Ralph Weiss	MSc	P	$4940	1	An analysis of velocities within the Lake Hope 3D seismic survey area
1994	University of Adelaide	Dr R. Hillis	Shane Squires	Hons	P	$5000	1	Seismic shear wave anisotropy experiment
1993	University of Queensland	Dr Steve Hearn	Natasha Hendrick	Hons	P	$4800	1	Evaluation of seismic trace inversion in the Surat Basin, Qld

Shane Squire 1994

The ASEG RF grant provided funding for field experiments to observe and record shear-wave anisotropy using a (sledge) hammer-induced seismic source, in an area where fractures were known to exist in the shallow sub-surface. We had a large railway sleeper (~2 ft × 1 ft × 1 ft) engineered to be encased in 1 cm metal plates, and had two ~2 ft (1 inch thick) nails driven through the block so they protruded ~1 ft to allow better coupling with the ground. This acted as our source plate/block for generating hammer-induced p-waves (via a vertical strike) or s-waves (horizontal strike), the energy from which was then recorded along a short 2D array of surface geophones.

I joined Santos in 1995 and have built an extensive 19 year career involving portfolio risk analysis, seismic interpretation in exploration and appraisal, both onshore and offshore, and most recently rock physics, seismic inversion, AVO modelling and analysis and geostatistics. My current role as a Staff Geophysicist with the Quantitative Interpretation Group is focussed on providing high-end geophysical support to Santos.

Ralph Weiss 1994

Ralph Weiss with daughter Beth.

In February 1993 I returned home to Adelaide after a 6 year sojourn working throughout Southern Africa, newly married, with some savings and a slot in the Adelaide University, National Centre for Petroleum Geology and Geophysics (NCPGG) MSc program (now the Australian School of Petroleum). Prior to leaving Australia I had been accepted for this program but deferred, the lure of adventure and excitement in Africa too great to resist. On my return and now a 'mature age' student at the grand old age of 31, married and with almost 10 years' work experience under my belt, I was definitely the old man of my cohort. Nevertheless, I enjoyed the return to student life and diligently applied myself to my studies (first year was coursework only) and emerged at the end of first year with very good results. Fortunately! Giving up a very good, exciting and well-paid job to resume a poverty-stricken student existence was not a huge selling point for my translocated wife. As I finished my first year and started work on the project part of the MSc program it became apparent that even with my wife's earnings and a very frugal lifestyle, we were slowly working our way through dwindling savings and faced the very real prospect of running out of money before I completed my thesis.

So, with cap in hand, I approached both Bill Stuart, the director of the NCPGG at the time, and the ASEG, and received a grant from both. These grants helped us tremendously and enabled us to keep our head above water and the bailiffs from the door. Just when my thesis was mostly complete, my wife and I found ourselves pregnant with our first child. With my wife soon to be unable to work and our savings almost depleted, I hastily started looking for work and in the mid-1990s slump could not find any work in petroleum geology and geophysics. I managed to secure work in minerals exploration and spent the next 2 years searching for diamonds in the remote Kimberley.

Unfortunately with a new job, new baby (Beth) and lots of field work I missed my submission deadline and hence failed to complete my MSc, something that I regretted strongly at the time. However, on a positive note I did learn a tremendous amount at the NCPGG and now, with the benefit of hindsight and the wisdom of age, I view my experience at the NCPGG much more philosophically – learning for learning's sake. My education there ultimately enabled me to gain employment in the petroleum side of the geology and geophysics industry.

In 1998 after having flipped between mineral and oil exploration a number of times, I finally leapt across to the petroleum sector for the last time, working for an oil services contractor in Perth. This ultimately led to my current job with Woodside where I have been for the past 14 years. So now, at the other end of my career, with three children (with my first child herself now at university) and still married to my now naturalised Australian wife, it is interesting to look back all those years to my enjoyable student (oh the benefits of rose-tinted hindsight!) days at the NCPGG. Undoubtedly the education I received gave me the confidence and theoretical background needed to progress within the petroleum geology and geophysics industry. I have been very fortunate to have worked for some great companies on truly amazing projects, both locally and internationally, and for this I will always be grateful for the wonderful support I received from both the NCPGG and ASEG RF.

Nick Direen 1995

Being a recipient of an ASEG RF grant in 1995 was of great benefit to me in two distinct ways. Practically, it funded the costs of my 3–4 months of gravity and magnetic fieldwork, involving numerous extended trips to the Longford Basin in northern Tasmania. It funded food, fuel and accommodation away from home, freight of samples and instruments (I had borrowed a SIROTEM from the mainland), and practical costs like buying survey maps, geology reports, making thin sections and sample slabs – and printing hardcopy of everything in the days just before lots of data was available online! Intangibly,

there were benefits too: I was assigned an industry mentor for the project, John Bishop, who gave friendly input in addition to that of my two Honours advisors, David Leaman and Michael Roach. The prestige and recognition of the award was also useful when I was negotiating access to data from third parties like (then) World Geoscience, who had flown airborne EM and magnetics over part of my field area; I remember speaking on the phone to Greg Street in Perth and mentioning the fact I had an ASEG RF funded project ... his collaboration was forthcoming! ASEG support also led to further good outcomes: my poster reporting the results at Sydney ASEG 1996 with David Leaman was awarded Best Poster paper of the conference, and was subsequently published in *Exploration Geophysics* in 1997 – along with a companion paper on the electromagnetics/rock physics study, co-authored with Michael Roach. These group achievements were also a welcome boost for the profile of geophysics within the Geology Department/CODES at the University of Tasmania, which at the time (like many small geophysics research groups) was under some pressures (see my article in *Preview* **68**, 1997, as well as that by Derecke Palmer in the same edition, and Norm Uren, *Preview* **63**, 1996).

In my subsequent career, I've been fortunate to be able to continue my applied research interests which started with my ASEG RF grant. From 1996 to 1999 I completed a PhD, applying gravity, magnetics and electrical/MT studies to the Koonenberry Belt, sponsored by AGSO and Mineral Resources NSW. I was then employed at AGSO from 1999 to 2002 as a Research Scientist, working first in the National Gravimetry project, then in regional geophysical mapping of the Lachlan Foldbelt and Gawler Craton, and the offshore Australian Antarctic Territory. During this time I served as Secretary then President of the ACT ASEG. In 2002, I took up a tenured position teaching Exploration Geophysics at the University of Adelaide, supervising several Honours and PhD students in geophysics – many of whom also had their research published internationally, and who have gone on to careers in industry and government. I also served on the SA ASEG committee. In 2006 I joined resource consulting firm FrOG Tech, based first in Adelaide then Hobart, consulting to the oil and minerals industry in over 20 countries, including undertaking fieldwork in many of them. During this period I maintained adjunct research positions at University of Adelaide (until 2011) and University of Tasmania (ongoing), publishing many pieces of applied geophysical research and, with co-workers such as Anya Reading, attracting valuable ARC Linkage and private funds for geophysical research, as well as co-supervising more geophysics graduate students. In 2013, I joined ExxonMobil Exploration in Houston, where I am part of the Gravity, EM and Magnetics Centre of Expertise – with oversight over all of ExxonMobil and affiliate company potential fields and EM acquisition, technology development and interpretation worldwide.

A closing thought, verbatim from my 1997 *Preview* article:

> *With the demand for well-trained geophysicists almost certain to increase in future, because of the desire to probe the third dimension beneath us, we should also be sure that there will be government entities and companies who are prepared to 'put in' to assist in training the geophysicists of the future.*

It was true in 1995. Let's keep it true in 2015; support the ASEG Research Foundation: it *does* make a difference.

Philip Heath 2002

I received a grant from the ASEG RF in 2002 to assist in my Honours project at the University of Adelaide. The project involved a study of inversion techniques for potential field data. The research grant allowed purchase of valuable software and texts for the study. After completing Honours, I continued with study at Adelaide, completing a PhD in 2007. I then worked for Canadian Micro Gravity as an operational and processing geophysicist for their airborne gravity system, travelling globally. I am now working with the Geological Survey of South Australia as a senior geophysicist, and am an active ASEG member and volunteer.

Mike Hatch 2007

I was awarded an ASEG RF grant in 2007 to evaluate the performance of various soil probes designed to log variation in soil conductivity and moisture content over time. The intention was to determine which probe would be the most suitable to use at various study sites in the Murray River floodplain environment to correlate with near-surface geophysical surveys that we were running to map salinity distribution and geological variation on the floodplain. The study tested probe performance in the lab over a range of conditions over the period of a few months. Interestingly, while all worked well under relatively resistive conditions, none proved suitable for use in the often saline conditions that we encountered in our study areas. Even though this study 'failed', it was still a useful part of my research at that time. Since the completion of my PhD I have had the opportunity to continue my research career, including more work on the Murray, as well as another project to measure and map greenhouse gas concentrations in various settings around eastern and central Australia. Recently I was part of a group that completed a smaller but still interesting project funded by the SEG Geoscientists without Borders program to use ground-penetrating radar to locate wombat burrows in western South Australia.

Projects 2014

The following seven projects were supported in 2014 from 10 applications (Table 3).

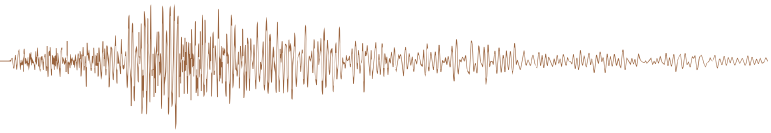

Table 3. 2014 supported projects

University	Supervisor	Student	Degree	Field	Funding	Years	Topic
Australian National University	Dr Eva Papp	Sanjay Govindan	BSc	M	$5000	1	Developing a direct current-based geoelectrical method to estimate the depth of aeolian cover over the Dargues Reef gold deposit and surrounding area
University of Adelaide	Professor Graham Heinson	Michael Stepan	BSc	M	$5000	1	Magnetotelluric imaging of the Delamerian–Lachlan transition, western Victoria
Curtin University	Dr Anton Kepic	Maria Cornelia Kitzig	PhD	M	$10 000 $10 000 $10 000	3	Integration of down-hole geophysics and geochemistry for geological characterisation
University of Western Australia	Professor Mike Dentith/ Associate Professor Alan Aitkin	Sasha Banaszczyk	PhD	P	$4000 $8000 $9500	3	Regional-scale interpretation of airborne electromagnetic and magnetotelluric data: workflow and application to exploration in sedimentary basins
University of Adelaide	Dr Simon Holford	Alexander Robson	PhD	P	$9500 $9500 $10 000	3	Structural and geomechanical evolution of the Ceduna Delta, Bight Basin, Australia
University of Adelaide	Dr Simon Holford	Fun Julie Ellen Meeuws	PhD	P	$8400 $9200 $7600	3	Understanding the impacts of magmatism on hydrocarbon prospectivity along the southern Australian margin through the integration of geophysical, geochronological and geochemical methods
University of Western Australia	Associate Professor Jeffrey Shragge	Benjamin Witten	PhD	P	$10 000 $10 000 $10 000	3	Elastic parameter estimation using 3D image-domain adjoint-state tomographic inversion of passive seismic wavefields

ASEG RF grant application process

In early December each year applications are solicited from tertiary institutions by circulation of a poster with the relevant details. Applications close near the end of February. After closing, the applications are studied by one of three sub-Committees of the ASEG RF: Minerals; Petroleum; and Engineering/Environmental. After ranking and recommendations, the availability of funding determines which projects can be supported. The guidelines below apply to successful grants.

Guidelines summary

Funds will be granted in support of research projects at BSc (Honours), MSc and PhD levels carried out in an Australian tertiary institution. Grants will be made to projects rather than people. That is, they will not be 'scholarships'. For BSc (Honours) and MSc projects, annual grants of up to $5000 will be made to the tertiary body responsible for the project. Grants of up to $10 000 per annum will be made for PhD projects. The funds are to be used in support of the project, e.g. for travel costs or rental of equipment. Funds must be accounted for and, if not used, should be returned to the ASEG RF.

The project supervisor will be responsible for drawing the funds as required and for managing the expenditure. He or she should ensure that a research report and financial reconciliation is provided to the ASEG RF on completion (or cessation) of the project. On the completion of the project, all results must be available in the public domain. Projects will be selected by the relevant ASEG RF sub-Committee. They will select projects in applied geophysics with an emphasis on practical or applied research.

On completion of the project, an abstract will be published in *Preview* and publication as a paper must first be submitted to *Exploration Geophysics*. The supervisor would normally be expected to be a co-author and will be responsible for submission of a publication.

Interim progress reports will be required and should be forwarded to the Chairman/Secretary of the ASEG RF. For each project, an industry monitor will be appointed, who should be a member of the ASEG (but not necessarily of the ASEG RF Committee), and who will monitor the progress of the project and report to the Committee. This would involve at least one and preferably more visits to the institution where the project is being carried out.

Members of the ASEG RF Committee will be responsible for checking the final report from each project. Copies of the report (e.g. thesis) will be available to any interested members, on request. It is expected that the student undertaking the project will be a student member of the ASEG.

Details of the application process can be found on the ASEG website at https://aseg.org.au/RF-application.

Source of funds and donations

The ASEG RF can only carry on its work because of generous donations from individuals and companies. The ASEG has provided the most significant contributions in the past few years and we hope it will continue to do so in the future. We want to encourage individual ASEG members, companies and other institutions with an interest in exploration geophysics to make a donation to the ASEG RF. A portion of corporate membership fees is allocated to the ASEG RF and a larger amount from Corporate Plus members (currently Velseis), and we encourage annual contributions from companies, institutions and individuals. All contributions are fully acknowledged in *Preview*. Furthermore, since the ASEG RF is an ARI, all contributions are fully tax deductible. The foundation is also exempt from GST obligations.

ASEG RF Committee – volunteers wanted!

ASEG members from minerals, engineering and petroleum areas, as well as from academia, serve on an honorary basis on the

ASEG RF Committee (Table 4). All administrative costs are borne by the Committee members themselves and no ASEG RF funds are used for operating expenses. Phillip Harman is the current Chairman of the Foundation. Doug Roberts is the current Secretary and Peter Priest is the Honorary Treasurer.

Phillip Harman

The ASEG RF is regularly looking for keen and enthusiastic new members with an interest in supporting university students and research into exploration geophysics. We are especially keen for volunteers from the petroleum industry at present. Please contact members of the Committee to find out how to get involved.

Table 4. Current ASEG RF Committee

Name	Company	Position/sub-Committee
Bourne, Barry	Terra Resources	Minerals
Clifton, Roger	NT Geological Survey	Minerals
Denham, John	Consultant	Petroleum (convenor)
Dentith, Mike	University of WA, Department of Geology and Geophysics	Academic
Emerson, Don	Systems Exploration (NSW)	Engineering/ Environmental (convenor)
Golden, Howard	Rio Tinto	Minerals
Greenhalgh, Stewart	University of Adelaide	Academic
Harman, Phil	Stellar Resources	Chairman
Hearn, Steve	University of Queensland, Department of Earth Sciences	Academic
Heinson, Graham	University of Adelaide	Academic
Long, Andrew	PGS	Petroleum
Mudge, Stephen	Vector Research	Minerals
Priest, Peter	Chartered Accountant	Treasurer
Roberts, Doug	Beach Energy	Secretary
Rutter, Hugh (passed away in June 2014)	Consultant	Minerals (convenor)
Smith, Bob	Consultant	Minerals
Williams, Peter	Consultant	Minerals
Lisa Vella	Southern Geoscience Consultants	Minerals
Julian Vrbancich	DSTS	Minerals/ Environmental

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The Lodestone, from Plato to Kircher

D. W. Emerson

Systems Exploration (NSW) Pty Ltd
systemsnsw@gmail.com

Introduction

The natural magnet, the lodestone, exerted a strong fascination in the Mediterranean and Eastern regions during ancient and medieval times. Then it was regarded as a wondrous, marvellous material. It has an interesting history. The lodestone ('loadstone', 'leading' stone, 'course' stone) made possible the development of the magnetic compass, but the lodestone had other roles in the culture of prior generations of humankind. Adams (1954) provides a good introduction, and general information is available in paper and digital format encyclopaedias, but probably not the esoterica herein discussed with a somewhat arbitrary selection of views, over time, from the Mediterranean–European regions. Middle Asia, and the Far East where the Chinese knew of and used the lodestone, are not treated here.

The ancient Greeks located a lodestone supply in the vicinity of the fifth century BC Thessalian colony of Magnesia, ad Sipylum, on the western shore of Asia Minor (~33 km NE of Smyrna, modern Izmir, Turkey). They called it the Magnesian stone, the magnet. The Greek noun is feminine as it was a special kind of stone, ἡ Μαγνῆτις λίθος. A variety from one or more of the many places named Heraclea was called Heraclean stone. The Romans called it *magnes* or *magnes lapis*, the magnetic stone (*magnes* functioning both as a masculine noun and an adjective).

What is lodestone? It is locally altered magnetite. It is not stoichiometrically pure magnetite: dark, crystalline or massive, dense, conductive, with high magnetic susceptibility and strong remanence. Such magnetite does not constitute a magnet; it will not pick up nails or support a chain of paper clips or magnetise a needle (try it, see Figure 1). Magnetite is attracted to a magnet; lodestone acts as a magnet.

The nature and genesis of lodestone was discussed, inconclusively, by Newhouse (1929), Gruner (1929) and Bandy (1930). Newhouse invoked oxidation as the means whereby zones in magnetite bodies were converted to lodestone by the formation of a brownish iron oxide. Gruner did not find such material in examined lodestones, rather the effect was ascribed to the concentration of the earth's field at the extremities of magnetic bodies. Bandy rejected both and proposed that the strong magnetic fields from lightning strikes on magnetite outcrops generated lodestone which, in his experience, was an uncommon mineral of erratic occurrence, found more frequently in the higher, more exposed parts of magnetite bodies.

Wasilewski and Kletetschka (1999) proposed lightning as the lodestone charging mechanism, demonstrating that the material struck should comprise magnetite hosting some maghemite, arising from oxidation and exsolution, and also with an assumed concomitant favourable microstructuring. Magnetic hardness was shown to be optimised by large values of coercive force, saturation magnetisation, saturation remanence, and a relatively large ratio of saturation remanence to saturation magnetisation (>0.2 for lodestone, usually <0.05 for coarsely crystalline magnetite).

Lodestone may be found in private and museum collections; local specimens have been curated by the Australian Museum (Figure 2).

Figure 1. *A magnet will stick to these collector-grade magnetite octahedra from Bolivia, but they will not pick up a paper clip.*

Figure 2. *Lodestone from Lionsville NSW. Image by K. Lowe, courtesy of Australian Museum, Sydney ©.*

The Greeks

Thales (sixth century BC) was the highly regarded Sage of Miletus (southwest Asia Minor). To him is ascribed the view that the lodestone must have a psyche, the sign of life, ἡ ψυχή, equivalent to the Latin *anima* or breath of life. What he probably meant was that lodestone had a significant essence differing from its material body because it was dynamic with power to attract, repel, and to move to other objects; so it was live. Thales' writings, if any, have not survived.

Plato (427–347 BC) was the disciple of Socrates, and teacher of Aristotle. His works have been the origin or the catalyst of much Western philosophical thought. Plato related Socrates' comments on the rhapsode Ion's recitation histrionics. In a vivid analogy the Muse is likened to a magnet whose mysterious power is clearly manifest in a charged chain of attracted iron rings extending from its (i.e. the lodestone's) surface. Inspiration flows from the Muse, to the poet (Homer), then to the rhapsode, and on to the members of the audience. Ion's skill is not human, it derives from divine possession, beyond reason, like the magnet. In this perspective there are distinct theological overtones reflecting Socrates' belief in divinities. Plato, *Ion* 533D:

> ἔστι γὰρ τοῦτο τέχνη μὲν οὐκ ὂν παρὰ σοὶ περὶ Ὁμήρου εὖ λέγειν, ὃ νῦν δὴ ἔλεγον, θεία δὲ δύναμις ἥ σε κινεῖ, ὥσπερ ἐν τῇ λίθῳ ἣν Εὐριπίδης μὲν Μαγνῆτιν ὠνόμασεν οἱ δὲ πολλοὶ Ἡρακλείαν. καὶ γὰρ αὕτη ἡ λίθος οὐ μόνον αὐτοὺς τοὺς δακτυλίους ἄγει τοὺς σιδηροῦς, ἀλλὰ καὶ δύναμιν ἐντίθησι τοῖς δακτυλίοις ὥστ' αὖ δύνασθαι ταὐτὸν τοῦτο ποιεῖν ὅπερ ἡ λίθος, ἄλλους ἄγειν δακτυλίους, ὥστ' ἐνίοτε ὀρμαθὸς μακρὸς πάνυ σιδηρίων καὶ δακτυλίων ἐξ ἀλλήλων ἥρτηται. πᾶσι δὲ τούτοις ἐξ ἐκείνης τῆς λίθου ἡ δύναμις ἀνήρτηται.
>
> Because, as I was just now saying, declaiming Homer well is not your skill; what moves you is divine power like that in the stone which Euripides called a magnet (Magnesian stone) but the majority of people know it as the stone of Hercules. For this stone not only takes iron rings to itself but also puts into them the power to do the same as the stone, and attract other rings in turn. So sometimes there is indeed a long chain of rings and bits of iron hanging one from another; all of them empowered by the stone.

Theophrastus (c370 – c287 BC) was a pupil and colleague of Aristotle. He wrote on a great variety of subjects, including stones. Unfortunately what appears to have survived seems to be an abbreviated version of a larger work on minerals to which Pliny, centuries later, had access. Theophrastus did refer to an Heraclean lodestone in company with the touchstone (black, flinty, siliceous slate or jasper used as comparative streak plates), but seemed more in cautious awe of the possibilities of mineral breeding and propagation. Belief in the supposed regeneration of stones and minerals was not uncommon. Pliny mentioned claims that marble grew in its quarries.

The Romans

The chance discovery of an old manuscript in 1417 saved an outstanding ancient work from oblivion. It was a copy of a ninth century document (now in Leiden): Lucretius' *De Rerum Natura (DRN)* – On the Nature of Things. This great Latin poem, in six books comprising 7415 robust hexameters, expounded post Aristotelian Epicurean technical philosophy and physics: void, atoms, and their motion. It was subsequently printed, circulated and tolerated (nearly ending up in the Index of Prohibited Books during the Inquisition). His work has been studied, and argued about, down to the present day because of its visionary content and uncompromising style. Titus Lucretius Carus (98 – c55 BC) was a great debunker of superstition and myth – no magic or immortality for him. Although a believer in the pagan gods, he did not invoke them to explain physical phenomena.

Lucretius discussed, at length, in his book 6, features of the natural world and included a lengthy analysis of the lodestone's powers of attracting iron. He was intrigued by action-at-a-distance and made prior mention of the combustion of kindling remote from a flame. Lucretius, *DRN,* 6. 906–916, introduced the magnet:

> *Quod superest, agere incipiam quo foedere fiat*
> *naturae, lapis hic ut ferrum ducere possit,*
> *quem Magneta vocant patrio de nomine Grai,*
> *Magnetum quia sit patriis in finibus ortus.*
> *hunc homines lapidem mirantur quippe catenam*
> *saepe ex anellis reddit pendentibus ex se.*
> *quinque etenim licet interdum pluresque videre*
> *ordine demisso levibus iactarier auris,*
> *unus ubi ex uno dependet subter adhaerens*
> *ex alioque alius lapidis vim vinclaque noscit*
> *usque adeo permananter vis pervalet eius.*
>
> Moving on I shall begin to discuss by what law of nature it is that this stone can attract iron. The Greeks call it a magnet, after its fatherland, seeing that it cropped up in the native territory of the Magnesians. Men look at this stone with wonder for time and again it creates a chain of little rings dangling from itself, and as a matter of fact one can see five, sometimes more, serially suspended, swayed by breaths of air, where one hangs from another one, in ever lower attachment, and one from another recognises the connecting force to the extent that it pervasively maintains its power.

Lucretius first established four principles involving relative effects: flux, the continuing emanation of particles from things, e.g. heat from the sun; the disparity of fluxion effects, e.g. sun bakes clay but melts snow; the pervasive porosity in things, e.g. otherwise how could odours pass through a wall; the disparity of porosity to fluxions e.g. sounds traverse stones, but sights don't.

For the lodestone/magnet, he had three agencies. Firstly, strong seeds (current, flux) emanate from the lodestone shifting away air between it and iron (which has unusually tightly bound atoms requiring iron to move as a unit) so the iron is sucked into this vacuum (being loosely structured, wood and rocks don't do this so their emanations simply abrade off and the bulk material does not move). Secondly, the iron is pushed by the thicker air behind it, like wind in a ship's sails. Thirdly, air in the iron's pores, in perpetual restless motion, is an internal engine of movement too.

Thus the lodestone's power is explained, Lucretius, *DRN,* 6. 998–1011:

Quapropter bene ubi haec confirmata atque locata
omnia constiterint nobis praeposta parata,
quod superest facile hinc ratio reddetur et omnis
causa patefiet quae ferri pelliciat vim.
Principio fluere e lapide hoc permulta necessest
semina sive aestum qui discutit aera plagis
inter qui lapidem ferrumque est cumque locatus.
Hoc ubi inanitur spatium multusque vacefit
in medio locus, extemplo primordia ferri
in vacuum prolapsa cadunt coniuncta fit utque
annulus ipse sequatur eatque ita corpore toto.
Nec res ulla magis primoribus ex elementis
indupedita suis ar(e)te conexa cohaeret
quam validi ferri natura et frigidus horror.

So that now these principles have been determined for us – all set, established, ready to apply, and authoritative, then next an explanation is readily supplied and the entire reason revealed as to what induces the vigorous movement of iron (to the lodestone). Firstly, it must be the case that very many atoms emanate from this stone, perhaps acting as a surge which by its buffeting displaces whatever air is positioned between iron and stone. When this interval is emptied and plenty of space is unoccupied in the middle, right away the elements of the iron moving as a cohesive unit are launched into the emptiness, and it happens that the (test iron) ring itself in its entirety yields (to the force) and moves. Nor is there anything, comprising primary particles linked and bound, more compactly held together than the structure of iron with its cold rigidity.

In his rugged poetry Lucretius endeavoured to show the way to Epicurus' goal of mental tranquillity by removing fear of the gods and of death. The aim was a mind freed from disturbance, not one wallowing in the self-indulgent hedonism of popular repute. He provided rational explanations of phenomena using Epicurean physics: atoms (*primordia rerum)*, void (*inane*), and porosity (*raritas*). His catalogue of explicable marvels included earthquakes, volcanoes, stormy skies, the vastness of seas, and it culminated in the lodestone. Quite an honour for a nondescript rock.

Sextus Propertius (c50 BC – after 16 BC) wrote many poems in a refined style. One of these was devoted to the bawdy witch Acanthis, and her precepts on how women should manage men. Among several instances of her awesome abilities, Propertius, *Elegiae* 4. 5, 9, cited:

illa velit, poterit magnes non ducere ferram

should she wish, lodestone will not attract iron

Pliny the Elder (Gaius Plinius Secondus, AD 23–79) was a prolific writer; he died south of Pompeii, documenting the eruption of Vesuvius. His outstanding achievement was the compilation of thirty seven books of natural history, the *Naturalis Historia (NH),* which included information on the lodestone. Regarding its discovery Pliny, *NH*, 36. 127, noted:

magnes appellatus est ab inventore, ut auctor est Nicander ... invenisse autem fertur clavis crepidarum, baculi cuspide haerentibus, cum armenta pasceret.

Nicander advises that it was called magnes after its finder ... and indeed is reported to have discovered it clinging to his sandal nails and staff tip, when grazing his herds.

To the ancients, rocks could be weird. Nature provided them with a voice (echoes, earthquake rumbling: Pliny, *NH*, 2. 115, 193) but lodestone was really remarkable. Lodestone's strangeness and affinity for iron were emphasised, Pliny, *NH*, 36. 126–127:

quid enim mirabilius aut qua in parte naturae maior inprobitas? dederat vocem saxis, ut diximus, respondentem homini, immo vero et obloquentem. quid lapidis rigore pigrius? ecce sensus manusque tribuit illi. quid ferri duritia pugnacius? pedes ei impertivit et mores. trahitur namque magnete lapide domitrixque illa rerum omnium materia ad inane nescio quid currit atque ut propius venit, adsilit tenetur amplexuque haeret.

What is more amazing (than this stone) or at least where has nature shown greater devilry? She gave rocks a voice answering, or rather answering back, to man. What is more indolent than the inert character of stone? Yet nature has endowed it with awareness and hooking hands. What is more unyielding than the harshness of iron? On it nature has bestowed feet and a mode of behaviour. For it is drawn by the lodestone, and the all-subduing substance hastens to something like a vacuum, and on its approach it leaps towards the stone, is held and kept there by its embrace.

Pliny (*NH*, 34. 118) mentioned an aborted application of magnetic energy where the third century BC architect Timochares died before he could install lodestone in the vaulted roof of Arsinoë's Temple (Alexandria), so the iron cult image would hang mid-air. Pliny documented various lodestone locations, the best variety being blue and from Ethiopia (Ethiopia, Arabia and India were somewhat indefinite and confused locations in ancient and medieval times). He reckoned that, properly prepared, lodestone was useful in treating eye problems and burns.

In late antiquity the lodestone featured in a poem of pagan praise by Claudius Claudianus (AD fl. 395), and as a contributor to the proof of the reality of hell and damnation by Saint Augustine – Aurelius Augustinus (AD 354–430), Bishop of Hippo.

Claudian was Rome's final eminent poet in the classical tradition. He wrote in hexameters on many topics, and showed interest in the world of nature e.g. seven poems on a liquid inclusion in a crystal. His poem on the lodestone is quite instructive, as it gives an indication of the esteem in which it was held by the ancient world and also provides some information on one of the religious ceremonies. Claudian does not seem to have been a Christian even though his emperor Honorius' court was. So we see the lodestone through admiring, terminally pagan eyes.

Claudian, *Magnes* 1–9, classed the lodestone with other major phenomena as requiring clarification by philosophers.

> *Quisquis sollicita mundum ratione secutus*
> *semina rimatur rerum, quo luna laborat*
> *defectu, quae causa iubet pallescere solem,*
> *unde rubescentes ferali crine cometae,*
> *unde fluant venti, trepidae quis viscera terrae*
> *concutiat motus, quis fulgura ducat hiatus,*
> *unde tonent nubes, quo lumine floreat arcus,*
> *hoc mihi quaerenti si quid deprendere veri*
> *mens valet expediat.*
>
> Whoever, having observed the universe, investigates with anxious consideration the basic principles of physical phenomena and the reasons for the lunar and solar eclipses, the fiery comets with baleful tail, the streaming winds, the movement quaking the earth's interior, the airy cleft drawing lightning along, the thundering clouds, the shining rainbow; if an intellect is capable of discovering some truth, then for me a seeker of truth, let him explain this:

'This' is the lodestone, an unlikely marvel rivalling all others. The worth of lodestone in the ancient world was indicated by its being esteemed above the best pearls (*margaritae*) which were held in very high regard, Claudian, *Magnes* 9–21:

> *Lapis est cognomine magnes*
> *decolor obscurus vilis. non ille repexam*
> *caesariem regum non candida virginis ornat*
> *colla nec insigni splendet per cingula morsu,*
> *sed nova si nigri videas miracula saxi*
> *tunc pulchros superat cultus et quidquid Eois*
> *Indus litoribus Rubra scrutatur in alga.*
> *nam ferro meruit vitam ferrique rigore*
> *vescitur, hoc dulces epulas, hoc pabula novit,*
> *hinc proprias renovat vires, hinc fusa per artus*
> *aspera secretum servant alimenta vigorem,*
> *hoc absente perit, tristi morientia torpent*
> *membra fame, venasque sitis consumit apertas.*
>
> There exists a stone called lodestone; discoloured, dingy, nondescript. It does not lend distinction to the combed locks of kings, nor to the fair necks of girls, nor does it gleam on the showy clasps of sword belts. But in fact if you pay due regard to the strange marvels of this dark rock then it outshines elegant adornments and anything, on far eastern shores, that the Indian looks for in the weed of the Red Sea (i.e. pearls). Moreover it sustains itself with iron, feeding on its hardness, recognising such fodder as a fine feast, thereupon refreshing its peculiar power, the harsh nourishment preserves its hidden liveliness. Without iron it wastes away, its withering inner parts grow sluggish from grim hunger, and thirst exhausts its opened arteries. [Red Sea – Mare Rubrum – the Arabian and Persian Gulfs]

Regarding pearls in the ancient world, Pliny, *NH*, 9. 106, remarked:

> *principium ergo columenque omnium rerum pretii*
> *margaritae tenent … praecipue autem laudantur circa*
> *Arabiam in Persico sinu maris Rubri.*
>
> so pearls hold first place and top rank of all valuable things (from the sea) … but pearls around Arabia on the Persian Gulf of the Red Sea are particularly esteemed.

Pearls were valued in second spot, above emeralds but below diamonds. Pliny, *NH*, 37. 55, 62:

> *maximum in rebus humanis … pretium habet adamas …*
> *proximum apud nos Indicis Arabisque margaritis pretium*
> *est.*
>
> diamond is the most valued of human possessions ... next in value in our eyes are Indian and Arabian pearls.

The lodestone is activated by its own warm feelings; iron responds to its beckoning. Claudian, *Magnes*, 40–44:

> *Quis calor infudit geminis alterna metallis*
> *foedera, quae duras iungit concordia mentes?*
> *flagrat anhela silex et amicam saucia sentit*
> *materiem placidosque chalybs cognoscit amores.*
>
> What warmth instils the reciprocal bonds in kindred metallics?
> What harmony pairs their hardy dispositions?
> The stone, afire, sighing, smitten, perceives congenial material,
> and the iron finds quiet attachment.

In the rest of the poem Claudian described a religious ceremony mating two deities: a polished iron statue of Mars and a lodestone image of Venus. She is in control, she does the attracting, she subdues his murderous ferocity by giving him peace in her embrace. The lodestone functioned here as a ritual therapeutic agent.

In his *De Civitate Dei Contra Paganos (CD),* The City of God Against the Pagans, Augustine diligently sought to demonstrate the credibility of hell with its fiery torments for wicked bodies that must yet need to survive an eternity of burning. He noted reports of the salamander living in fire, worms tolerating hot springs, volcanoes burning without being consumed. His approach, *CD*, 21. 5 was:

> *quanta sint quorum ratio nequeat agnosci et tamen eadem*
> *vera esse non sit ambiguum*
>
> in what degree there are things whose rationale cannot be identified but are true without doubt.

The lodestone was included as a well-known marvel that existed but was inexplicable. Augustine commented, in words reminiscent of Lucretius and Plato, *CD*, 21. 4:

> *Magnetem lapidem novimus mirabilem ferri esse raptorem;*
> *quod cum primum uidi, uehementer inhorrui. Quippe*
> *cernebam a lapide ferreum anulum raptum atque*
> *suspensum; deinde tamquam ferro, quod rapuerat, vim*
> *dedisset suam communemque fecisset, idem annulus alteri*
> *admotus est eundemque suspendit, atque ut ille prior lapidi,*
> *sic alter annulus priori anulo cohaerebat; accessit eodem*

modo tertius, accessit et quartus … Quis istam virtutem lapidis non stuperet?

We recognise in the lodestone an extraordinary ability to seize iron; I was much perturbed when I first saw it. The reason is that I clearly saw an iron ring grabbed and held up by the stone. Then just as if the stone had given its own power to the attracted iron, and made it communicable, this ring was moved to another and it held it up. And then as the first ring was hanging on the stone so the second held on to the first; a third ring and a fourth ring were added in the same way … Who would not be amazed at this power of the stone?

Augustine maintained, since such marvels are manifest, the inability to provide explanations did not mean that some things could never have existed or would never exist i.e. his biblical interpretations should be accepted by the faithful. The lodestone's curious role in theological sophistry on the credibility of hell seems not to have been pursued much in later centuries.

Medieval Beliefs

In the early Middle Ages, Marbod (1035–1123) was Bishop of Rennes, ~300 km WSW of Paris. Between 1061–1081, before the printing press, he compiled the first and most popular of all the medieval lapidaries with sixty minerals, gems, stones and their magical and medicinal properties, in 735 Latin hexameters. It included a thirty line poem on the lodestone. Perhaps he believed that the hexameter rhythm helped his students to master the intelligence that follows. Marbod's mineralogy was cited in the prestigious *Laborintus*, Eberhard's 13th century didactic poem, as a curriculum author of importance in those days. Marbod was popular for centuries. Beckmann (1799) gave a listing of the many editions and provided a complete Latin text and commentary. Marbod's poem, *De Magnete*, has some absorbing detail:

Magnetes lapis est inventus apud Troglodytas,
Quem lapidum genetrix nihilominus India mittit.
Hic ferruginei cognoscitur esse coloris.
Cui natura dedit vicinum tollere ferrum.
Deendor magus hoc primum dicitur vsus,
Conscius in magica nihil esse potentius arte.
Post illum fertur famosa venefica Circe
Hoc in praestigiis magicis specialiter vsa.
Hinc et apud Medos, cum res venisset in vsum,
Detexit lapidis magis experientia vires.
Nam qui scire cupit, sua num sit adultera coniux,
Suppositum capiti lapidem stertentis adaptet;
Mox quae casta manet, petit amplexura maritum,
Non tamen evigilans. Cadit omnis adultera lecto,
Tanquam pulsa manu, subito foetore coacta,
Quem lapis emittit celati criminis index.
Si fur claustra domus spoliis gazisque refertae,
Ingrediens, prunas ardentes per loca ponat,
Et superaspergat magnetis fragmina prunis;
Mox in ea quicunque domo mansere, fugantur,
Vt per tetragonum fumi vapor alta vaporet.
Mentibus eversis, velut impendente ruina,
Diffugient omnes, in ea quicunque manebant,
Et fur securus rapiet quaecunque libebit.
Conciliare potest vxoribus ipse maritos,
Et vice conuersa nuptas revocare maritis.
Gratia praestatur simul, et suadela per ipsum,
Sermonisque décor, disceptandique facultas.
Cum mulso datus, hydropem purgando resolvit.
Et combusturas super aspersus medicatur.

The lodestone was discovered in Ethiopia,
Yet India is the source of exports.
This stone is known to have dusky colour.
Nature gave it the ability to pick up iron nearby.
Learned Deendor is reckoned to have made use of it first,
Well aware that nothing is mightier in magic.
After him Circe the famous sorceress is said
To have used it, particularly in occult deceptions.
Henceforth in Persia, when its use became customary,
Experience revealed more of the stone's power.
For anyone who wants to know whether his spouse is unfaithful,
Let him position the stone under her head while she snores,
Soon, if chaste, she seeks to embrace her husband,
Yet she is not awake. But any adulteress falls out of bed,
As if pushed by hand, compelled by a sudden stench,
Which the stone emits as proof of her secret sin.
If a thief overcoming the bolted gate of a richly furnished house.
Places glowing coals throughout,
And sprinkles fragmented lodestone over the coals,
Then any who did stay there would soon be forced to flee
As a result of clouds of smoke everywhere filling the house.
In panic, as collapse threatens,
Any remaining will scatter, all of them,
So the untroubled thief will grab whatever he likes.
Actually, it is possible for lodestone to win over husbands to wives,
And conversely to induce wives to return to husbands.
Charisma and the power of persuasion is produced through its agency,
Together with elegance of speech and skill in debate.
Given with honeyed wine it cures the dropsy by cleansing
And in fact it heals when sprinkled on burns.

The Garden of Health, *Hortus Sanitatis (HS),* was a compilation of facts and factoids, probably from many authors, about the therapeutic virtues of natural tissues (animals etc) and materials (minerals). It was the most popular of the medieval herbals; many editions were printed. The writer has consulted the 1497 edition. In the volume on stones *(Tractatus De Lapidibus*, *TL)*, on the authority of Serapion, the Moor sage, lodestone's deadly effects (see Figure 3) on the unwary are described, *HS*, *TL* 57:

Magnes. Minera huius lapidis est in maritinis prope terras indie. Et quando naves appropinquant monti minere ipsius non remanet in eis aliquod ferrum quod non egrediatur a navi et volet sicut avis usque ad montem. Et no(n) e(st) aliquis clavus insitus taliter q(uod) possit evelli ... et propter hoc naves illarum partium non clavantur cum clavis ferreis sed cum clavis ligneis. Nam si forent clavat(a) e clavis ferreis quando appropinquare(n)t illi monti dilacerantur.

Figure 3. *The fate of ships with ferrous fixtures venturing foolishly close to a lodestone mountain. Woodcut Hortus Sanitatis.*

> The lodestone. There is a deposit of this stone by the coast of India. When ships come near a mountain of this mineral, any iron object not only does not stay on a ship but also quits it and flies off quickly like a bird to the mountain. However, it is not the case that any driven fastening can be plucked out in such a way ... and because of this ships from those parts are not riveted with iron nails, but with wooden ones. For, if fastened with iron nails, when they come close to that mountain, they collapse in pieces.

Perhaps this tale was inspired by Pliny's claim, *NH*, 2. 211:

> *duo sunt montes juxta flumen Indum quorum alteri natura ut ferrum omne teneat alteri ut respuat, itaque si sint clavi in calciamento vestigia avelli in altero non posse in altero sisti*

> Near the Indus are two mountains, a feature of one is to hold tight to all iron and of the other to reject it. Accordingly, if there are nails in shoes, on one mountain footsteps are locked to, and on the other repelled from, the ground.

Pre Modern Times

Georgius Agricola (1494–1555), the German Georg Bauer, was born in Saxony during a time of the European revival of classical learning. His mineralogy book *De Natura Fossilium (DNF),* published in 1546, surveyed all known minerals of importance. He categorised them by their physical properties i.e. colour, hardness, weight etc. This book earned him a great reputation, the Father of Mineralogy, further enhanced by the posthumous publication in 1556 of *De Re Metallica,* which for the next two centuries was the standard mining textbook. It mentioned that lodestone was found in iron mines. He classified lodestone in his first genera, common stones, pointing out that while it always occurred in iron mines, of which there were many, it was only found in a few. He gave several general locations in Europe, Middle East, Ethiopia and India.

Agricola reviewed the properties of lodestone, *DNF* 5:

> *different vero Magnetes colore. qui aut niger est, aut in nigro ceruleus, aut in nigro rufus, aut contra, in rufo niger. differunt spissitudine et raritate. nam alii toti densi sunt, & similes smiridi, alii aliqua parte rari, & velut exesi, pumicique similes. different pondere, quod partim graves sint, partim leves, mediocres partim. different viribus. etenim quidam valide ad se trahunt ferrum, quos mares nominant. aliqui parum valide, quos foeminas. optimus certe magnes non modo ad se trahit & tenet ferrum, sed etiam vim suam in id ita transfundit, ut possit aliud ferrum, quod appositum. fuerit, apprehendere & tenere.*

> Lodestones differ in colour which is either black or dark bluish black, either reddish brown-black or black-reddish brown. They differ in density and porosity for some are entirely solid and are like emery, others in some degree have an open texture as if hollowed out and are like pumice. They differ in weight with some heavy, some light, some in between. They differ in strength for particular types attract iron strongly, these are called males; some have only a little attraction, these are females. Of course the best lodestone not only attracts and holds iron but also transfuses its own force into it, so that it in turn is able to seize and hold another piece of iron set beside it. [Emery is ferruginous corundum containing some magnetite]

Agricola used the findings of previous authors, presumably supplemented by his own observations. The information on colour has been interpreted rather than translated here. In English it is not easy to represent subtle colour by words because speech is inadequate for what an eye sees. Latin colour words are quite difficult to translate as they often reflect an impression, aspect, radiance, or sheen rather than something recognisable in a modern quantitative colour chart. Agricola's *ceruleus* can mean the blue of the sky, the blue-green of the sea, the grey-green of plants, or a dusky-dark colour. Agricola's *rufus* usually means red, or reddish, but it can mean tawny or chestnut (red brown, golden brown). All this is relevant if one is trying to identify what the documented lithologies actually were.

As to the nature of the lodestone's power, Agricola remarked, *DNF,* 5:

> *quae res quia vulgo maximam admirationem movet, ferrum, cui lapis ille dedit vim suam, vivum ut scribit Plinius, appellant: quia philosophis Agrigentinus Empedocles magnetem animatum esse affirmavit. certe his eius viribus Theologi actiones diuinas, medici naturales, quarum ratio reddi non potest, confirmant.*

> Because these phenomena occasion considerable wonder in the populace, they call the iron, to which the lodestone conferred its power, 'living', as Pliny records, in view of the fact that Empedocles of Agrigentum [southern Sicily] maintained that the lodestone was animate. Without any doubt, theologians ascribe divine influences for the lodestone's inexplicable power; doctors declare the causes to be natural.

Agricola himself was a medico; he was Joachimsthal's town physician, having studied philosophy, medicine, and natural science in Italy. Physician (natural) philosophers were

intellectually very influential in those times. They had empirical chemical knowledge (derived from alchemy), and some had proto-scientific interests in minerals, mines, and miners' diseases, e.g. Agricola's famous and contentious contemporary Paracelsus (c.1490–1541).

Additional lodestone features and fancies were noted by Agricola, *DNF*, 5:

> *Aethiopico autem tam valida(m) vim esse Plinius scribit, ut magnetem alium ad se trahat. sed magnes ad se non allicit ferrum si fuerit rubiginosum, aut impurum, aut oblitum allii ceparum ve succo. nec vero minus adamas eius viribus resistit. si enim iuxta ferrum ponitur, non potest id magnes ad se allicere, aut si iam traxit, quamprimum adamas fuerit appositus, ipsum dimittit. quinetiam magnes si diu ferro aut eius vena careat, aliquam uirium iacturam facit: quod ne fiat, squama ferri est obruendus.*

> Regarding the Ethiopian type, Pliny writes that it is so strong as to attract another lodestone. However, lodestone does not attract rusty or impure iron or iron coated with the juice of garlic or onions. And no less does diamond resist the lodestone power for if one is placed next to iron the lodestone cannot attract it, or if already attracted, straightaway the lodestone lets it go if a diamond is placed beside it. What is more, if lodestone is kept away from its (parent) vein or iron for a long time it results in some loss of strength. Lest this happen it is necessary to cover the lodestone with a platy fragment of iron.

These observations are a mix of fact and fiction pre-dating the initiation of inductive science by Francis Bacon (1561–1626) and others; their motto was: *plurimis cognita et plurimis probata* – phenomena openly acknowledged and publicly tested.

For the miners in the Magnetum Iron Mine near Eibenstock (Saxony) the lodestone vein therein provided a handy means of tool storage. Agricola, *DNF,* 5:

> *ita etiam nostris, qui in fodina ferri, quam magnetum vocari supra dixi, operam dederunt. cum enim, definito labore perfuncti, cuneos & malleos de minibus in solo cuniculi, ut sit, deposuissent, aut abiecissent, postero die ad eundem laborem redeuntes, instrumenta non invenerunt in solo cuniculi, in quo deposita errant, sed ad superiorem alterius lateris partem: ex qua lapidis uiribus attracta pendebant: quod operarii, harum rerum rudes, admirati dominis indicarunt. ex quibus cum accepissent magnetis venam esse, vim illam suis facetiis ludentes instrumenta saepenumero de lapide suspenderunt.*

> So too (the power of lodestone was revealed) to our countrymen who worked in the Magnetum iron mine mentioned above for, having completed their shift, and, as usual, put down their wedge and hammer hand tools on the mine floor, on returning to their labours next day they found the tools not where they had been left on the floor, but in contact with the upper part of the nearby face from which they hung down, drawn up by the power of a particular stone. The surprised workmen, ignorant of such matters, pointed this out to the mine owners. Told that it was a vein of lodestone, they sportively indulged themselves with the force and oftentimes hung up their tools from the stone.

The lodestone had a key role in the magnetic model of the earth postulated by William Gilbert (1544–1603) the greatest scientist of the reign of Queen Elizabeth I. After original thinking and inspired experimentation and analysis, in 1600 he published his conception of the earth as a great magnet and explained the inclination of magnetic needles. He used a ball of lodestone as a terrella, a little earth, and wisps of iron wire to prove his point (see Figure 4). Overall, his work was very controversial then (e.g. his statements about heliocentricity and planet rotation) so the work was condemned during Galileo's 1633 trial. Gilbert's words are simple and direct, *De Magnete* 5. 2:

> *Ostenditur declinatio ferri magnetici super terrellam, per varia fila ferrea æqualia, longitudinis grani hordei, disposita super meridianum. Fila in æquatore virtute lapidis diriguntur versus polos, & decumbunt super corpus ad horizontis eius planum. Quo propius apponuntur polis, eo magis conuertibili natura eriguntur. In polis ipsis perpendiculariter ad centrum ipsum tendunt. At obeli ferrei non recte eriguntur nisi in vegeto lapide, si fuerint iusto longiores.*

> The attitude of iron magnetised on a terrella is shown by means of several uniform iron strands of the length of a barleycorn distributed above a meridian. The filaments on the equator are directed towards the poles, by the lodestone's power, and lie horizontally on the terrella. The nearer they are placed to the poles the more erect they become by an ability to align. At the poles, now perpendicular, they point to the terrella's centre. However, iron points if they be longer than that prescribed do not incline correctly unless placed on a powerful stone. [A barleycorn, hordeum, is about 8 mm in length.]

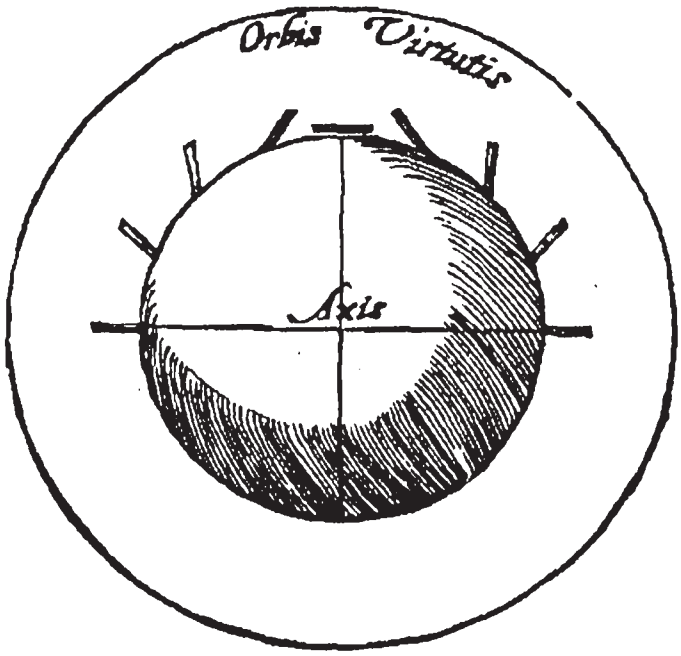

Figure 4. *Gilbert's lodestone sphere demonstrating the earth's magnetism by the variation in inclination of fine iron needles. Orbis virtutis: sphere of force – limit of terrella's magnetic field.*

Polydore Vergil (1470–1555) in his *De Inventoribus Rerum*, 1499, gave an account of many inventions from antiquity to his day. He greatly admired the magnetic compass but had no idea who invented it or when it was invented. Magnetic compasses in Europe were first mentioned in the 12th century, and were probably in use before then. Mariners came to rely on the lodestone-magnetised needle for direction in the day, when the sun was hidden by clouds, and in the night, whenever the polestar was obscured. The poem La Bible Guiot by Guiot de Provins (c1206) stated that a needle touched by an ugly brown stone and floated by a stick or straw on water turns its end to the polestar.

The possible medical benefits of lodestone still seem to have been taken seriously in the seventeenth century. Richard Burton (1577–1640) was an Oxford scholar and author of the massive and popular Anatomy of Melancholy (AM). He wrote it in English, after considering and deciding against Latin. Burton, AM 2. 4. 1. 4 noted: 'Nicholas Cabeus, a Jesuit of Ferrara, in the first book of his Magnetical Philosophy, cap.3, speaking of the virtues of a loadstone, recited many several opinions; some say that if it be taken in parcels inward, *si quis per frusta voret, juventutem restituet,* it will, like viper's wine, restore one to his youth; and yet if carried about them, others will have it to cause melancholy; let experience determine.' So, if ingested (*frustum:* 'bit') it may do good; if carried about in a pocket it may cause harm. Lodestone pills seem not to have survived as a rejuvenating medicine, even in rustic and folk remedies. It is interesting that Aulus Cornelius Celsus (AD 14–37) who, in elegant Latin, surveyed, quite impressively, the whole field of ancient professional medicine, did not mention lodestone in his list of medicaments, although hematite, lead, sulphur, nitre, and other minerals were included.

After Gilbert, matters magnetic continued to occupy the minds of the 17th century intelligentsia. Burton took a break from his mournful compilation and allowed himself a digression. Burton, AM 2. 2. 3:

> ... concerning those northern parts under the Pole … whether there be … a great rock of lodestones which may cause the needle in the compass to bend that way, and what should be the true cause of the variations of the compass, is it a magnetised rock, or the polestar, as Cardan will; or some other star in the bear … vel situs in vena terrae [or situated in a vein/extended mass of the earth] as Agricola; or the nearness of the next continent, as Cabeus will; or some other cause … till we have better intelligence let our Dr Gilbert and Nicholas Cabeus the Jesuit, that have both written great volumes of this subject, satisfy these inquisitors.

The Jesuit Athanasius Kircher (1601/2–1680) was an extraordinary, erudite, polymath based in Rome from 1638. His views on many subjects, sometimes contentious, were very influential throughout Europe. He revered antiquity and embraced occult philosophy. His extensive treatises on earth science (*Mundus Subterraneous,* and *Magnes*) were a blend of the esoteric and the empiric. He climbed Mt Vesuvius and proposed that eruptions resulted from subterranean cyclic events rather than the displeasure of deities. This was an important geological insight, remarkable for its time. Yet Kircher was very much a 17th century natural philosopher. The bases of natural bodies were believed to be Aristotle's four elements, fire, earth, air, water. These elements were not concrete matter but represented certain properties which, in mediated combination, resulted in the production of materials (Adams 1954). Furthermore, celestial forces impinging on the earth, and on the elements, were regarded as causative agents for minerals and stones, both common and exotic. The sun's heat baked clay; Venus' creative influences led to the development of copper, Mars' to iron, Jupiter's to tin, Saturn's to lead. The theory of the lapidifying juice (mineral bearing solutions) was also current, although its nature was controversial. This juice operating through the earth's porosity and permeability produced minerals and stones (e.g. stalactites in limestone caves). Following Seneca (~4 BC – AD 65), these macrocosmic events were regarded as analogous to the microcosm, the human body, where fluids circulated and materials formed (e.g. kidney stones). All these perceptions were to change completely in the 18th century.

Kircher accepted the notion of an essential lapidifying agency, *Causa Formalis, Magnes* 1.1.2:

> *Causa porro formalis lapidum nihil aliud est, quam vis quaedam lapidifica, quae vel materiae praeparatae insidet, vel efficienti causae accedere debet.*
>
> Furthermore the essential cause of stones is nothing other than a kind of lapidifying force: be it intrinsic to the readied material, or necessarily added to the efficient cause [The heavenly 'general worker' driving terrestrial activity].

Lithological variety could be explained, *Lapidum Generatio, Magnes* 1.1.2 :

> *Dum enim materia succum lapidificum ducens, terrae partes intrat, atque aqua e massa iterum exstillat, vel ab exhalatione calida expellitur atque absumitur: massa illa paulatim expulso humido indurescit, donec in lapidem formam massae servantem abeat. Hinc pro diversitate succi terrestris, massae, aut etiam matricis, in qua formantur constitutione, variae quoque lapidum species nascuntur.*
>
> For when the material cause guiding the lapidifying juice enters parts of the earth, and, next, water trickles out of the (intruded) mass, or is expelled by warm vapor and taken away, that dewatered mass gradually hardens until it is changed into stone, preserving the form of the mass. Regarding this: on account of the diversity in lapidifying juice, the mass, or even its interstitial texture in which substances are structured, so too are various kinds of stone produced.

Addressing lodestone magnetite directly, Kircher acknowledged its importance and global reach, *Magnetis Generatio, Magnes* 1.1.2:

> *si in terrestri materia, vera, genuina & homogenea telluris portione, seu matrice Magnetica, fuligo dicta Magnetica recepta inibi varia decoctione, ab omni humido superfluo fuerit vindicata, ea vi lapidifica ibidem latente in lapidem formam virtutesque; massae, matricisque; seruantem videlicet Magnetem, convertetur, cuiusmodi Magneticis saxorum fibris totius telluris compagem certo ordine a polo ad polum, non secus, ac quandam veluti mundani dorsi*

spinam, qua partes partibus firmius solidiusque; connecterentur, mirabili sane sagacissimae naturae consilio constitutam esse in sequentibus fusius declarabitur

if in terrestrial material, a natural and homogeneous portion of the earth, that is to say the host for magnetic matter, dark thick magnetic vapour has been accepted, there freed from all excess moisture by changing heating events, it will be altered to lodestone in that very place, hidden in the subsurface, by the lapidifying force, preserving the form and properties of mass and internal structure. It will be amply shown in the following discussion that the framework of the whole earth has been established, in a remarkable plan of very clever nature, by magnetic veining of rocks of whatever kind, in specific arrangement from pole to pole just like what might be called the backbone of the world whereby parts are quite strongly and extensively linked together.

Kircher, for geological reasons, objected to Gilbert's simple model of the earth as a magnetic continuum, *Tellus non est magnus Magnes*, *Magnes* 1.1.3:

nemo me terram propterea cum Gilberto Magnetem magnum asserere existimet, dum enim venarum Magneticarum mentionem facio, non eas ita accipi volo, quasi ex perfecto & formato Magnete omnes constent; sed quod pleraeque inchoatae quaedam ad Magnetica corpora venae sint, quae etsi ob externo malo foedatas partes, & heterogenearum materiarum variam misturam in perfectum Magnetem, utpote verioribus & magis genuinis terrae partibus nimium dispersis & disunitis non excrescant.

no one should think, with Gilbert, I claim, that the earth is a huge magnet, for, while I do make mention of magnetic veins, I do not propose such observations to be thus accepted as if all such comprise perfectly produced magnetic material. On the contrary, the fact is that very many kinds of veins have originated in the neighbourhood of lodestone occurrences, and yet these do not increase in their extent to a full mass of lodestone owing to contamination of their parts by extraneous impairment, and because they are an inconstant mixture of different materials; as one might expect. These are very much distributed in scattered fashion in the actual regions of the earth.

The lodestone was employed by Kircher (1654) to illustrate, by analogy, his technique of deciphering Egyptian hieroglyphics, using the impresa of the Jesuit Parthenian Academy in Rome (Figure 5). An impresa is a cryptic emblematic device, of fanciful design, which includes a motto, but no explanatory text. The image needs to be studied together with the motto to elicit its meaning; each is insufficient without the other. Kircher, *Oed. Aegypt.* 3.1:

… in Impresia quavis duo continentur, symbolum, & sententia, quarum coniunctione in abditam tandem eius, quod praesefert, symboli significationem deuenimus; Verbi gratia in hoc Phrenoschemate praesente Magnetem vides, a quo concatenata annulorum series trahitur; vidisti symbolum, considera gnomen, quae est, 'arcanis nodis':

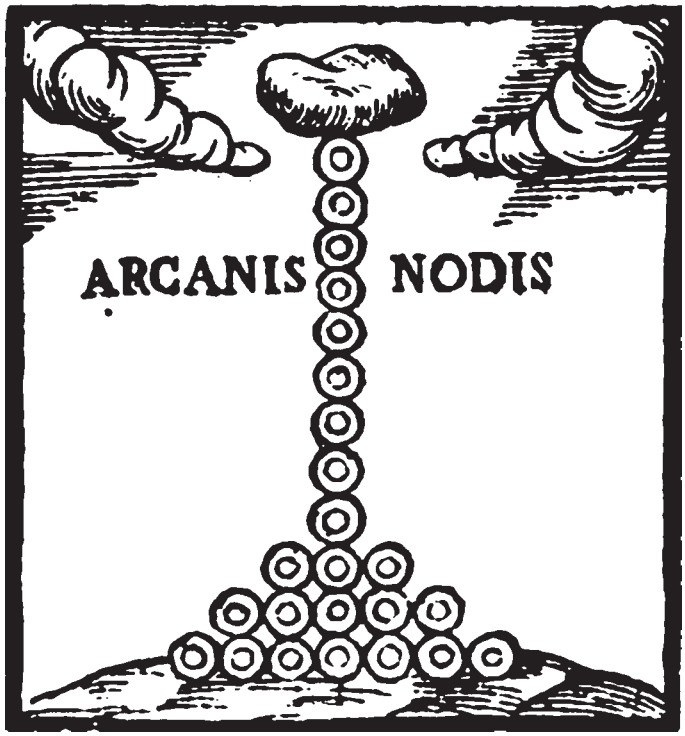

Figure 5. *Kircher's (1654) impresa showing Plato's lodestone, iron rings and the key words 'by mysterious bonds' or 'by secret knots'.*

quae verba nisi apposita fuissent, nihil in symbolu certi innotuisset …

… in any impresa you like to consider two things are included, the depiction and the sentiment. After time and effort we arrive at the hidden meaning of this depiction to the extent exhibited. For instance in this informative pictorial presentation you see the Lodestone which attracts a series of rings linked together. Having seen the device, consider the label which is 'by mysterious bonds'. If these words had not been put on, nothing definite in relation to the depiction would have been intelligible …

The lodestone and Plato's rings inspired the enigmatic impresa, a tribute to and reminder of the mysterious and marvellous.

Kircher's extensive earth science works warrant translation and study, for their inherent historical value, and for the information, attitudes, and insights they contain.

Concluding remarks

A curiosity now, famed for two millennia at least, the lodestone has been discussed here from several perspectives. Lodestone, while not rare, is not common in its occurrence as a special variety of magnetite that has a natural power of attracting iron. Magnetite is very familiar as one of the most common terrestrial oxides and one with salient physical features of great benefit to modern geoscience. Lodestone, being very unusual, greatly impressed previous generations. Despite its unattractive appearance it was an admired mineral type more precious than pearls, it was celebrated in persuasive Latin hexameters, it was an analogue for the power of deities, it took a witch to subdue

Figure 6. *Tennant Creek Ironstone core showing the magnet effect which is patchy and not manifest on all the core surfaces.*

it, it was deemed explicable by Epicurean atomic theory, it was involved in a rather tenuous argument for eternal punishment of wicked persons, it meant doom for unwary mariners, it furnished fodder for folk lore, it resided in the arsenal of the apothecary, it helped to demonstrate the earth's magnetism, and it assisted navigation. What other mineral has such a record? The lodestone was quite a remarkable rock; it still is, and oddly, yet to be completely studied and documented.

Previous generations had attitudes to nature quite different from current viewpoints. Belief in the four elements endured well into the 1600s. In 1650 the Old Testament chronologist Archbishop Ussher proposed 4004 BC as the date of all creation, which the scriptural literalist, and alchemical devotee, the great Sir Isaac Newton accepted. The review of lodestone given here very much pertains to earlier worlds. It seems strange that they appeared to know, at least in a general and empirical sense, more about lodestone than current geoscience. Where are the lodestone deposits? None are shown on the Barrington Atlas of the Greek and Roman World. What is their geometry? Can they be sampled and tested? What is the reason for the reported remarkable variations in colour and appearance? To what depth(s) does lightning charging extend? Are there other mechanisms for lodestone generation? The writer has observed unexplained, patchy, magnet effects in Tennant Creek Ironstone, (magnetite with ~5% hematite content), drilled at depth (Figure 6). Is the lodestone effect important in the bulk magnetisation of some geological bodies? The mineralogy, petrophysics, and petrochemistry of lodestones are worthy of more attention.

Acknowledgements

Dr D. F. Branagan introduced the writer to the wealth of geoscience information in Latin literature. Figure 2 was kindly provided by Mr Ross Pogson, Collections Manager Geosciences, Australian Museum Sydney and the photo was taken by Ms Kate Lowe; copyright is held by the Australian Museum. Dr. Phil Schmidt assisted with advice on lodestone's magnetisation characteristics and carried out some saturation magnetisation experiments on magnetite (these did not yield a magnet). Mrs S Franks, Mrs L Kalnins, and Mr D Kalnins prepared the manuscript. Many thanks to all.

This contribution on lodestone arose from the writer's continuing translation work on Marbod's Lapidary for which Beckmann's summary edition of 1799 has been used, but Beckmann's footnotes in Latin and Greek have not been included here. All the translations herein are the writer's. Formal translations with scholarly introductions and commentaries may be found in the Loeb Classical Library (LCL) and other editions in Bibliography, except for Marbod, Hortus Sanitatis, and Kircher; as far as the writer is aware there are no English translations of these works. The discussion of the compass in medieval Europe is based on an entry in the Encyclopaedia Britannica, vol. 6, 1968 edition.

The Lionsville lodestone (Figure 2) seems to come from magnetite lenses within a probable pendant of volcanics and sediments in granitoids of the Dumbudgery Creek Granodiorite in the New England Fold Belt NSW (The Mineral Deposits of NSW, 1974, see Ch. 5 by N. L. Markham – fig. 5.20, location no. 86).

The Tennant Creek Ironstone with the patchy magnet effect was one of a suite of magnetite samples, from the Proterozoic Tennant Creek Inlier in the Northern Territory studied in the Emerson & Yang Australian Mineral Industries Research Association (AMIRA) Project P416: Electrical properties of magnetite rich rocks and ores (1994). The sample shown in Figure 6 is microcrystalline, spongy textured magnetite with minor hematite, chlorite and quartz occurring as veinlets or clusters. Maghaemite, if present, was not identified in routine thin section analysis. The physical properties are: 4.91 g/cc density, 11 Sl magnetic susceptibility, 0.6 S/m DC galvanic conductivity, 3.3 S/m electromagnetic (induced) conductivity. The EM and galvanic responses differ on account of texture, which is also responsible for the quite low conductivities (compared to magnetite's single crystal conductivity of ~20 000 S/m). The sample came from 150m depth, below the zone of oxidation.

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Career advice for young geophysicists in a declining market

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A regular column like 'Data Trends' gives me massive carriage to comment on almost any issue. The editor of *Preview* would prefer, of course, that my contribution has at least some vague reference to geophysics or to science in general, but as long as it is three columns wide, and fills a page, I think I am safe. In the case of this article, I address the overlying 'Data Trends' of our fickle industry's ups and downs.

One of the things about writing an article for an intensely technical publication such as *Preview* is that I do have to be very careful not to be too smart. Smart generates feedback, and in general feedback is not good in technical writing. So, I try to walk the fine line of witty intelligence, with an undertone of life experience.

Witty intelligence in general is a far stretch for me, well at least half of it is. But life experience I have in spades. In my many past lives I have been a cook, an army medic, a truck driver, a cardiac technician and a CEO. I now have five kids, have been married for 25 years, have been to the north pole, climbed a mountain and swam with whale sharks. I have met prime ministers, rock stars and comedians, and have suffered loss and seen hard fought gains. I feel qualified to talk to young geophysicists about their careers (and hopefully none of them will ask me any technical questions).

So, having informed you of my qualifications and convinced you of my authenticity, let me offer some career advice to our youngest graduates who no doubt are actively seeking some direction (in the context of the current state of the market for geophysicists).

1. If you are reading this article and are a young geophysicist that means you are a member of the ASEG and are off to a good start (or it means your dentist has a shortage of magazines for their waiting room).
2. Find the discipline within geophysics that you enjoy the most and keep pushing. If your objective is to be the best in your field, this advice sticks. If your objective is to become immensely wealthy, this advice also sticks (about 1% of the time), win–win.
3. Commodity prices will rise and fall and, seemingly, so will the degree of appreciation you get from your employer. Don't let the industry roller coaster make you change your views about your chosen profession. Continue development in your area of interest, even if you are driving a taxi part time to pay the bills. Just ride it out and live with the certainty that better times always follow the bad.
4. Lastly, never take advice from an old, balding geophysicist who claims to be offering free career counselling.

On a more serious note, the industry has a boom and bust cycle – feast or famine. That is just the way it is. Our most remarkable talents in geophysics did not get to their positions by stopping their feet from moving underneath them on the basis of market conditions. As my father used to tell me, 'good things come to those who wait'. He just never specified how long I had to wait.

The Government's Industry Innovation and Competitiveness Agenda

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In October the Government announced an Industry Innovation and Competitiveness Agenda (http://www.dpmc.gov.au/publications/Industry_Innovation_and_Competitiveness_Agenda/index.cfm) to describe its vision for a strong and competitive economy:

> *It is a business-focused element of the Government's Economic Action Strategy.*

So far so good, then we go into spin-doctor speak. According to the media release:

> *The Industry Growth Centres Initiative (the Initiative) is the centrepiece of the Government's new industry policy direction and part of the Industry Innovation and Competitiveness Agenda. It will lift competitiveness and productivity by focusing on areas of competitive strength. This will help Australia transition into smart, high value and export focused industries.*

Furthermore,

> *The Initiative will enable national action on key issues such as deregulation, skills, collaboration and commercialisation. It will drive excellence, not dependence and create an economy that ensures Australia's ongoing prosperity.*

These are wonderful words; full of clarity and meaning!

In practice, the Government will provide $188.5 million over the first four years and the Initiative will initially focus on five growth sectors in which Australia already has a competitive advantage. These are:

1. Food and Agribusiness
2. Mining Equipment, Technology and Services
3. Medical Technologies and Pharmaceuticals
4. Advanced Manufacturing
5. Oil, Gas and Energy Resources

Notice that there is no category for transport, renewable energy or IT communications.

The Growth Centres will be not-for-profit organisations, led by industry leaders and the initiative will definitely provide direct assistance to the private sector.

> *Funding of $63 million will be available to develop and deliver large scale collaborative projects to build the capability and competitiveness of the sector. Project funding will focus on market, value chain or technology issues to deliver commercial outcomes. Sector projects will not only benefit the project participants but have impact across the whole sector and contribute to the outcomes of the Initiative.*

As part of the Initiative $60 million will be available on a competitive basis to help convert ideas with high potential into profitable commercial realities. It is also stated that:

> *The Initiative will also facilitate engagements between enabling services and technologies, such as Information and Communications Technology, where they provide essential and direct support to the growth sectors.*

More wonderful words; with more clarity and meaning!

In fact this means that there will be $9.4 million per year available for each Centre and $3 million per year for each sector to commercialise research outcomes.

> *The Growth Centres will be looking at four broad themes:*
>
> - *increasing commercialisation opportunities,*
> - *enhancing workforce skills,*
> - *addressing regulatory barriers, and*
> - *forging closer links with supply chains in their specific sector.*
>
> *They will also build export ready capabilities of firms in the sectors.*
>
> *Overarching activities that all Growth Centres will complete include:*
>
> - *Development and implementation of a roadmap to lift sector competitiveness;*
> - *Provision of advice to Government on how to best reduce regulatory burden within their sector; and*
> - *Development of annual industry knowledge priorities to help inform the research sector of industry needs and commercialisation opportunities.*
>
> *The* **Oil, Gas and Energy Resources** *Growth Centre* **may** *assist businesses to lower costs through greater collaboration, better sharing of infrastructure and logistics support (especially on remote projects), greater development and uptake of new technology and innovation, and improved planning across all areas of the resources value chain.*

I am told that the $188.5 million is not 'new money' but just a re-allocation of resources from within the Industry portfolio. The base level funding for Geoscience Australia and CSIRO has not changed and the cuts of $55 million listed in the June *Preview* still apply.

Anyway, $9 million per year is a sizeable sum to help develop a good project. So if you think you have a good idea go to industrygrowthcentres@industry.gov.au or telephone 13 28 46 and make the best use of the funds available.

Seismic attributes and Nintendo geophysicists

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I started this article about seismic attributes and it was half written when I attended a SEAPEX meeting in Perth where Bob Shoup gave a talk titled 'How workstations cause dry holes'. The talk highlighted how blind faith in computer generated products without the application of sound geological principles has led to many needless dry holes. Part of the problem is the lack of mentoring in many companies.

Most of today's seismic interpretation software can generate a plethora of seismic attributes. Some of these are useful, while others don't add much to our understanding. In practice those attributes that support a prospect are kept and, unfortunately, those that don't are quickly forgotten. An impressive list of seismic attributes and situations where they are useful can be found at http://opendtect.org/opendtect_attributes_matrix. Other similar but less detailed matrices can be found on some vendor websites but they are not as easy to access. With all these attributes available, I am often asked 'which attribute is best for finding hydrocarbons?' I will give the answer to this question later. But first, some comments about Nintendo geophysicists and geologists.

In many companies seismic attributes are churned out by a Nintendo geo (Figure 1). This slightly derogatory term is used by some to describe a generally younger geologist or geophysicist that was brought up on computer games and as a result can think and work in 3D space. They can create eye catching 3D visualisations in gaudy colours with ease. But, these displays can distract from the detail and hide many short comings in an interpretation or model. Technology has always been part of our industry, but this over-reliance on technology is new and has many people concerned because there is often a lack of understanding of the principles behind the workstation screens. This has not gone unnoticed with many in the industry commenting on Nintendo geos. For example, Durham (2006) states 'seismic is not geology' and '…many geoscientists … started to believe that computers find oil and gas. Nintendo geology had arrived. But you can … shortcut the geology for only so long'. And these comments from Brown (2004):

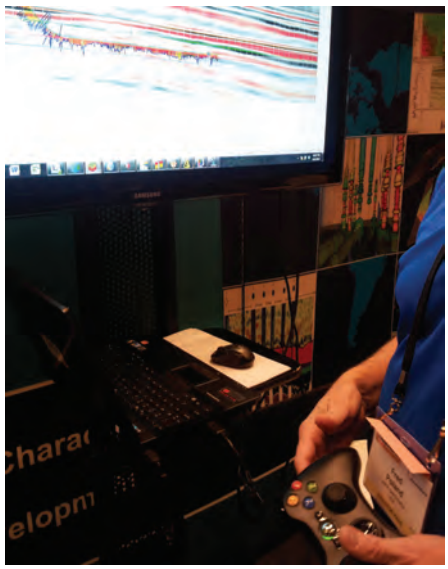

Figure 1. *Nintendo controller used with LMK interpretation software demonstrated at Melbourne ASEG Conference and Exhibition 2013.*

> 'I was first introduced to the term Nintendo geologist by a petroleum industry professional who saw that the new school geoscientists were relying more on computer graphics than geologic thought' (Roger Slatt, Professor of Petroleum Geology, University of Oklahoma) and 'They are computer jockeys but they don't know anything about the horses they ride' (Andrew Hurst, Professor of Production Geoscience, University of Aberdeen).

So, back to the best attribute. As powerful as computers are, they cannot find oil or gas without a good interpreter with good ideas. The most useful attribute any of us can use is a sound background in geology and an understanding of depositional processes. This is where good interpreters have the edge – they have ideas and test them against the data available. This knowledge is gained (by me at least) over many years of working with good geologists and having a mentor to make suggestions and keep interpretations realistic. Even today, we still spend too much time searching for data or getting things to work, and not enough time thinking of geology and testing ideas with peers and mentors. Every Nintendo geo needs a good mentor but many companies think mentors are expensive to maintain. Well, we're a bargain when compared to the cost of drilling a dry hole that could easily have been avoided.

References

Brown, D., 2014, Geology, Interrupted: *AAPG Explorer*

Durham, L. S., 2006, Digits can Distract from the Rocks: *AAPG Explorer*.

January	**2015**		
11–14	3rd South Asian Geosciences Conference and Exhibition http://geo-india.com/	New Delhi	India
February	**2015**		
15–18	ASEG–PESA 2015: Geophysics and Geology together for Discovery 24th International Geophysical Conference and Exhibition http://www.conference.aseg.org.au/	Perth	Australia
March	**2015**		
18–21	PACRIM 2015 http://www.pacrim2015.ausimm.com.au	Hong Kong	China
22–26	SAGEEP 2015 http://www.eegs.org/Annual-Meeting-SAGEEP/SAGEEP-2015	Austin, Texas	USA
April	**2015**		
19–22	SEG/CGS Workshop: GEM Chengdu 2015 Gravity, Electrical and Magnetic Methods and their Applications http://www.seg.org/events/upcoming-seg-meetings/gem-chengdu-2015	Chengdu	China
May	**2015**		
15	2nd Great Basin and Western Cordillera Mining Geophysics Symposium being held in association with the Geological Society of Nevada Symposium http://gsnv.org/2015-symposium/	Reno, Nevada	USA
17–22	20th Caribbean Geological Conference http://www.thegstt.com	Port-of-Spain	Trinidad & Tobago
June	**2015**		
1–4	77th EAGE Conference and Exhibition 2015 http://eage.org	Madrid	Spain
July	**2015**		
7–10	2nd Near-Surface Geophysics Asia-Pacific conference (NSGAP) http://www.seg.org/events/upcoming-seg-meetings/2015/ns-asia-pacific-2015	Hawaii	USA
September	**2015**		
6–10	1st European Airborne Electromagnetics Conference and 21st European Meeting of Environmental and Engineering Geophysics – Near Surface Geoscience 2015 http://eage.org/event/index.php?eventid=1325&Opendivs=s3	Turin	Italy
October	**2015**		
5–8	8th Congress of Balkan Geophysical Society http://www.eage.org/event/index.php?eventid=1313&Opendivs=s3	Chania	Greece
18–23	SEG International Exhibition and 85th Annual Meeting http://www.seg.org	New Orleans	USA
November	**2015**		
18–20	12th SEGJ International Symposium http://www.segj.org/is/12th/	Tokyo	Japan
December	**2015**		
7–9	9th International Petroleum Technology Conference http://www.iptcnet.org	Doha	Qatar
October	**2016**		
16–21	SEG International Exhibition and 86th Annual Meeting http://www.seg.org	Dallas	USA
July	**2017**		
2–17 (TBC)	3rd Near-Surface Geophysics Asia-Pacific conference (website TBA)	TBA	Australia

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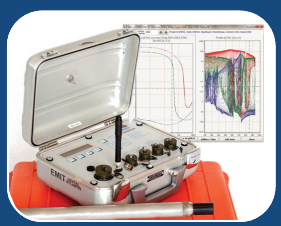

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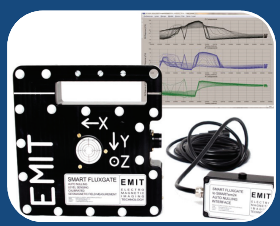

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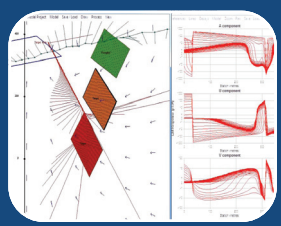

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