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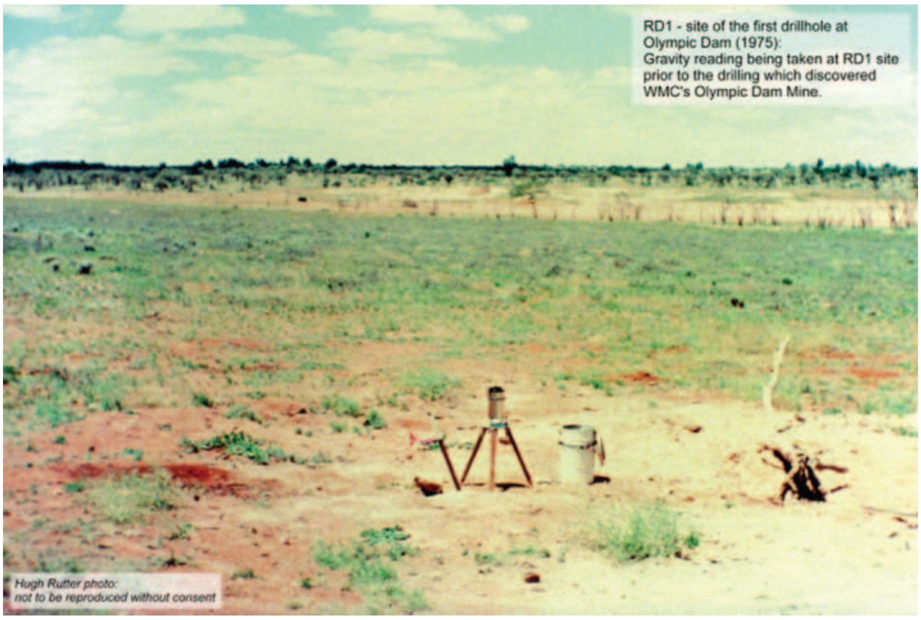
# Vale Hugh Rutter (1941–2014)




Colleagues and friends are saddened by the recent death of distinguished geophysicist, Hugh Rutter. Hugh graduated in geology from Durham University in 1963 and worked for the British Geological Survey. In 1967 he migrated to Australia and joined the Geological Survey of Western Australia. The excitement of the nickel boom enticed him to Kalgoorlie in 1969, to work for Western Mining Corporation (WMC.)

Three years later he took leave of absence, returned to the UK and completed a Master's degree in geophysics at Royal School of Mines, Imperial College, London, which included a dissertation on transient electromagnetics, a technique that was just becoming popular in Australia.

Hugh returned to Kalgoorlie then transferred to Melbourne, where he joined WMC's newly established eastern states' exploration office. This was an exciting time, culminating in the discovery of Olympic Dam (Roxby Downs.) The following is an extract from an interview with Roy Woodall of WMC:

> *We had access to a very good geophysicist, Hugh Rutter, who was on our staff, based in Melbourne. So Hugh was consulted, and he came and got involved. He got access to the Bureau of Mineral Resources' regional airborne maps of magnetics and ground-survey gravity maps of northern South Australia and noticed that there was a small copper deposit at a place called Mt Gunson. That was not really close to where Douglas (Haynes) thought we ought to go drilling for copper, where he had found rocks that could have sourced copper. But for a geophysicist, why not have regard for the geophysics – the geophysical imprint, the geophysical image of this little copper deposit? It was very clear that there was a substantial magnetic anomaly at the copper deposit and a substantial gravity anomaly as well.*

After Hugh interpreted all the Roxby Downs geophysics – gravity, magnetics and seismic, he and Jim Lalor sited the first drill hole (RD1-Roxby Downs 1) which was mineralised. Jim Lalor recalls:

> *I worked with Hugh from 1970 until his move to BHP and greatly admired his scientific skills and his practical ability to manage every situation.*

Hugh's skills and the systematic approach he took to mineral exploration are obvious in the 1985 paper he wrote with Don Esdale on the geophysics of the Olympic Dam discovery (Rutter and Esdale, 1985). This paper is reprinted in full on the pages that follow this obituary.

In his early days with WMC, Hugh was responsible for pioneering the use of a number of new techniques, even travelling to Russia and returning with new instrumentation (MPPO1) and techniques which led to the development of SIROTEM, under the auspices of the CSIRO Division of Mineral Physics led by Ken McCracken.

In 1978 Hugh joined BHP as Chief Geophysicist where he was instrumental in establishing a geophysical section and helped to formulate exploration policy. He took a series of initiatives in the introduction of new technology into mineral exploration. Hugh left BHP in 1981 and founded Geophysical Exploration Consultants Pty Ltd and was a founding member of the Flagstaff group of consulting geologists and geophysicists in Melbourne. As well as consulting to the mining industry, his geophysical assignments extended to various civil works and even forensic investigations.

In addition to becoming a leading practitioner of exploration geoscience, Hugh taught numerous industry courses in geophysics for the Australian Mineral Foundation as well as at Monash, Melbourne and Ballarat Universities. He has also worked for the CSIRO Division of Geomechanics as a Program Manager in charge of geophysical aspects of research.

During his career Hugh's working experience extended throughout Australia and overseas to Malaysia, Thailand, Indonesia, Philippines, Fiji, New Zealand, Mexico, Chile, Ghana and Yukon Territory, Canada.

Hugh was an active member of several professional societies in Australia and overseas, including The Australasian Institute of Mining and Metallurgy (The AusIMM) and the Australian Society of Exploration Geophysicists (ASEG). He was a Fellow of The AusIMM and served on the Melbourne Branch Committee for some years. He was a member of ASEG since its inception in 1970, serving as

Federal President from 1992–94 and was awarded Honorary Membership in 1998.

Hugh was also a keen sailor. He was an active member of the Hobsons Bay Yacht Club for some 22 years and served as Commodore for some time. As the proud owner of 'The Alchemist' he won many club trophies. Hugh also belonged to the Balwyn Rotary Club where he was a valued member.

Hugh Rutter was a distinguished geophysicist – he was also a gentleman and a gentle man, who loved his family, sailing, art, music and travelling. Sincerest sympathy is extended to Hugh's wife Anthea and his children David and Jane and their families.


## Reference

Rutter, H., and Esdale, D.J., 1985, The geophysics of the Olympic Dam discovery: *Exploration Geophysics*, **16**, 273–276.

*Kim Frankcombe, Bob Smith, Jim Lalor and Phil Schmidt (on behalf of Greg Street)*

# The geophysics of the Olympic Dam discovery

**H. Rutter and D. J. Esdale**

The central southern part of South Australia was one of a number of areas considered favourable for economic deposits of copper mineralization by WMC geologists in 1974 (Fig. 1). This area was far too large to be explored in detail. The process of ground elimination and target selections required the use of all the available geological and geophysical information.

The geological model was that of a sediment hosted copper deposit where the metal source was considered to be a thick pile of continental tholeiite basalt lavas; mobility was to be provided by hydrothermal fluids active during metamorphic alteration processes. This was translated into a geophysical model which consisted of a magnetic anomaly caused by the tholeiitic basalts and a gravity anomaly related to a horst block within the main basaltic mass. The object was to identify this situation within the geological province using the regional gravity and magnetic data.

Samples of Roopena Volcanics (of Willouran age) considered to be similar to the source rock, were obtained from exposures at Roopena Station and Depot Creek both close to Port Augusta. Measurements of magnetic susceptibility and density were made and compared to the same parameters measured on samples of Marinoan rocks (Whyalla Sandstone, Tregolana Shale, Corraberra Sandstone, Arcoona Quartzite, Tent Hill Formation). The susceptibility contrast was variable and related to the degree of alteration of the basalt samples, but a density contrast of 0.3 gms/cc was established with a greater degree of credibility.

The regional magnetics were first assessed with the object of locating a basaltic pile of sufficient thickness, lateral extent,

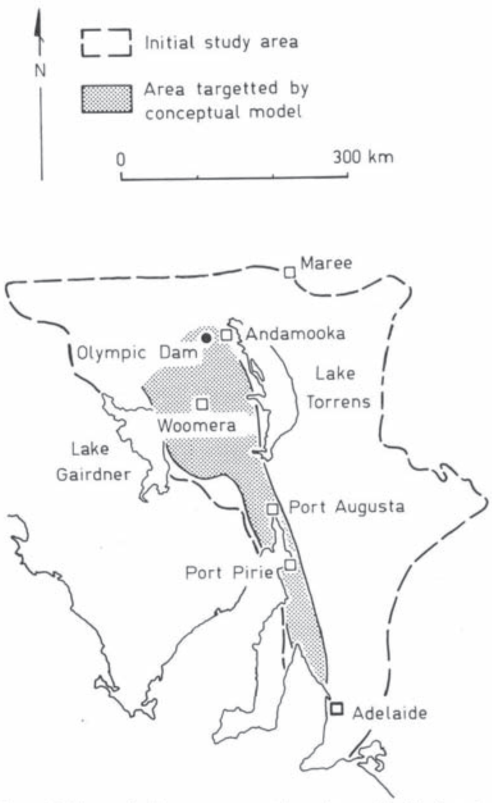



**Fig 1** Location of Olympic Dam copper deposit and initial study area.

and nearness to surface to fulfil the conditions of the geological model while still being amenable to exploration.

It soon became apparent that the magnetic anomalies on the Torrens and Andamooka 1:250 000 sheets were of prime interest, although far more distant areas were also considered. The magnetic complex on the Andamooka sheet satisfied many of the criteria for extensive, thick, and faulted basalts, and was subjected to a first stage magnetic interpretation. Six anomalies were selected as being caused by a source relatively close to the surface; of these, five were on the Andamooka sheet and became known as Bills Lookout, Olympic Dam, Appendicitis Dam, Andamooka Island and Lake Torrens. All five were also associated with a positive gravity anomaly.

The original gravity map published by SADM consisted of 2 mgl contours compiled from stations spaced on a 6 km grid. This data was carefully recontoured at a 1.0 mgl interval in the area of each anomaly and from the new contours a profile was taken for interpretation. Simple geometric models were used in conjunction with a density contrast of 0.3 mgls to simulate uplifted blocks of basaltic material in a sedimentary environment. The errors that could result from an interpretation based on such widely spaced data relative to the size of the source were fully realised; it was expected that the true anomaly would be smoothed and the source interpreted to be too deep.

The estimated depth to the source of the gravity anomaly at Andamooka Island was 1700 m; Lake Torrens 2700 m; Bills Lookout 2200 m; Appendicitis Dam 4800 m; and Olympic Dam 1150 m. As a result the Olympic Dam anomaly was one of those selected for further investigation; and it soon became apparent that by adjusting the physical dimensions of the body but maintaining the density contrast the source could be as shallow as 850 m.

An interpretation of the total magnetic intensity, again using simple models, placed the depth to the magnetic source at about 2000 m. Relating the magnetic and gravity interpretations to the original model was becoming difficult because of the inconsistent depths; but it was considered still possible because of the regional nature of the data and the possible interpretation errors that could have been incurred.

Olympic Dam was also favoured because of accessibility because the Lake Torrens and Andamooka Island anomalies were both beneath Lake sediments of unknown thickness and Bills Lookout anomaly was in the Andamooka Opal Field, an area restricted to opal mining and inaccessible to general exploration.

Ground inspection followed, but there was little to see on the ground other than sand dunes, some Cretaceous outcrop, and in the vicinity of Olympic Dam, outcropping Cambrian limestones. A ground magnetometer traverse was run from a point 2 km SSE of Olympic Dam, through Olympic Dam to Coronation Dam and on to the Vermin Proof Fence (Fig. 2). The profile form is identical to the airborne profile and other than confirming the ground location of the anomaly, no further information concerning the source was achieved. It is relevant to note that a small speck of malachite on a sandstone rock was found a short distance north of Olympic Dam while on this magnetic traverse. It had little to do with the subsequent mineral discovery but it added encouragement at the time. Confirmatory geophysical evidence was sought from seismic refraction and reflection surveys. Using equipment and personnel from SADM three refraction seismic traverses were run firstly along the road from Axehead Dam to Phillips Ridge Hut; secondly along the N–S fence towards Olympic Dam from Phillips Ridge Hut and thirdly west from this fence to Olympic Dam and slightly beyond (Fig. 3). Reflection seismic data was collected only at Olympic Dam, but the results were the most significant in that they identified a strong reflector at about 1000 ft (305 m).

The geophysical signatures recorded at Olympic Dam were those expected to result from the conceptual geological model. The magnetics reflected extensive thicknesses of tholeiitic basalts in the area with shallower parts at Olympic Dam; the gravity confirmed the presence of denser rock; and the seismic indicated that optimistically this might be at a depth as shallow as 300 m. RD 1 was sited 200 m west of Olympic Dam, 10 June 1975 and drilling began four days later. It was a stratigraphic hole to determine the lithologies and check for the presence of basalts in the context of the initial conceptual geological model. RD 2 was sited at Appendicitis Dam (now named Acropolis) 18 km southeast, using only the regional gravity and airborne magnetics. RD 1 was completed to 411 m, intersecting the following succession: Andamooka Limestone 0–37.9; Arcoona Quartzite 37.9–197.5; Corraberra Sandstone 197.5–209.9; Tregolana Shale 209.0–334.9; Medium to coarse grained hematitic sandstone 334.9–335.7; Coarse grained altered hematitic amygdoloidal basic volcs 335.7–411.0.

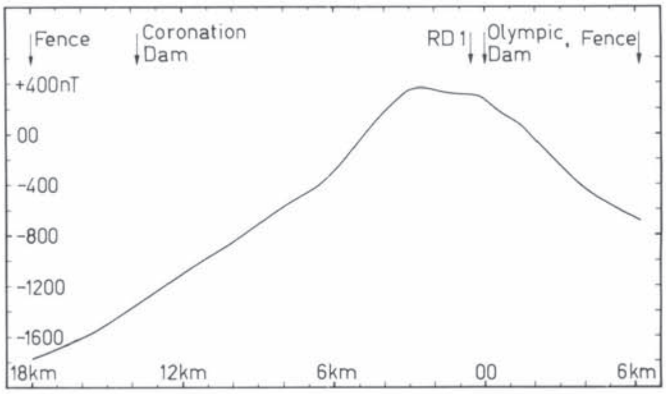



**Fig 2** Ground magnetic traverse Coronation Dam–Olympic Dam relative values.

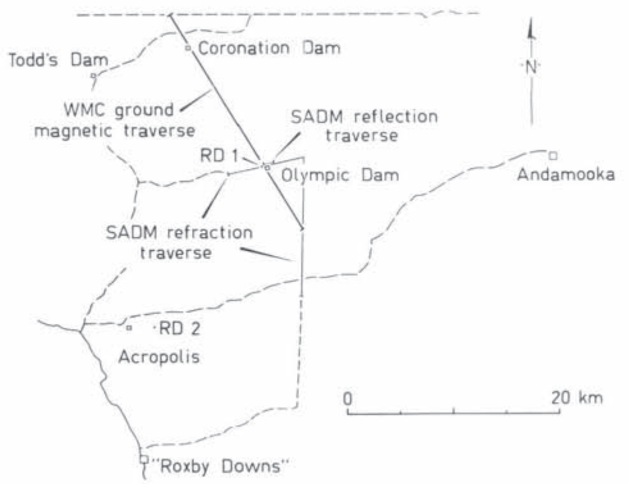



**Fig 3** Geophysical ground surveys.

Subsequent assays gave 38 m of 1.05% Cu in the lowest unit which was not magnetic but had a high density which went far in explaining the gravity anomaly. The hematitic brecciated rock could be the cause of the gravity but not the magnetic anomaly. The upper surface could be the seismic reflection detected from the surface, but so could the top of the coarse sandstone, only a metre higher up the hole.

It was decided to run a seismic refraction traverse from RD 1 to RD 2 to determine which horizon was the refractor at RD 1, follow it to RD 2 and relate the geological intersections of both drillholes. As a result of this survey the refractor was found to be the Tregolana shale and Tent Hill Fm interface.

Gravity and magnetic measurements were taken at 90 m intervals along this line and also along a line perpendicular at both RD 1 and RD 2. The contoured gravity data at Olympic Dam indicated a peak NE of the drillhole.

An Elmac logger was used to record the natural gamma radiation in RD1, with rather spectacular results in the lowest unit. The appropriate sections of the core were examined using a spectrometer with the surprising result that the cause was not just potassium but predominantly uranium.

Considerable interest was generated in the Olympic Dam prospect with its unusual rock type and anomalous copper and uranium to the extent that a seismic reflection crew, on its way to the Pedirka Basin, was diverted for a brief test traverse across Olympic Dam. It is doubtful that the results were particularly meaningful because of the noise generated in the cavernous Cambrian limestone but it is an indication of the interest being placed in the prospect at that time. Drilling continued but the results were not spectacular.

A detailed gravity grid was surveyed over the area with lines 500 m apart and stations at 100 m intervals (Fig. 4). The data placed the centre of the gravity anomaly 1.3 km north of Olympic Dam and outlined a feature which was approximately 2.5 km in diameter.

A conventional IP line was run across the centre of the feature: using a dipole–dipole array with 100 m dipoles to $n = 8$:both apparent resistivity and percentage frequency effect data were gathered. There was no obvious relationship between either parameter and subsurface mineralization.

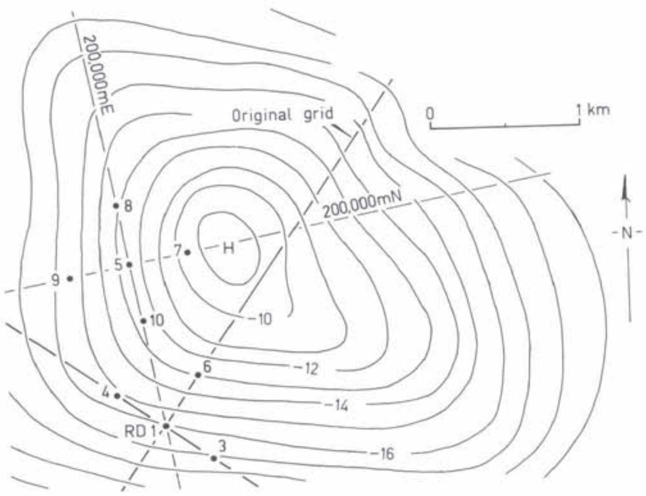



**Fig 4** Detailed gravity survey and drillhole location. Contours in milligals.

The results of RD 10 became available in November 1976 (17 months after RD 1) which included an intersection of 168 m at 2.13% Cu and later in that same month the results of all drillholes RD 1–RD 10 were announced at the WMC Annual General Meeting.

The original conceptual model had not been found. The stratigraphic hole RD 1 had located a hematitic brecciated granitic rock and not tholeiitic basalts: if the latter had been intersected, exploration would have moved to locate the copper mineralization which was hoped would surround this centre in the draped sediments.

The deposit is quite different. The gravity anomaly is quite clearly caused by the prodigious amounts of hematite. The magnetic anomaly remained unexplained up to the stage of drilling RD 10, because the interpreted depth of the source, 1800 m, had not been reached.

The uranium was in equilibrium and apart from using the gamma logs to define uranium rich sections, the logs were also used to estimate uranium content prior to a formal geochemical analysis. The regional gravity and magnetic data provided the basis for the original study which located the site of RD1. Even though the data is widespread and interpretations of the gravity data overestimated depth, the relative depths were correct; Olympic Dam was the shallowest feature. The regional gravity was enhanced by reprocessing and contouring at a 1.0 mg interval (Fig. 5).

Late in 1976 with the RD 10 intersection, the realization of the size of the deposit, and the effort required for evaluation became apparent. A programme of drilling was established and various studies in many facets of the Earth Sciences were proposed. The results of these studies, in particular those of geophysical significance, will, no doubt, become available as time progresses.


**Fig 5** Geophysical summary. Magnetic contours: ——— original; — — detail. Gravity contours: ——— original; ---- detail.

# ASEG-PESA 2015 registration now open, extended abstracts due 31 August!


Registration for the ASEG-PESA 2015 conference is now open and the deadline for the submission of extended abstracts is fast approaching. The conference will be held 15–18 February 2015 at the Perth Convention and Exhibition Centre in Western Australia. The conference theme is 'Geophysics and Geology together for Discovery' – invoking the fundamental tenets behind our shared efforts to effectively and safely discover the natural resources needed for future generations.

Abstracts are invited for posters and presentations in the concurrent technical streams that be will be running over the three days of the conference. However, delegates are particularly invited to address two key discourses related to our 2015 conference theme:

- Acknowledging the physical properties of the earth that lead to the geophysical signatures we measure and investigate, and
- Case studies that showcase improved geological understanding based on geophysical endeavours.

National and international keynote speakers have been secured as a catalyst to ensure dynamic and relevant technical sessions. The full and very exciting line up of speakers can be viewed on the conference website (http://www.conference.aseg.org.au/).

While you are on the website, we encourage you to take a look at the workshops that have been organised over the weekend leading up to the conference. These include workshops on velocity modelling, full waveform inversion, rock physics and sequence stratigraphy. There is also a university student quiz night.

Student registration fees have been kept low to encourage student participation. There is a discount for members of ASEG and PESA and, as part of the registration package, complementary membership of either society is being offered to non-members. There are also early bird specials.

We look forward to seeing you in Perth in February 2015. Remember, abstracts are due by 31 August!

*ASEG-PESA 2015 Conference Organising Committee*
*www.conference.aseg.org.au*

# Geophysics at the Australian Earth Sciences Convention, Newcastle 2014

The Australian Earth Sciences Convention (AESC) was held in Newcastle during 7–11 July 2014. The AESC is the major biennial event of the Geological Society of Australia and this year had concurrent sessions on the Environment, Energy, Dynamic Planet, Resources, Living Earth and Infrastructure, Service and Community. The 39th Symposium on Advances in the Study of the Sydney Basin, and a symposium on Comparisons and Contrasts in Circum-Pacific Orogens, comprised separate streams. The conference was attended by approximately 650 geoscientists, many of whom were geophysicists, and a number of presentations had a distinctly geophysical flavour.

The geophysics presented covered a broad spectrum of methods of widely varying scale lengths. The following are extracts from the abstracts of geophysical presentations roughly ordered according to scale length, beginning with big-picture topics through to the nano-scale. Laurie Hutton, the President of the Geological Society of Australia, is thanked for permission to publish these extracts.

We have tried to give a flavour of the geophysics at the meeting, rather than methodically and comprehensively reporting on each and every presentation that mentioned geophysics, some of which touched on geophysics (usually seismic or magnetic surveys) without focussing on the detail. Hopefully we have not unwittingly introduced gross errors, although it is inevitable our abbreviation may have altered import. Readers are encouraged to access the original abstracts of those presentations they find interesting (http://www.aesc2014.gsa.org.au/assets/Various-reg-partner-opp-workshop-summ-/AESC-Abstract-Proceedings.pdf).

## Is there a window for plate tectonics in terrestrial planet evolution?

Craig O'Neill, Adrian Lenardic, Siqi Zhang and Jonathon Wasiliev
*Macquarie University, Sydney, Australia*

These authors use visco-plastic mantle convection simulations, with evolving core–mantle boundary temperatures and radiogenic heat decay, to explore tectonics over the lifetime of a planet. The implication of these results is that plate tectonics may be a phase in planetary evolution between hot and cold stagnant end-members.

## Was the early earth stagnant?

Craig O'Neill and Vinciane Debaille
*Macquarie University*

Modelling early Earth high mantle temperatures reveals weak slabs that would not have sustained subduction. Early Earth stagnant lid tectonics explains a number of observations of the Hadean/Archean.

## Reconstructing ancient ocean basins and evolving plate boundary configurations – a key to understanding solid earth evolution

R D Müller, N Flament, S Zahirovic, G Shephard, K J Matthews, S E Williams, M Seton and M Gurnis
*University of Sydney,and California Institute of Technology*

Mantle convection mainly depends on the location, geometry and velocities of subduction zones and age of subducted lithosphere providing primary constraints on solid Earth evolution. The authors have constructed and combined a global relative/absolute plate motion model since the Jurassic, which illustrate Australia's late Cenozoic northeast-ward motion towards a downwelling related to the sinking eastern Gondwanaland slabs in the lower mantle. A surface expression of this plate–mantle interaction is the well-documented progressive late Cenozoic anomalous subsidence of the northwest and western shelf of Australia – up to 1000 km away from the nearest plate boundary.

## State-of-the-art review of earthquake forecasting algorithms

Andreas Schreas, James Daniell and Hans-Peter Bunge
*Ludwig-Maximilians-Universität, Munich, Germany, Center for Disaster Management and Risk Reduction Technology (CEDIM), Karlsruhe Institute of Technology (KIT) Germany, and The General Sir John Monash Foundation, Melbourne*

More than 20 earthquake forecasting methods were categorised into time-independent, time-dependent, and hybrid. The first category yields robust and stable forecasts, but has poor accuracy and predictive abilities. A simple toolbox has been developed which covers most elements of time-independent forecasting algorithms, including smoothing, handling of Gutenberg-Richter parameters and probability calculation elements. Time dependent and hybrid methods cover many facets of computational approaches, and are divided into pure statistical approaches, which depend only on historical data, and algorithms which incorporate further information e.g. spatial data of fault distributions, or which incorporate physical models like static triggering. Time-independent algorithms were tested in Turkey and Italy with up to 1000 years of historical data. The choice of time-independent method has only a marginal influence on likelihood. The most important factor in generating forecasting maps is the choice of smoothing parameters and the handling of the Gutenberg-Richter relation. Increasing complexity, like the introduction of spatially varied b-values, tends to destabilise the results. Thus time-independent methods are not considered to be useful as forecasting tools. In contrast, time-dependent methods are better forecast-generating algorithms.

## A paleomagnetic test of the Columbia supercontinent at 1.88 ga; constraints from radiating mafic dyke swarms in the Dharwar craton, India

Mercedes Elise Belica, Elisa J Piispa, Joseph G Meert, Lauri J Pesonen, Jüri Plado, Manoj K Pandit, George D Kamenov and Matthew Celestino
*University of Western Australia, Michigan Technological University, Houghton, USA, University of Florida, Gainesville, USA, University of Helsinki,*

*Finland, University of Tartu, Estonia, and University of Rajasthan, India*

Earth's history was punctuated by numerous supercontinental configurations. Paleomagnetic techniques remain the only quantitative test of reconstructions of pre-Pangea, Proterozoic supercontinents. The Precambrian geologic record suggests a major global rifting event from 2.2 to 2.0 Ga followed by global orogenesis from 1.9 to 1.7 Ga. The orogenic belts that formed during this event were used to generate a plausible supercontinental assemblage named Columbia. Here we report results from 4 separate magmatic events during the Paleoproterozoic, including a ~85 000 km$^2$ radiating dyke swarm at 1.88 Ga. The Grand Mean dual polarity paleomagnetic pole falls at 36.5° N and 333.5° E for 29 sites from the present study combined with previously published sites. Using our continental reconstruction for India at *ca* 1.9 Ga and the database of well-dated paleomagnetic poles for this time period, we test the geometry of the archetypal Columbia model. Our conclusion is that either Columbia did not exist as a coherent supercontinent, or it was not assembled by 1.88 Ga. Finally, we provide an Apparent Polar Wander Path for Peninsular India from 2.37–1.88 Ga and analyse potential cratonic relationships for each magmatic interval.

## The first national-scale mapping of magnetisation direction

Dean Hillan, Clive Foss and James Austin
*CSIRO*

Much of Australia is covered with aeromagnetic data measured on flight lines at 400 m spacing or less, and from this data Geoscience Australia has compiled a national total magnetic intensity (TMI) map at 80 m cell size. The authors have applied to this grid a novel analysis, which adaptively clips the grid into rectangular samples containing isolated anomalies. These samples are then analysed to recover an empirical estimate of their source magnetisation direction. This analysis has the considerable advantage that it is not dependent on the spatial distribution of magnetisation and that the cross-correlation metrics are insensitive to uncorrelated noise. The analysis has already been proven successful on application to synthetic grids forward computed for specified magnetisations. The national grid has been sliced and projected into the seven UTM zones 50–56 and analysed separately returning a TMI image for the analysed anomaly, along with the relevant information such as the recovered magnetisation direction, local field, confidence etc. Each result is then viewable in Google Earth as a KML file.

## The advantages of a national approach to mapping depth beneath cover from magnetic field interpretation

Clive Foss and Tony Meixner
*CSIRO and Geoscience Australia*

Magnetic field interpretation is the most extensively used geophysical method for remotely investigating basement geology beneath cover. One important aspect of this interpretation is quantitative estimation of depth to magnetic sources (commonly referred to as 'depth to basement mapping'), some methods of which leave much to be desired. CSIRO's method is based on two key recognised facts; that magnetic fields carry useful source information only in specific 'sweet spots' above and around suitable magnetic sources, and that model-based inversion of the data carefully clipped to those sweet spots provides the highest resolution recovery of depth information, with associated sensitivity values. Geoscience Australia and CSIRO have investigated implementation of methodologies based on this analysis as a documented and recommended process to recover source depth values from magnetic field data across Australia.

## The character of the lithosphere–asthenosphere transition beneath the Australian continent

Brian Kennett and Kazunori Yoshizawa
*Australian National University and Hokkaido University*

A variety of seismic parameters may be used to gauge lithospheric thickness and the transition to the underlying asthenosphere. The asthenosphere is convective so seismic wavespeed gradients may indicate the transition from the thermally conductive lithosphere to the more adiabatic asthenosphere. In brief, it was found that the transition beneath cratonic areas is thick with fast wavespeed, but much thinner in the suture zone between cratons, particularly in the Musgrave block in central Australia. The lithosphere–asthenosphere transition is quite sharp beneath the Phanerozoic eastern margin of Australia.

## Australian earthquakes: when, where, why?

Kevin McCue
*Australian Earthquake Engineering Society*

The location and mechanism of earthquakes reflect the stresses acting on the intraplate crust resulting in a diagnostic tool for predicting where and how often future damaging earthquakes could be expected. Advances in the knowledge of where and when future earthquakes are more likely to occur will make costly building codes changes more palatable, learning from recent disasters such as the Christchurch NZ earthquake. Earthquakes in Australia show post-instrumental earthquakes occur in most of the same broad locations as those in the pre-instrumental period. The locations of up to 150 years of earthquakes, together with the focal mechanisms of the larger post-1965 earthquakes, and better focal depth control from more recent targeted studies, gives some degree of confidence for recommending that a continental-scale rheological model could be explanatory.

## The Australian remanent anomalies database – a resource for the investigation of regional magnetisation events

Clive Foss, Peter Milligan, Dean Hillan, Peter Warren, Phil Schmidt and Robert Musgrave *CSIRO and Geoscience Australia*

Australia has magnificent national magnetic field coverage, managed by Geoscience Australia, and composed in large part of surveys flown by State and Territory Governments. This magnetic field data is the most widely and intensely used of all Australian geoscientific datasets. Magnetic field variations from crustal sources are due in approximately equal amounts to induced magnetisation and remanent magnetisation. Many magnetic field interpretations disregard remanent magnetisation, except where its influence is so pronounced that it cannot be avoided. This neglect is a common reason that deep drill-holes fail to intersect their targets, and is also a missed opportunity to recover additional geological information from magnetic field data. CSIRO and Geoscience Australia have established a national remanent anomalies database (the first of its kind in the world). The database can be accessed through the AuScope portal, and supplies details of anomalies recognised to be in large part due to remanent magnetisation. Magnetisations recovered from magnetic field interpretation are vector resultants of induced and remanent magnetisations, in widely varying and poorly predictable ratios. Presently, tools are being developed to analyse the recovered magnetisation directions. We hope that the database can be extended as a community effort of government, industry and academic geoscientists.

## Receiver-based passive seismic probing of the Australasian lithosphere

Nita Sebastian, Hrvoje Tkalčić, Christian Sippl, Anya M Reading and Fabrice R Fontaine
*The Australian National University, University of Tasmania, Private Bag 79, Hobart, Tas 7001, Australia and Université Paris Diderot, France*

The receiver-function technique is a proven tool for extracting lithospheric shear-wave velocity profile beneath a receiver by source-equalisation. Lithospheric structural information is obtained from teleseismic receiver functions by non-linear optimisation algorithms within a Bayesian inference, which can handle their non-unique nature. Surface and body wave tomography and receiver function analysis have yielded lithospheric structural patterns of most regions of Australia. We carry out receiver function analysis with an attempt to include other compressional waves, deriving compressional and shear-wave velocity ratios and crustal thickness. We use a recently developed hierarchical and transdimensional Bayesian inversion of receiver functions. This tool is void of explicit parameterisation, damping and smoothing, and treats the noise in the data as a free parameter. This becomes particularly useful in noisy environments such as coastal areas and the interior of Antarctica. Here we present preliminary results of our imaging applied to different regions of Australasia.

## Multi-array, multi-frequency probing of the earth's heterogeneity

Josip Stipčević, Hrvoje Tkalčić, Brian L N Kennett and Satoru Tanaka
*The Australian National University and Japan Agency for Marine-Earth Science and Technology, Yokosuka, Japan*

The use of seismic arrays allows signals with small amplitudes to be enhanced by exploiting the coherency of waveforms at adjacent stations. Since the establishment of the Warramunga array (1965) many similar experiments have been carried out across Australia (e.g., SKIPPY, SEAL) but all focused on using single array methods. We plan to extend array techniques from single to multiple, simultaneously operating networks. Data from two temporary arrays, in Queensland and Western Australia, will be combined with fixed seismic arrays (Warramunga – WRA and Alice Springs – ASAR in the Northern Territory, and the new PSAR array in the Pilbara) linked to nearby deployments of broad-band stations. The first stage will use well-established array processing methods such as beam forming, velocity-spectral analysis and frequency-wave number method (fk analysis) to map energy from well-known deep interfaces such as the core–mantle boundary. Next step will be to utilise advanced methods such as sliding window fk analysis and migration to map energy scattered from unknown sources. We will use data from a seismic event recorded on multiple arrays to 'triangulate' on the source and refine understanding of the nature of heterogeneities, and exploit the range of phases. By utilising data from multiple arrays we hope to push the resolution limit of seismic tomography.

## Investigating the electrical lithosphere of the Flinders Ranges using magnetotellurics

Kate Robertson, Graham Heinson, Stephan Thiel and Lars Krieger
*University of Adelaide*

The Gawler Craton and the Curnamona Province occur either side of the Flinders Ranges but may have been connected prior to rifting. Seismic reflection and passive teleseismics have not fully resolved the deep crustal and upper mantle architecture. Long period magnetotelluric data show in a bandwidth of 1000–4000s, with scale lengths of about 100 km, induction arrows indicating a significant conductive central region within the Flinders Ranges (known as the Flinders Conductive Anomaly). Significant distortion is observed at longer periods due to the complex deformational history of the region.

## Interpreting basement geology in the southern Thomson Orogen

David Purdy, Rosemary Hegarty, Michael Doublier and Janelle Simpson
*Geological Survey of Queensland and Geological Survey of New South Wales*

Restricted outcrop in the poorly exposed Thomson Orogen (TO) reveal several mineralisation styles. A preliminary basement interpretation map integrating new geophysical data is seamless across the Queensland–NSW border and is part of an ongoing collaborative project between the Queensland and NSW state geological surveys and Geoscience Australia. Regional aeromagnetic and gravity datasets reveal significant detail and complexity under cover. Basement geophysical domains were interpreted and matched with observations from outcropping areas, water bore logs, seismic data, and recent mineral exploration drilling to tentatively define lithological units and major structures.

## Moving window power spectrum analysis of potential field data: new tools for imaging basement topology and stratigraphy in the Sydney Basin

Philip McClelland
*Ultramag Geophysics Pty Ltd*

The radial power spectrum of potential field data can be used to extract geological contacts and interfaces. Long wavelengths are associated with deeper targets. Models concentrate on the tops of a continuum of equi-sized vertical prisms, with unlimited depth extent. The method minimises many of the ambiguities inherent in potential field interpretation including target magnetisation/density contrast, location, strike and size. The target becomes an interface that is well suited to sub-horizontal stratigraphic mapping in sedimentary basins. The Moving Window Power Spectrum Analysis (MWPSA) overcomes earlier shortcomings. Preliminary work indicates up to 6 surfaces can be mapped in the Bowen Basin with the deepest surface at 1200 m depth. Uses include both academic and commercial purposes.

## Mapping the architecture of sandstone-hosted uranium mineral systems in the Callabonna sub-Basin, Lake Frome region, using regional-scale airborne electromagnetic (AEM) data

Ian Roach, Subhash Jaireth and Marina Costelloe
*Geoscience Australia*

The Frome airborne electromagnetic (AEM) survey covers a large number of sandstone-hosted uranium deposits associated with paleodrainage systems flowing from uranium-enriched Proterozoic rocks of the Curnamona Province. Interpretation remaps paleovalley systems in the southern Lake Frome area, pointing to possible new uranium discoveries adjoining the survey area to the east and new paleodrainage systems to the north of the Flinders Ranges associated with sandstone-hosted uranium discoveries.

## The giant Lachlan orocline: Where? When? How? Why? And some economic implications for eastern Australia

Ross Cayley and Robert Musgrave
*Geoscience Victoria and Geological Survey of NSW*

NSW aeromagnetic data reveals a giant oroclinal fold superimposed on the northern Stawell Zone. Relationships between Victorian LFB 'zones' mean that this unfolding must cascade zone-by-zone far into the eastern LFB, only halted at the Melbourne Zone–Tabberabbera zone boundary in the early Devonian. Palinspastic restoration results in a narrow, linear, accretionary LFB with a single arc – the Macquarie Arc – active along east Gondwanaland in the Ordovician. Explaining LFB evolution through the Silurian–Devonian to its present complex configuration requires a new geodynamic model. In the Late Ordovician, the Macquarie Arc subduction–accretion system transitioned into convergence as a micro-continent – Vandieland –entered its southern end. The Benambran Orogeny was the result, extinguishing the Macquarie Arc and forming the LFB.

## Testing the Tasmanide oroclines

Robert Musgrave
*Geological Survey of New South Wales*

Arcuate structural elements are present throughout the assemblage of late Neoproterozoic to Paleozoic orogens that constitute the eastern Australian Tasmanides. An orocline has been proposed within the Thomson Orogen of northern Queensland and repetition of tectonic terranes in the southern part of the Lachlan Orogen has been recognised for many years after advances in filtering of aeromagnetic data allowed structures to be traced below thick post-tectonic cover. Paleomagnetic declinations from the southern New England Orogen, when expressed as anomalous declinations relative to the Gondwana polar wander path, yield a positive but incomplete orocline test. The circular distribution of paleomagnetic poles from the Nackara Arc provides a positive orocline test (m = 0.97) for this part of the Cambrian Delamerian orocline. An isolated Silurian pole from the northern Thomson Orogen can be reconciled with the Gondwana polar wander path by removal of the proposed North Queensland orocline. Preliminary paleomagnetic results from Cambrian basement on the limbs of the western ('Boosey') fold of the Lachlan orocline also pass the orocline test (m = 1.02).

## Remanence anomalies in the western Tasmanides

Robert Musgrave
*Geological Survey of New South Wales*

Prominent negative 2D aeromagnetic anomalies occur at several locations across the western Tamanides. Inversion of the anomalies suggests a uniform reversed polarity remanence direction. Negative anomalies in the Stawell gold field of Victoria are associated with mineralised meta-turbidites. Magnetic petrophysics of samples from the Stawell gold field establishes that the remanence is carried by a population of pyrrhotite with a high remanence stability. This pyrrhotite population is associated with zones of fluid expulsion during early Silurian Benambran deformation, a process also resulting in gold endowment. Negative 2D anomalies in the Cobar–Bourke region are also associated with zones of concentrated deformation of meta-turbidites during latest Ordovician to early Devonian orogeny. Anomalies sourced in rocks of the Stawell gold field and the Girilambone Group near Cobar both invert to yield remanences corresponding to a paleomagnetic age in the Silurian to early Devonian. Magnetic overprinting driven by fluid expulsion due to late Ordovician through early Devonian compression of marine sediments appears to characterise the western Tasmanides, and remanent anomalies produced by this mechanism may be useful indicators of mineralisation.

## Structure and geometry of the Fraser Zone, east Albany-Fraser Orogen

Lucy I Brisbout, Catherine C V Spaggiari and Alan R A Aitken
*Geological Survey of Western Australia, University of Western Australia*

Structural analysis and forward modelling of potential field data from the 425 km long, 50 km wide, Mesoproterozoic, meta-gabbro-dominated Fraser Zone in the east Albany-Fraser Orogen has led to new interpretations of its structural architecture. Interlayered gabbro–granite sheets intruding Archean–Paleoproterozoic crust were deformed under granulite facies conditions shortly after *c* 1290 Ma, during Stage I of the Albany-Fraser Orogeny. High resolution aeromagnetic data and field-based structural information shows that the Fraser Zone can be divided into domains that are dominated by regional-scale, northeast-trending tight to isoclinal folds, and domains that contain northeast trending dextral shear zones. The Fraser Zone is also host to the recently discovered Nova-Bollinger Ni–Cu deposit, which coincides with a structural feature defined in aeromagnetic data known as 'The Eye', one of several similar features throughout the Fraser Zone that have sigmoidal geometries. A long wavelength (~150 km) gravity anomaly to the southeast of the Fraser Zone is interpreted as a sill-like body of mafic–ultramafic material.

## Magnetotelluric survey across central Australia: new constraints on lithospheric architecture

Stephan Thiel, Martin Hand, Alan Oertel and Kate Robertson
*University of Adelaide*

Meso and Paleoproterozoic crust in Central Australia record Grenvillian-aged (*c* 1200–1100 Ma) events. A 350 km long north–south MT profile with 26 long-period (LP, 10–10 000 s periodicity) MT stations was deployed in July 2013 along the Stuart Highway from the SA–NT border to c 100 km north of Alice Springs. To the south, the profile crosses the eastern part of the Musgrave–Albany Fraser Orogen and extends across the Amadeus Basin into the Arunta region north of the Redbank Shear Zone. The LP profile connects to the Goma MT line in South Australia, significantly extending the profile to more than 500 km. Horizontal magnetic transfer functions at longer periods (>100 s) of the LP data sense conductive features oblique to the profile and are likely related to sediments to the east. For periods below 100 s, the horizontal magnetic transfer functions are primarily related to the east–west trending shear zones, visible from potential field data. The significant step functions in the gravity data of the E–W aligned orogens are also visible in the phase tensor representation of the LP MT data along the 350 km N–S profile.

## Heat flow in the northern Officer Basin, Central Australia

J Schulz, M Hand, G Baines and B Bendall
*University of Adelaide, and Department for Manufacturing, Innovation, Trade, Resources and Energy South Australia (DMITRE)*

The Neoproterozoic to Paleozoic northern Officer Basin overlies the interface between the Paleoproterozoic northern Gawler Craton and the predominantly Mesoproterozoic Musgrave Albany Fraser Orogenic System (MAFOS). Heat flow measurements have been obtained from drill holes. Areas of the northern Officer Basin underlain by MAFOS lithosphere have heat flow typically around 60 $mWm^{-2}$. Regions of the basin that appear to be underlain by northern Gawler Craton lithosphere are characterised by heat flow values of 80–100 $mWm^{-2}$. This is consistent with heat flow in the South Australian Heat Flow Anomaly. Heat flow over the interface between the MAFOS lithosphere and the Gawler Craton is similar to the eastern Gawler Craton, in contrast with other geophysical studies that suggest this lithosphere may have more in common with the MAFOS. Comparatively 'normal' heat flow in MAFOS lithosphere could reflect deep levels of late Grenvillian orogenic denudation that removed heat production from the upper parts of the crust. Alternatively low heat flow in the younger MAFOS lithosphere may point to a different development from the older and higher heat flow regions of lithosphere to the north and south.

## Heat flow in southern Australia: implications for geothermal energy

Michael Dello-Iacovo, Henry Johnson, Derrick Hasterok, Martin Hand and Bendall Betina
*University of Adelaide and Department of Manufacturing, Innovation, Trade, Resources and Energy, South Australia, Adelaide*

The South Australian Heat Flow Anomaly (SAHFA) has a low average elevation in relation to its heat flow, which at some sites exceeds 120 $mW/m^2$, suggesting that the heat flow is not associated with mantle related heating but rather high crustal contents of U and Th of granitic rocks. This is consistent with the large concentration of high heat producing radiogenic elements (HHPRE), sharpness in the spatial distribution of heat flow, and a low level of correlation with seismic activity associated with the individual heat flow anomalies. However, the widespread extent of the SAHFA suggests that upper crustal granites alone are not the overall cause of the elevated crustal heat flows suggesting that the SAHFA may be underlain by compositionally anomalous lithospheric mantle. This work has allowed the delineation of new geothermal energy targets in South Australia, potentially reducing the reliance on non-renewable energies and opening the pathway for a new industry.

## Giles, complex magnetism

*James Austin*, Dean Hillan, Phil Schmidt and Clive Foss
*CSIRO and Magnetic Earth*

The geophysical characteristics of the Giles Complex are poorly known, but have received renewed interest since discovery of the Nebo-Babel Ni–Cu–PGE deposit. Magnetic field data are a major mapping tool over this vast area of poor exposure. Remanence can be highly stable, lasting millennia, through to highly unstable, acquired at low temperatures in the present field, or during drilling. Some lithologies, e.g., Kalka Intrusion cumulates have >50% magnetite, associated with very high magnetic susceptibilities (e.g., >1 SI). However, remanence is very soft and held in multidomain magnetite. Others, e.g., Mount Harcus, have high intensity (up to 200 A/m) and very stable remanence in lamellar interfaces between hematite and ilmenite exsolution. Pyrrhotite may also be the primary remanence holder in some circumstances, e.g., graphitic zones of the Pallatu Intrusion. Knowledge gained from rock magnetic studies can elucidate characteristic remanent magnetisation vectors for specific rock suites, which are integrated with automated techniques, to map mafic suites. The remote identification of specific mafic suites, based on their characteristic magnetisation directions can be used to refine areas that are prospective for magmatic Nickel PGE mineralisation.

## A new paleomagnetic study of the Warakurna large igneous provence: the Giles Complex, Musgrave Ranges, Central Australia, and Earoo area, Yilgarn Craton, Western Australia

Phillip Schmidt and James Austin
*MagneticEarth and CSIRO*

Paleomagnetic investigations of the Giles Complex, Central Australia and the Earoo intrusion, Yilgarn Craton, repeat the observed ~40° difference in declination between the Alcurra Dolerite from the Musgrave Block (Northern Australian

Craton, NAC) and the Bangemall Basin Sills (Western Australian Craton, WAC) providing more evidence for a Neoproterozoic rotation between the WAC and the NAC.

## Paleomagnetics of the Paleozoic Lachlan Orogen: implications for its tectonic evolution and the existence of an orocline

Michael Tetley, Phillip Schmidt, Simon Williams, R. Dietmar Müller and Robert Musgrave
*University of Sydney and CSIRO*

Key paleomagnetic poles from the Lachlan Orogen, required to constrain the tectonic relationships between southeastern and cratonic Australia prior to *c* 400 Ma, remain incompatible with cratonic poles. In this study two new early Paleozoic paleomagnetic poles are established from previously unsampled Cambrian basalts in northern Victoria. Results were used to re-evaluate the previous paleomagnetic studies within the Lachlan and establish the geographical location for the previously unconstrained central Lachlan at *c* 500 Ma. Through tectonic reconstructions using the *GPlates* software, the relationship between the central Lachlan, eastern Lachlan/Molong-Monaro terrane, and cratonic Australia from *c* 500–400 Ma was established, providing a new allochthonous Lachlan tectonic evolution model for this period. Fisher statistical analysis indicated that magnetisation occurred prior to ~100° of rotation. This suggested that the geological units sampled at each location formed a continuous approximately north–south trending unit between the Cambrian and the Silurian, consistent with published accretionary models and the orocline model.

## Pre-competitive minerals activities in the southern Thomson Orogen: unlocking the region's hidden resource potential

Richard Blewett
*Geoscience Australia*

The southern Thomson Orogen is true 'greenfields' country although the mineral potential of the region is largely unknown. Collection of pre-competitive data is well advanced in its first stage. A revised solid geology map will form the basis of a 3D model (map). In support of the 3D map, a programme of geophysical acquisition, processing and interpretation is under way. These datasets include: airborne electromagnetic (data acquisition and processing underway), broad-band magnetotelluric and gravity data (both in advanced planning stage). Datasets will be released throughout the project, with the final results delivered to industry in 2016–17.

## The Nullarbor: first images of the Eucla-Gawler deep seismic reflection line (13GA-EG1)

Richard Blewett, Ian Tyler, Steve Hill, Brian Kennett and Tanya Fomin
*Geoscience Australia, Geological Survey of Western Australia, Geological Survey of South Australia, AuScope*

The Eucla–Gawler deep seismic reflection line (13GA–EG1) forms the 'missing piece' in a now complete east–west transect of the continent. The Eucla–Gawler region (Nullarbor Plain) is a major geological frontier, with very little information available on the subsurface geology. The region lies between the Yilgarn Craton to the west and the Gawler Craton to the east, however, the extensive sedimentary cover associated with the Eucla Basin has led to the bedrock underlying this region being very poorly represented and understood. Unmigrated field stacks of the full crustal sections (20 second two-way-time) were presented answering some of the geological unknowns.

## Crustal electrical resistivity heterogeneity: a vector to mineralisation?

Graham Heinson, Stephan Thiel and Paul Soeffky
*University of Adelaide*

Magnetotellurics (MT) can image entire mineralising systems in three-dimensions effectively frozen in place, from the base of the crust and uppermost mantle to the near surface, and from reduced to oxidised conditions. From an array of ~200 long-period MT sites spaced about 10 km apart, we present new 3D crustal resistivity models of the eastern Gawler Craton and Stuart Shelf covering an area approximately 300 km by 100 km, and to a depth of 50 km. The resistivity models image an extensive conductive cover sequence, but also show large variations at mid and lower crustal depths. The Achaean core of the Gawler Craton is electrically resistive (>1000 Ohm.m), while Proterozoic basement beneath the Stuart Shelf is two to three orders of magnitude more conducting. Major mineral deposits, including Olympic Dam and Carapateena, are coincident with the maximum gradients in mid and lower crustal resistivity. The newly collected data provide much higher resolution of upper and mid-crustal resistivity than have been seen before, and have been integrated with existing 5 km spaced long-period MT data over 200 km. Conductive pathways are imaged through the resistive basement, connecting the highly conductive surface sediments with a large conductive zone at approximately 20 km depth. The conductive heterogeneity of the crust is proposed to help constrain region of potential mineralisation, and indicates that such conductive upper-crustal pathways may be a vector to mineralisation.

## The Granites-Tanami Orogen subsurface geometry as revealed by an integrated potential field geophysical and geological study

David Stevenson, Leon Bagas and Alan Aitken
*The University of Western Australia*

The Granites-Tanami Orogen (GTO) is a Paleoproterozoic terrane on the southern margin of the North Australian Craton (NAC), which was inverted, deformed and intruded during amalgamation of the Kimberley and Tanami basins to form the NAC and later amalgamation of the NAC with the Central Australia Craton. We use combined gravity and magnetic interpretation together with structural outcrop mapping to reveal mechanisms and structural complexities. The regional $D_{GTO1}$ event resulted in N to NE trending isoclinal fold trains ($F_1$) of the Tanami Group with wavelengths ≥10 km. $F_1$ folds are recognised through the joint interpretation of gravity and magnetic anomalies. In outcrop, $D_{GTO1}$ is recognised as isoclinal folds ($F_1$) with a strong axial planar fabric ($S_1$). $D_{GTO2}$ is recognised in regional aeromagnetic data as poly-phase deformational interference figures caused by the refolding of $F_1$ folds.

On the outcrop scale, $F_2$ is recognised as two end members: a strongly developed ESE-trending axial planar fabric, and an ESE-trending axial planar cleavage crosscutting $S_1$. $D_{GTO1}$ preceded the emplacement of granitic plutons, whereas $D_{GTO2}$ was broadly coeval with granitic emplacement. Both deformation events represent thin-skinned folding of the Tanami Basin stratigraphy accompanying collision with the Kimberley Craton along the Halls Creek Orogen to the NW during *ca* 1850 Ma to form the NAC, and collision of NAC with the Arunta Orogen in the Central Australian Craton to the south during the *ca* 1800 Ma $D_{GTO2}$.

## A geological perspective on AEM interpretation for mineral exploration in a regolith dominated terrain: the SE Yilgarn Craton margin/Albany-Fraser Orogen, Western Australia

Ignacio González-Álvarez, Alan Yusen Ley-Cooper and Walid Salama
*CSIRO*

This study examines the implications of groundwater salinity on airborne electromagnetic (AEM) interpretation in the Albany-Fraser Orogen (AFO). Study Area 1 in the northeast AFO and Study Area 2 in the west central AFO have salinities of <3,000 mg/L and >35 000 mg/L, respectively. AEM datasets were processed using a sample-by-sample 1D layered earth inversion algorithm. In Study Area 1 AEM suggested regolith thickness from ~5 m to ~60 m, compared with up to ~70 m from field observations. Drilling information and EM interpretation are consistent. Transported cover varies from 2–25 m in thickness, and the *in-situ* saprolite ranges between 22 and 70 m. The total thickness of the transported cover fits the AEM interpretation of the less conductive unit at the top of the profiles. This unit corresponds mainly with aeolian sands above cemented lateritic sands and gravels. *In-situ* regolith is divided into three units (1) lower saprolite; (2) silcrete; and (3) sandy kaolinitic upper saprolite. Unit (2) has very low conductivity and mimics the EM response of the transported cover. Drilling and field observations were essential to estimate the thickness of the transported cover. In Study Area 2 high salinity is associated with the confluence of large paleochannels. In saline groundwater conditions the depth of AEM penetration is limited, as is its ability to discriminate between regolith units. However, the boundary between resistive basement and regolith is still resolvable, and packages of permeable sediment are well defined.

## Geophysical imaging of Great Artesian Basin mound springs

Graham Heinson, Kent Inverarity and Michael Hatch
*University of Adelaide*

The deep structure and relationship to faulting of artesian mound springs along the southwestern edge of the Great Artesian Basin (GAB) is not well understood. Self potentials show a pattern of larger voltages at spring vents and seeps caused by narrow, upwards flow paths beneath the springs.

Modelling of TEM and MT data show slightly more resistive areas underneath springs and spring complexes at a depth range of tens to hundreds of metres. Magnetotelluric anisotropic-modelling shows that fault zones exist under many of the mound springs suggesting that fluids may be sourced from the aquifer and deeper layers. We conclude that a combination of electrical geophysical methods can play a significant role in mapping complex groundwater dynamics in sedimentary environments.

## Hydrogeophysical data acquisition strategies for near-surface hydrogeological investigations in the Australian landscape context

K C Lawrie, N B Christensen, L Halas, Ross S Brodie, J Magee, Kokpiang Tan and J Clarke
*Geoscience Australia and Aarhus University*

Airborne electromagnetics (AEM) provides a rapid cost-effective means of mapping relatively large, hydrogeologically complex areas of salinity to depths of 200–300 m. For the Broken Hill Managed Aquifer Recharge (BHMAR) project the SkyTEM AEM system was chosen to map groundwater quality (salinity) distribution within a multi-layered sequence of sand and gravel aquifers and clay aquitards to depths of ~120 m within unconsolidated sediments of the Murray Basin . Utilising a flight line spacing of 200–300 m, the AEM data successfully mapped the key elements of the hydrostratigraphy, critical Neogene-to-recent tectonic features, and 14 potential MAR and groundwater resource targets.

## Imaging the regolith with full waveform refraction seismology

Derecke Palmer, Paul Lennox and Martin Van Kranendonk
*The University of New South Wales*

Traditional methods for processing near surface seismic refraction data have focussed almost exclusively on the use of scalar travel times. In recent decades, refraction data processing has employed model-based inversion, also known as refraction tomography. Automatic implementations of refraction tomography usually employ low-resolution 1D starting models. Usually, the resulting tomograms exhibit low resolution. This study demonstrates that full waveform near surface seismic refraction methods are able to generate significantly higher resolution images. The images are similar to the more familiar seismic reflection images, routinely employed in the study of deeper targets. Accordingly, they are well suited to the application of the substantial range of seismic reflection processing and post-processing methods. A major advantage of the full waveform refraction images is that they exhibit events from below the base of the weathering. These events facilitate the generation of more useful structural models. Furthermore, the full waveform images demonstrate the occurrence of multiples generated with the weathered layer. These multiples offer the possibility of more detailed delineation of layering within the weathering, especially for groundwater investigations, using seismic interferometry.

## The frequency-dependent seismic properties of cracked and fluid-saturated rocks: insights from the laboratory and modelling

Yang Li, Heather Schijns, Emmanuel C David, Douglas R Schmitt and Ian Jackson
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Frequency dependence of seismic wavespeeds in cracked and fluid-saturated crustal rocks complicates the use of laboratory wavespeed measurements in seismological interpretation. The dispersion results from the relaxation of spatial gradients in pore-fluid pressure by fluid flow for low frequencies. The solution lies in laboratory measurements of elastic wavespeeds or corresponding moduli on cracked media over an appropriately frequency wide range. Conventional measurements with MHz wave propagation methods are complemented by subresonant forced-oscillation techniques that provide access to mHz–Hz frequencies. Ultrasonic and forced oscillation measurements of thermally cracked low-porosity specimens of natural quartzites and sintered aggregates of glass beads, tested dry or with argon or water saturants, show systematic increases in wave speeds/elastic moduli with increasing confining or differential pressure, and clear evidence of dispersion between Hz and MHz frequencies. Pressure dependent elastic properties of the cracked media have been modelled with differential effective medium theory. Crack density is first inferred from the modulus deficit for the dry specimen at each pressure, and the pressure dependence of the inferred crack density provides information concerning the distribution of crack aspect ratios. Finally, the calculated influence of fluid saturation of the inferred crack microstructure supports the attribution of the dispersion, observed between Hz and MHz frequencies, to local 'squirt' fluid flow.

## Small fault identification through seismic diffraction imaging

Binzhong Zhou, Weijia Sun and Peter Hatherly
*CSIRO, Chinese Academy of Sciences and Coalbed Geoscience Pty Ltd*

An unexpected small fault with a throw of a few metres can create safety issues and lead to costly delays in production in coal mines. Reliable techniques for resolving these minor faults are yet to be developed. Two types of seismic energies that can be used for subsurface imaging are specular reflections of conventional seismic surveys and diffractions. Numerical examples of diffractions illustrate that they can be used to identify faults with a throw of 1m, even in a moderately noisy environment and when the migration velocities are not accurate. In addition, there is an opportunity to extract the diffraction signals from existing final stacked seismic sections without the need for extensive reprocessing.

## Scope to predict soil properties at field scale from small samples using proximally sensed gamma ray spectrometer and EM induction data

Jingyi Huang, Murray Lark and John Triantafilis
*The University of New South Wales and British Geological Survey*

Costs associated with soil sampling and laboratory analysis are substantial. Two approaches to reduce costs are to either use classes from ancillary data or use a simple predictive linear model of the target soil property on the ancillary variables. We use proximally sensed gamma-ray spectrometry and electromagnetic induction (EMI) data to predict the variation in topsoil clay content and pH. The proximal data is numerically clustered using a fuzzy k-means (FKM) clustering algorithm to identify contiguous classes. The resultant digital soil maps, k = 2–10 classes, are consistent with a soil series map generated using traditional soil profile description, classification and mapping methods at a highly variable site near Shelford, Nottinghamshire UK. A linear mixed model (LMM) is fitted but the residuals are treated as a combination of a spatially correlated random effect and an independent and identically distributed error. In terms of prediction, the expected value of the mean squared prediction error suggested that the regression models were able to predict clay content better than FKM clustering but the reverse was true with respect to pH. We conclude that both methods have merit.

## Rock magnetic signature of gas hydrate in deep marine sediments of the Peruvian margin

Marta Vega and Robert Musgrave
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Gas hydrate has been identified in nature by indirect evidence through drilling or seismic data. The base of the hydrate zone is usually defined by a bottom simulation reflection (BSR), which results from a seismic velocity contrast between overlying, higher-velocity sediment containing gas hydrate and underlying sediments containing free gas. Rock magnetic techniques were shown to be effective proxies for the presence of gas hydrate on Ocean Drilling Program (ODP) legs through the detection of greigite and pyrrhotite. Coordinated rock magnetic and microbiological studies confirmed a characteristic rock-magnetic signal expressed as the index DJH, which is a reliable indicator not only of the present distribution of gas hydrate, but of past accumulations in cases where the hydrate zone has migrated. Plots of DJH show characteristic inflections both at the modern base of hydrate stability, and at past still stands of the base of the hydrate zone marked by seismic 'fossil BSRs'. Hydrate-bearing sediments from the lower slope of the Peru Trench show DJH gradually increases with depth through the upper parts of the gas hydrate stability zone. Intervals with higher values of DJH correlate well with recovery of gas hydrates in cores and lower pore-water chlorinity values. Like other sites known to have a 'fossil BSR', an additional, similar but stronger response is seen at Site 688 about 60 m below the modern BSR. At the Cascadia Margin sites sampled during legs 146 and 204, this lower inflection in DJH was inferred to be the position of the base of gas hydrate stability at the end of the last glacial. In the Peru Margin this feature is interpreted in the same way.

## Magnetic minerals, phase interfaces and magnetic anomalies

Suzanne McEnroe and Peter Robinson
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Magnetic anomalies are measured over many length scales and at elevations ranging from near surface to satellite heights. Parts of the continental crust have preserved excellent magnetic records, some for billions of years. Today, many 'remanent' magnetic anomalies reflect the time and global position of the initial acquisition of remanent magnetisation. Some minerals responsible for remanent anomalies carry a new interface-based remanence type,

## News

'lamellar magnetism' (LM), discovered in rocks containing finely exsolved (microns to nm) members of the rhombohedral hematite–ilmenite series. Rocks containing LM commonly have a strong, or dominant, remanent component to the anomaly.

### Peculiarities and problems in the remanent magnetisation of rhombohedral Fe–Ti oxides

Peter Robinson and Suzanne A McEnroe
*Geological Survey of Norway and University of Science and Technology Trondheim*

Strong remanent magnetisation commonly has two sources. In ordered metastable ferri-ilmenite solid solutions Ti substitution in alternate layers causes unequal and opposite moments, and strong ferrimagnetism. Quenching and annealing from high-*T* toward order, brings the material through transitory states with antiphase domain microstructures causing magnetic self-reversal. Fully ordered metastable ferrimagnets cannot survive slow cooling in deep-seated igneous and metamorphic environments, and will be replaced by ilmenite hosts with hematite exsolution lamellae (hemo-ilmenite) or hematite with ilmenite lamellae (ilmeno-hematite). Beginning in 2002, investigations show there is a substantial remanent moment related to contacts between exsolution lamellae and hosts, produced by Fe-enriched single 'contact layers' parallel to (001). Contact layers on both sides of a hematite lamella, or at both sides of an ilmenite lamella within a magnetised hematite host, have identical magnetic moments in the same direction, producing an 'uncompensated spin' in one direction creating a strong lamellar remanence.

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# Government R&D investment stagnates as percentage of GDP

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Australian Governments' total Research and Development investment in 2012–13 increased from $3.55 billion in 2011–12 to $3.73 billion, according to data released by the Australian Bureau of Statistics (ABS) in July 2014 (*8109.0 – Research and Experimental Development, Government and Private Non-Profit Organisations, Australia, 2012–13).* The dollar increase has been steady since the ABS started collecting these data in 1992–93. In that year the States, Territories and the Commonwealth invested a total of $1.82 billion on R&D.

Unfortunately, the investment on R&D as a percentage of GDP has been declining steadily over the same period. As shown in Figure 1, it has declined from 0.41% in 1992–93 to 0.24% in 2012–13. The general downward trend appears to be independent of whether a Labor or a Coalition government was in power federally.

The downward trend is disturbing because as science and technology becomes more important in our lives one would have hoped that the investment by governments in research and development would at least have kept pace with the growth in GDP. It is not reasonable to expect businesses to invest in long term basic research – that should be the responsibility of governments.

## Business spending on R&D also stagnates

The results from the business sector show a similar trend. The latest release by the ABS (*8104.0 – Research and Experimental Development, Businesses, Australia, 2011–12)* published in September 2013 shows that business investment has plateaued at about $18 billion from 2010 to 2012 and the percentage of GDP has fallen steadily from a maximum of 1.38% in 2008–09 to 1.24 in 2011–12 (see Figure 2). This is not an encouraging trend.

The total annual R&D investment in Australia is only published every other year because of limited resources in the Australian Bureau of Statistics. Just about every other OECD country publishes annual returns; even Estonia, Portugal and Slovak Republic publish annual data sets.

We are supposed to be an advanced 'Developed' country. It is time for governments to properly resource national institutions like the ABS. After all, everybody uses its data for economic planning.

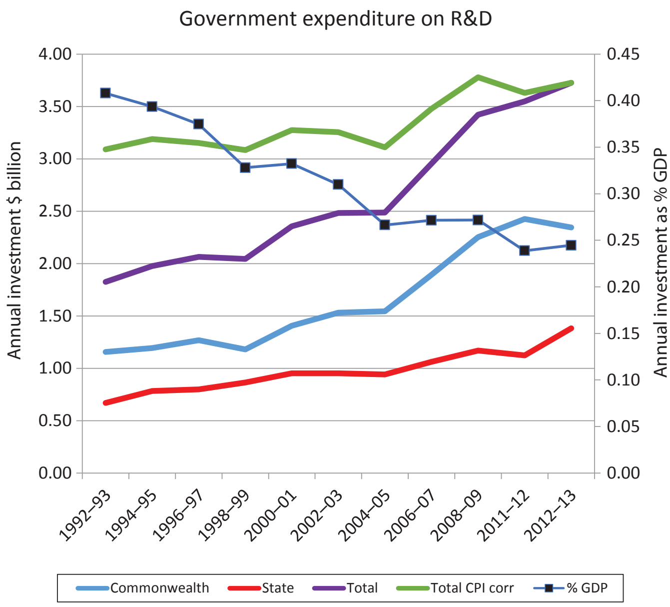


**Fig. 1.** *Trends in Australian governments' R&D investment from 1992–93 through 2012–13. The red curve shows the actual $s invested by the States and Territories; the blue curve shows the results for the Commonwealth; the green curve is the sum of the red and blue curves; the purple curve shows the CPI adjusted data from the green curve, normalised to 2012–13 dollars; and the blue curve with black data points shows the total investment as a percentage of GDP. The biannual data release period was changed between 2009 and 2011.*

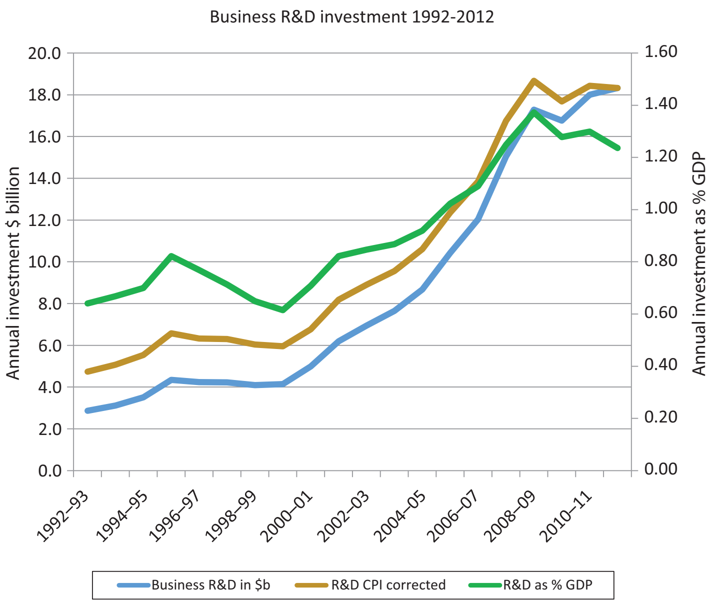


**Fig. 2.** *Trends in Business R&D investment from 1992–93 through 2011–12. The blue curve shows the actual $s invested; the brown curve shows the CPI adjusted data in 2011–12 dollars; and the green curve shows the investment as a percentage of GDP.*

# Mineral exploration continues to decline; petroleum remains steady

## Minerals

Mineral exploration, which peaked in the March quarter of 2012, continues to decline. According to figures released by the Australian Bureau of Statistics in March 2014 (*8412.0 - Mineral and Petroleum Exploration, Australia, Mar 2014)*, the trend[1] estimate of mineral exploration expenditure for the whole of Australia fell (from the December quarter) by $44.2 million (8.3%) to $487.7 million. This is 34% lower than the March 2013 trend estimate.

Figure 1 shows mineral exploration levels from 1986 through March 2014. It indicates that the recent peak has well and truly been passed and the level of expenditure is now lower than it has been since December 2006.

Western Australia took the brunt of the decline with a trend fall of $44.8 million or 14.9%.

However, 50.5% of Australia's mineral expenditure takes place in Western Australia, so it is well and truly still the Premier State for minerals.

[1]The trend estimate is the smoothed seasonally adjusted estimate.

By commodity, in original terms, the largest fall was in iron ore, down by 37.5% or $69 million; followed by gold exploration, which dropped by 29.9% to $34.8 million. These are the lowest figures since 2007 (for iron ore) and 2002 (for gold).

Falls were reported in both green field areas (down 31% or $54 million) and around existing deposits (down 23% or $85 million).

Perhaps the only bright spot was in New South Wales, which recorded an increase of $6.3 million to $40.7 million, due to increased interest in copper and coal.

It is unfortunate that the major resource companies are not able to smooth out the exploration trends we have experienced over the past 10 years. It does not help them in recruiting the brighter students in the geosciences, when the exploration trends are so erratic and long term employment so uncertain. But that's another story.

## Petroleum stays steady

In contrast to the minerals sector, the level of investment in the petroleum sector has remained almost constant. The trend value actually rose by 0.5% or $5.7 million to $1094 million in the March 2014 quarter.

Exploration expenditure on production leases rose by 10.4%, or $39 million, while expenditure on all other areas fell by 4.3% or $30.8 million.

Figure 2 shows the quarterly petroleum exploration numbers from 1986 through March 2014. Since 2006 the conventional and mainly offshore exploration has dominated, but in the last three years exploration for coal seam gas and shale oil and shale gas has boosted onshore exploration. As a result the onshore/offshore ratio has been at a healthy 40% during the last two years.

Western Australia is also the Premier State for petroleum, reporting a figure of $702 million in the March 2014 quarter. It accounted for 64% of Australia's total expenditure of $1094 million. In 2002 the mineral and petroleum exploration expenditure were approximately the same, in that State, at about $200 million per quarter. Now the petroleum expenditure is almost 3.5 times more than in the minerals sector.

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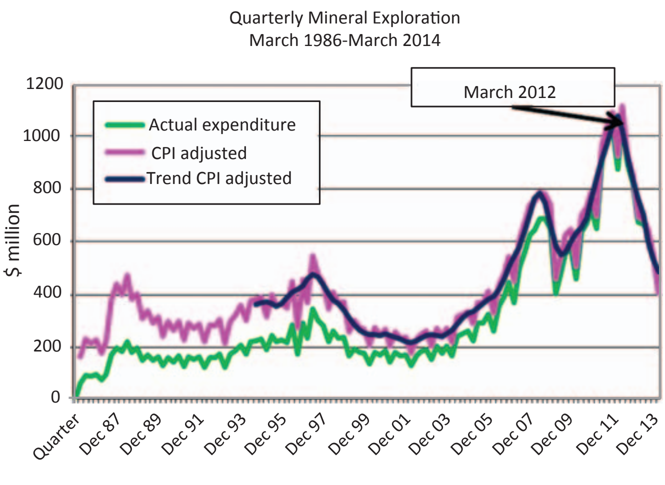


**Fig. 1.** *Actual and trend quarterly mineral exploration investment for the period March 1986 to March 2014. The CPI corrected data have been adjusted to March 2014 Australian dollars. The trend peak in the March quarter of 2012 was $1022.2 million.*

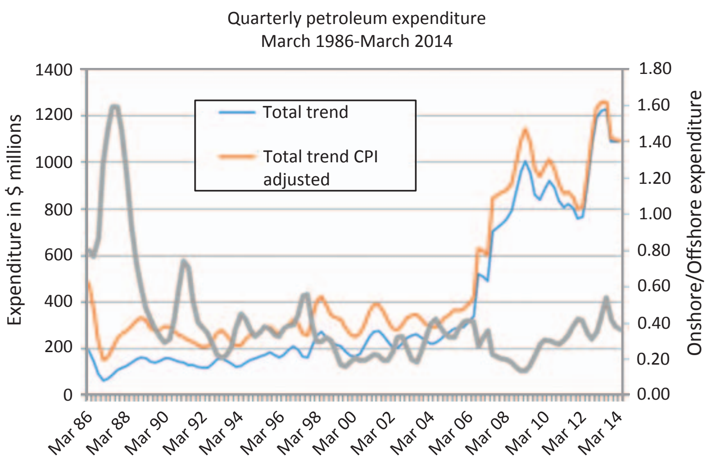


**Fig. 2.** *Quarterly petroleum exploration from March 1986 to March 2014. The CPI corrected data have been adjusted to March 2014 Australian dollars. Notice how the onshore exploration has remained at about 40% over the last two years.*

# Award of 10 new offshore petroleum exploration permits

Ten petroleum exploration permits were granted in May and June from the 2013 Offshore Petroleum Exploration Acreage Release, resulting in more than 375 million dollars being committed to offshore petroleum exploration investment over the next six years.

The areas that have been permitted are in the Otway, Bonaparte, Browse and Northern Carnavon Basins (see Figure 3):

## Otway Basin

**VIC/P69 (released as V13-1)** located offshore Victoria in the Otway Basin was awarded to Origin Energy Resources Limited. Origin proposed a guaranteed work programme of 1500 km 2D seismic reprocessing, geological and geophysical studies, acquisition of 517 km$^2$ new 3D seismic survey, seismic interpretation and prospect assessment totalling over $16.55 million. The secondary work programme consists of geological and geophysical studies including maturing a drilling candidate and one exploration well totalling $31.9 million.

## Bonaparte Basin

**AC/P57 (released as AC13-4)** located offshore Western Australia in the Vulcan Sub-basin of the Bonaparte Basin was awarded to Murphy Australia Oil Pty Ltd and Mitsui E&P Australia Pty Ltd. The joint venture proposed a guaranteed work programme of licencing 114 km$^2$ 3D seismic reprocessing, geological and geophysical interpretation of datasets, 335 km$^2$ 3D PTSM seismic reprocessing and AVO studies totalling $1.15 million. The secondary work programme consists of well planning, geological and geophysical interpretation of datasets, one exploration well and post well geotechnical studies totalling over $60.3 million.

## Browse Basin

**WA-504-P (released as W13-3)** located offshore Western Australia in the Caswell Sub-basin of the Browse Basin was awarded to Santos Offshore Pty Ltd and Inpex Browse E&P Pty Ltd. The joint venture proposed a guaranteed work programme of licensing 80 km$^2$ of 3D seismic data, geological and geophysical studies, including seismic interpretation and updating depositional model with regional data totalling $1.53 million. The secondary work programme comprises acquiring a new airborne gravity and magnetic survey and geological and geophysical studies, including interpretation of gravity and magnetics survey, totaling $1.6 million.

**WA-502-P (released as W13-2)** located offshore Western Australia in the Caswell Sub-basin of the Browse Basin was awarded to Santos Browse Pty Ltd and INPEX Browse E&P Pty Ltd. The joint venture proposed a guaranteed work programme of 496.9 km licence caswell mutliclient 3D seismic data, geophysical and geological studies and updating depositional model with regional data, totalling $7.1 million. The secondary work programme consists of one exploration well, geophysical and geological studies including integrating well data and updating prospect mapping and commercial studies totalling $80.6 million.

## Northern Carnarvon Basin

**WA-497-P (released as W13-18)** located offshore Western Australia in the Exmouth Sub-basin of the Northern Carnarvon Basin approximately 75 km west of Onslow was awarded to AWE Australia Pty Limited. AWE proposed a guaranteed work programme of 387 $km^2$ 3D seismic reprocessing – HCA04A 3D seismic survey, 339 $km^2$ 3D seismic reprocessing – west Gorgon 3D seismic survey, 250 km 2D seismic reprocessing, geological and geophysical studies and 400 $km^2$ 3D seismic inversion totalling $1.5 million. The secondary work programme consists of geological and geotechnical studies and two exploration wells totalling $40.2 million.

**WA-498-P (released as W13-10)** located offshore Western Australia in the Dampier Sub-basin of the Northern Carnarvon Basin approximately 163 km north of Karratha was awarded to Santos Offshore Pty Ltd and JX Nippon Oil and Gas Exploration (Australia) Pty Ltd. The joint venture proposed a guaranteed work programme of 80 $km^2$ 3D seismic reprocessing, geological and geophysical studies, including CSEM sensitivity studies and charge and migration modelling and prospect assessment totalling $385 000. The secondary work programme consists of new CSEM survey, geological and geophysical studies and one exploration well totalling $28.3 million.

**WA-503-P (released as W13-11)** located offshore Western Australia in the Dampier Sub-basin of the Northern Carnarvon Basin approximately 90 km north of Dampier in the Northern Carnarvon Basin; was awarded to Neon Energy Limited. Neon proposed a guaranteed work programme of 80 $km^2$ licence broadband 3D seismic, geological and geophysical studies, including seismic interpretation, QI analysis and AVO studies, prospect assessment and well planning, totalling $1.55 million. The secondary work programme consists of one exploration well, geological and petrophysical studies, including post well analysis, totalling $23 million.

**WA-501-P (released as W13-12)** located offshore Western Australia in the Dampier Sub-basin of the Northern Carnarvon Basin approximately 80 km north-west of Dampier was awarded to Carnarvon Petroleum Limited. Carnarvon proposed a guaranteed work programme of collate and interpret all open file seismic data, 80 $km^2$ PSDM 3D seismic reprocessing, biostratigraphy and reservoir studies; interpretation of reprocessed seismic data and petrophysical studies totalling $270 000. The secondary work programme consists of geological and geophysical studies and one exploration well totalling $20.12 million.

**WA-499-P (released as W13-13)** located offshore Western Australia in the Dampier Sub-basin of the Northern Carnarvon Basin approximately 160 km north-northwest of Onslow was awarded to Apache Northwest Pty Ltd. Apache proposed a guaranteed work programme of 890 $km^2$ new broadband 3D seismic data and PSDM processing, geotechnical studies, rock physics/quantitative interpretation and 3D seismic inversion studies and one exploration well totalling $20.4 million. The secondary work programme consists of 650 $km^2$ new broadband 3D seismic survey; PSDM processing and geotechnical studies totalling $6.4 million.

**WA-500-P (released as W13-9)** located offshore Western Australia on the Exmouth Plateau in the Northern

Carnarvon Basin approximately 190 km northwest of Dampier was awarded to Finder No 7 Pty Limited. Finder proposed a guaranteed work programme of geological and geophysical studies, licence/acquisition of 1200 km$^2$ new reprocessed 3D PSDM seismic data and 210 km new 2D seismic data totalling $2.2 million. The secondary work programme consists of 500 km$^2$ 3D QI/reservoir characterisation, geological and geophysical studies and one exploration well totalling $30.5 million.

## 2014 Offshore Petroleum Exploration Acreage Release

The 2014 Acreage Release comprises 30 areas located across four basins; the Bight, Bonaparte, Browse and Northern Carnarvon Basins (see Figure 4). Details about the release areas and their geology are available on http://www.petroleum-acreage.gov.au/2014/release-areas-and-geology. A number of areas in the Northern Carnavon and the Perth Basin that were released in 2013 have been re-released for work programme bidding.

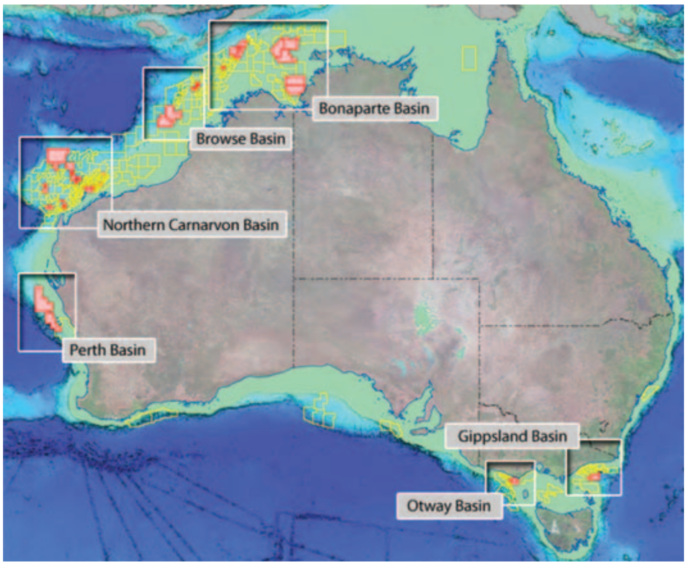


**Fig. 3.** *Acreage released in 2013. Source: http://www.petroleum-acreage.gov.au/.*

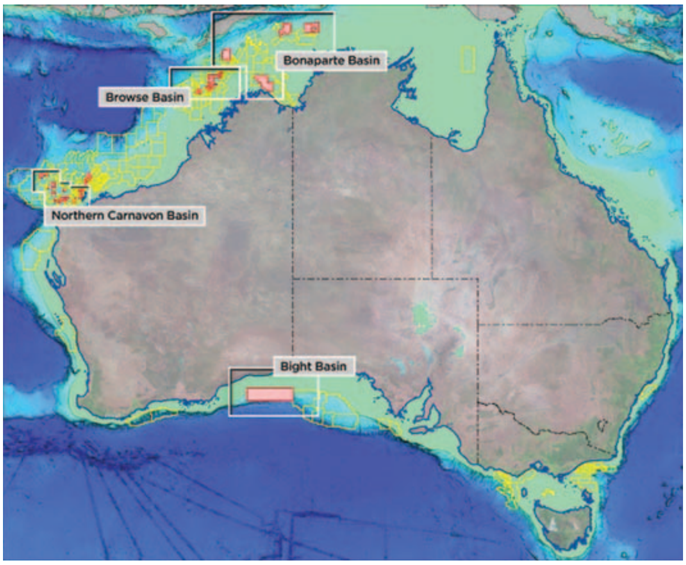


**Fig. 4.** *Acreage released in 2014. Source: http://www.petroleum-acreage.gov.au/.*

# 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 8 July 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). There are three new surveys listed in this issue. The Sir Samuel/Throssel gravity survey (Figure 1) will cover an area of approximately 73 800 $km^2$ with 11 702 stations on a regular 2.5 km grid. The West Amadeus gravity survey (Figure 2) will cover an area of approximately 45 050 $km^2$ with 8127 stations on a regular 2.5 km grid. The quotation request for the North McArthur Basin gravity survey (Figure 3) closed on 29 July. The proposed survey may cover all or part of Arnhem Bay, Gove, Mt Evelyn, Mt Marumba, Blue Mud Bay, Katherine, Urapunga and Roper River standard 1:250 000 map sheets. Further information on these surveys is available from Murray Richardson at GA via email at murray.richardson@ga.gov.au or telephone on (02) 6249 9229.

Table 1. Airborne magnetic and radiometric surveys

| Survey name | Client | Project management | Contractor | Start flying | Line (km) | Spacing AGL dir | Area ($km^2$) | End flying | Final data to GA | Locality diagram (*Preview*) | GADDS release |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kalgoorlie East and Kurnalpi North | GSWA | GA | Thomson Aviation | 5 Aug 13 | 122 000 | 100 m 50 m E–W | Kalgoorlie: 11 000; Kurnalpi N: 11 000 | 100% complete at 15 Mar 2014 | 12 Jun 14 | Issue 165 (Aug 13) p. 11 | Final data released via GADDS on 26 Jun 14 |
| Widgiemooltha North | GSWA | GA | UTS Geophysics | 25 Jul 13 | 92 000 | 100 m 50 m E–W | 8200 | 100% complete at 27 Jan 14 | 12 May 14 | Issue 165 (Aug 13) p. 11 | Final data released via GADDS on 29 May 14 |
| Menzies South | GSWA | GA | GPX Surveys | 28 Nov 13 | 92 000 | 100 m 50 m E–W | 8200 | 100% complete at 16 Mar 14 | 15 May 14 | Issue 165 (Aug 13) p. 11 | Final data released via GADDS on 29 May 14 |
| Kurnalpi South | GSWA | GA | UTS Geophysics | 28 Jan 14 | 92 000 | 100 m 50 m E–W | 8200 | 100.0% complete at 11 May 14 | 13 Jun 14 | Issue 165 (Aug 13) p. 11 | Final data released via GADDS on 26 Jun 14 |
| Coompana | GSSA | GA | TBA | TBA | TBA | Survey design is underway | The proposed survey may cover all or part of Noorina, Wyola, Cook, Coompana, Nullarbor, Ooldea, Maurice, Wells and Birksgate standard 1 : 250 000 standard Map Sheets | | | | |
| Dunmarra | NTGS | GA | GPX Surveys | 28 Jun 14 | 103 985 | 400 m 80 m N–S | 36 280 | 10.2% complete at 6 Jul 14 | TBA | Issue 170 (Jun 14) p. 24 | TBA |
| Yalgoo | GSWA | GA | TBA | TBA | 108 000 | 100/200 m 50 m E–W | Survey not proceeding due to WA DMP budget restrictions | | | | |

*TBA, to be advised.*

## Table 2. Gravity surveys

| Survey name | Client | Project management | Contractor | Start survey | No. of stations | Station spacing (km) | Area (km²) | End survey | Final data to GA | Locality diagram (*Preview*) | GADDS release |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sir Samuel – Throssel | GSWA | GA | IMT | 19 Jun 14 | 11 702 | 2.5 km regular grid | 73 800 | 25% complete at 5 Jul 14 | TBA | This issue | TBA |
| West Amadeus | NTGS | GA | Atlas | 29 Jun 14 | 8127 | 4 km regular grid with areas of 0.5, 1 and 2 km infill | 45 050 | 4.5% complete at 6 Jul 14 | TBA | This issue | TBA |
| Southern Thomson | GA/ GSNSW/ GSQ | GA | Atlas | Est. 12 Jul 14 | 3660 | 8 traverses at 333 m station spacing | TBA | Est. 12 Jul 14 | TBA | Issue 170 (Jun 14) p. 24 | TBA |
| Gippsland | GSV | GA | Atlas | 30 Jun 14 | 1440 | 12 traverses at 500 m station spacing | 8358 | 24% complete at 5 Jul 14 | TBA | Issue 170 (Jun 14) p. 24 | TBA |
| North McArthur Basin | NT | GA | TBA | TBA | 7315 | 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 | TBA | TBA | TBA | This issue | The Quotation Request was released on 8 Jul 14 and closed on 29 Jul 14. The proposed survey may cover all or part of Arnhem Bay, Gove, Mt Evelyn, Mt Marumba, Blue Mud Bay, Katherine, Urapunga and Roper River standard 1 : 250 000 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 13 | 8607 | 300/600 m | TBA | 100% complete at 15 May 14 | Final data to GA 20 Jan 14 | Issue 163 (Apr 13) p. 17 | TBA |
| Capricorn Orogen | GSWA | GA | CGG Aviation (Australia) | 19 Oct 13 | 29 697 | 5 km N–S | 146 300 | 100% complete at 9 Jan 14 | Updated datasets – 28 Apr 14 | Issue 166 (Oct 13) p. 34 | Data released by GSWA on 26 Jun 14 via http://www.dmp.wa.gov.au/14374.aspx#20260, GA released the data on 7 Jul 14 via GA's Discovery and Delivery System http://www.ga.gov.au/search/index.html#/ |
| Southern Thomson Orogen | GA/ GSNSW/ GSQ | GA | Geotech Airborne | 8 Apr 14 | 4198 (3327 in survey and 871 in traverses) | 5 km E–W | 16 270 | 100% complete at 5 May 14 | Additional work (traverses) over the Paroo and Darling Rivers to examine the potential for new groundwater resources was completed on 5 Jun 14. | Issue 168 (Feb 14) p. 24 | TBA |

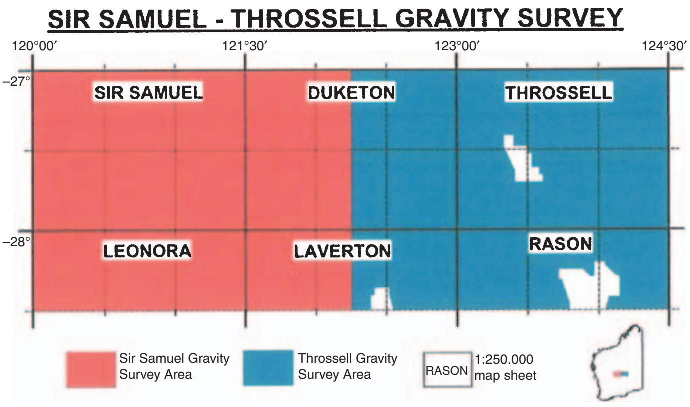


**Fig. 1.** *Location diagram for Sir Samuel/Throssel gravity survey.*

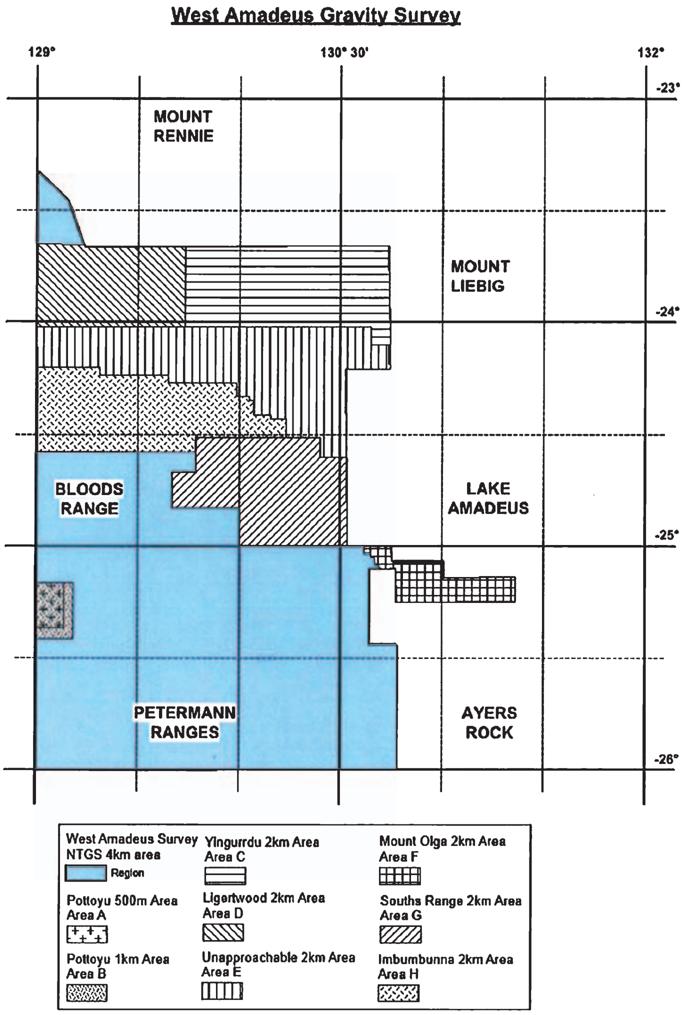


**Fig. 2.** *Location diagram for West Amadeus gravity survey.*

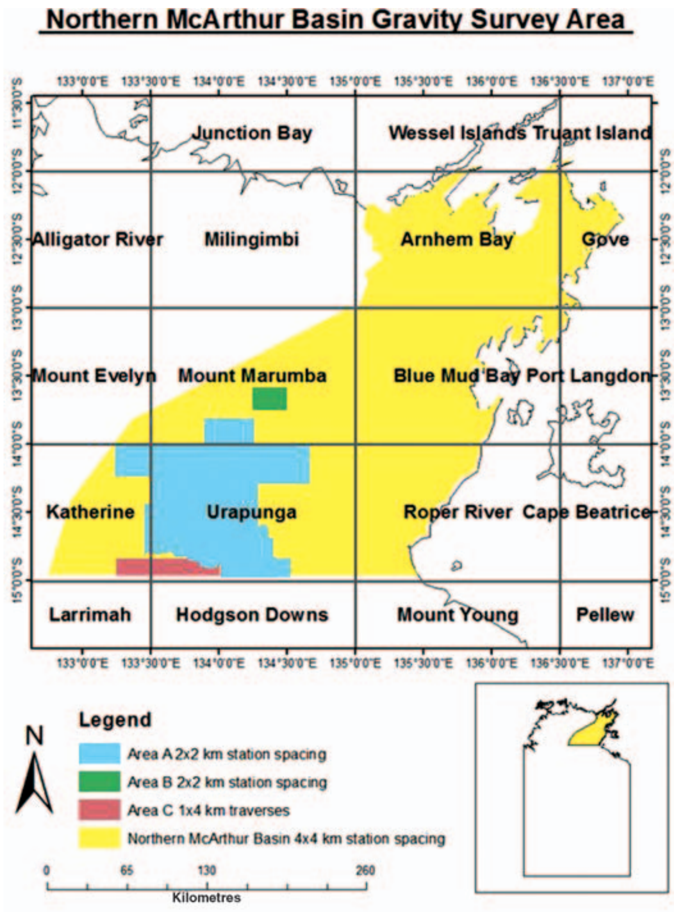


**Fig. 3.** *Location diagram for North McArthur Basin gravity survey.*

# New gravity in the Musgrave Province

A gravity survey conducted in two parts: between 23 August and 5 September 2013, and between 16 and 24 May 2014 was undertaken on the Alcurra, Agnes Creek and Tieyon 1:100 000 map sheets, located in the northwest region of South Australia (Figure 1). This work was performed in conjunction with the ongoing Geological Survey of South Australia Musgrave Province mapping programme. The survey has been designated the code 2014A1 for incorporation into the SA Government geoscience database SA_Geodata, and is now available for download through SARIG.

Prior to this survey, the only gravity data in the area was a regional 7 km by 7 km grid acquired in 1970, plus some recent detailed surveys acquired along the Stuart Highway and Adelaide to Alice Springs railway line. These stations were collected as part of the Gawler-Officer-Musgrave-Amadeus programme.

A Scintrex CG5 Autograv instrument was used for the duration of the survey, and positional information was obtained using a Sokkia GRX1 Real Time Kinematic Differential GPS system.

Samples were taken at 2 km intervals along roads and fences using 4WD vehicles. A total of 821 readings were collected, incorporating 689 new stations, 88 repeats (12.77% repeat rate) and 44 base measurements. The resulting grid incorporating the new data and previous regional data is displayed in the accompanying figure. More information – including the observed data – can be found in a detailed report, available through SARIG (www.sarig.pir.sa.gov.au).

The Geological Survey of South Australia Musgrave Province mapping team plan to continue mapping to the west of the current mapping area and into the Anangu Pitjantjatjara Yankunytjatjara lands. The geophysics team intend to continue collecting gravity data as part of this ongoing programme.

For more information please contact Phillip Heath (philip.heath@sa.gov.au).

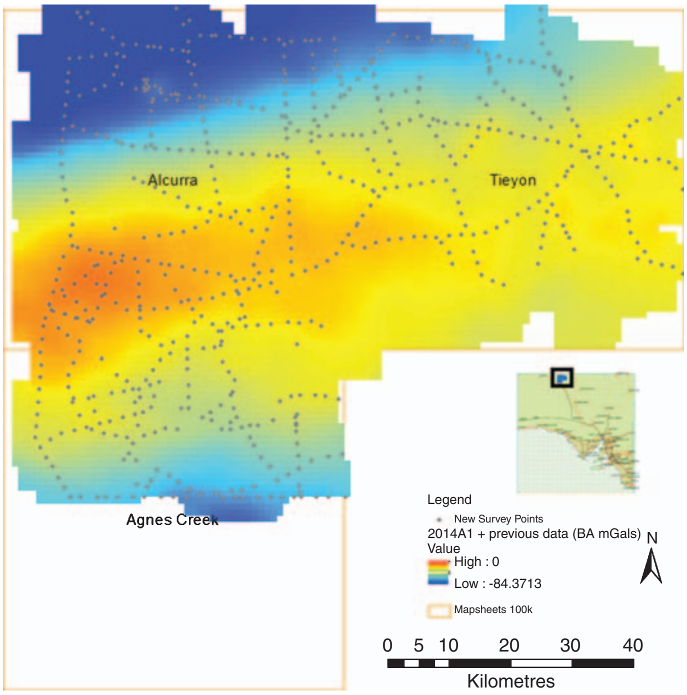


**Fig. 1.** *This new image of the gravity in the Musgrave Province incorporates the new survey data as well as regional data collected in the 1970s.*