



Contents

ISSUE 103 Sept 2011

Editor

Stephen Ross

Graphic Design

Henry Pippin & Daniel Rawson

Web Design

Henry Pippin

Graphics and GIS

Geographics Team

© Commonwealth of Australia 2010

ISSN 1035-9338

Geoscience Australia

GPO Box 378

Canberra ACT 2601 Australia

Cnr Jerrabomberra Avenue &

Hindmarsh Drive

Symonston ACT 2609 Australia

www.ga.gov.au

Chief Executive Officer

Dr Chris Pigram

Subscriptions

Online subscriptions

[www.ga.gov.au/about-us/](http://www.ga.gov.au/about-us/news-media/subscribe/index.jsp)

[news-media/subscribe/index.jsp](http://www.ga.gov.au/about-us/news-media/subscribe/index.jsp)

Editorial enquiries & Feedback

Steve Ross

p: +61 2 6249 9263

f: +61 2 6249 9926

e: ausgeomail@ga.gov.au

Sales Centre

p: +61 2 6249 9966

f: +61 2 6249 9960

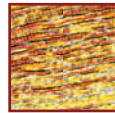
e: sales@ga.gov.au

GPO Box 378

Canberra ACT 2601 Australia

CEO comment

2



Hydrocarbon potential of the offshore northern Perth Basin

3

New data and knowledge deliver opportunities for petroleum explorers



Continental resource and energy systems

9

Academy of Science recommendations drive new project



New 3D Model of Capel and Faust basins released

14

Geological model assists in the assessment of offshore frontier basins



Exploring for calcrete-hosted uranium deposits in the Paterson region, Western Australia

18

Modelling points to prospective areas



Towards future energy discovery

23

Completion of the Energy Security Program

In brief

Review of rare-earth elements in Australia

26

Hydrocarbon seepage survey in northern Perth Basin

27

Product news

Frome airborne electromagnetic data Phase 2 release

28

Heat flow determinations for the Australian continent

29

New Isostatic Residual Gravity Anomaly Map of Australia (First Edition)

30

New geophysical datasets released

31

Events

36



CEO comment



Two important recent events for Geoscience Australia were the release of *Towards Future Energy Discovery* by the Minister for Resources and Energy, Martin Ferguson AM MP, on 20 June 2011 and the release of a comprehensive review of Australia's rare earth elements. This issue includes reports on both publications.

Towards Future Energy Discovery provides an overview of Geoscience Australia's Energy Security Program following its completion in mid-2011. This review is the first unified compilation of the activities undertaken during the course of the program. It will inform stakeholders of the new opportunities and key products embodied in a range of datasets, regional studies, assessments, maps and publications.

The major rare-earth-element deposits of Australia: geological setting, exploration, and resources is a comprehensive review of Australia's rare-earth elements which outlines their distribution, geological characteristics, and potential. Because of an expanding portfolio of applications, particularly for developing technologies crucial to our future, these elements are increasingly becoming more attractive commodity targets for the minerals industry.

Geoscience Australia scientists have recently completed a major assessment of the hydrocarbon prospectivity of the northern Perth Basin. The assessment process, which provided an improved understanding of basin evolution and the spatial distribution of key petroleum system elements, is outlined in this issue. The new knowledge generated during this study underpinned the release of area W11-18 in April 2011 as part of the Australian Government's 2011 release of offshore petroleum exploration acreage.

An influential Australian Academy of Science think tank has called for Australian geoscientists to cooperate in an innovative, well-defined and nationally-coordinated strategy to bring competitive advantage to Australian mineral exploration. This issue includes a report on Geoscience Australia's activities within this strategy through the formation of the 'Continental Resource and Energy Systems' project. The aim of the project is to develop continental-scale methods to investigate and model the Australian crust which will guide and attract future minerals and energy exploration.

There is also a report on a recently completed study of the

petroleum prospectivity of the Capel and Faust Basins. These deepwater basins, located 800 kilometres off the east coast of Australia, have previously seen little scientific or petroleum exploration effort. This study used 3D geological modelling at a basin scale to answer key questions about the area's petroleum prospectivity.

This issue also includes an article outlining the geological and geochemical factors which control the formation of calcrete hosted uranium deposits. The article then examines the presence of appropriate source rocks, drainage systems and depositional environments which makes the Paterson region in Western Australia prospective for calcrete-hosted uranium deposits.

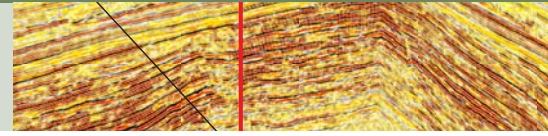
As always we welcome your feedback and encourage you to use the email address at the end of each article.



Dr Chris Pigram
CEO Geoscience Australia

Hydrocarbon potential of the offshore northern Perth Basin

New data and knowledge deliver opportunities for petroleum explorers



Andrew Jones, Diane Jorgensen, Ron Hackney and Chris Nicholson

Geoscience Australia has recently completed an assessment of the hydrocarbon prospectivity of the offshore northern Perth Basin to stimulate exploration in the basin by Australia's offshore oil and gas industry. The study was mainly based on new data collected as part of Geoscience Australia's Offshore Energy Security Program. A review of the Program is included in this issue of *AusGeo News*.

The new datasets, including regional two-dimensional (2D) and three-dimensional (3D) seismic, potential field and well data, provided an improved understanding of basin evolution and the spatial distribution of key petroleum system elements. The new

knowledge generated during this study has enhanced the potential for new oil and gas discoveries in the Perth Basin. It also underpinned the release of area W11-18 in April 2011 as part of the Australian Government's 2011 release of offshore petroleum exploration acreage (see *AusGeo News* 102).

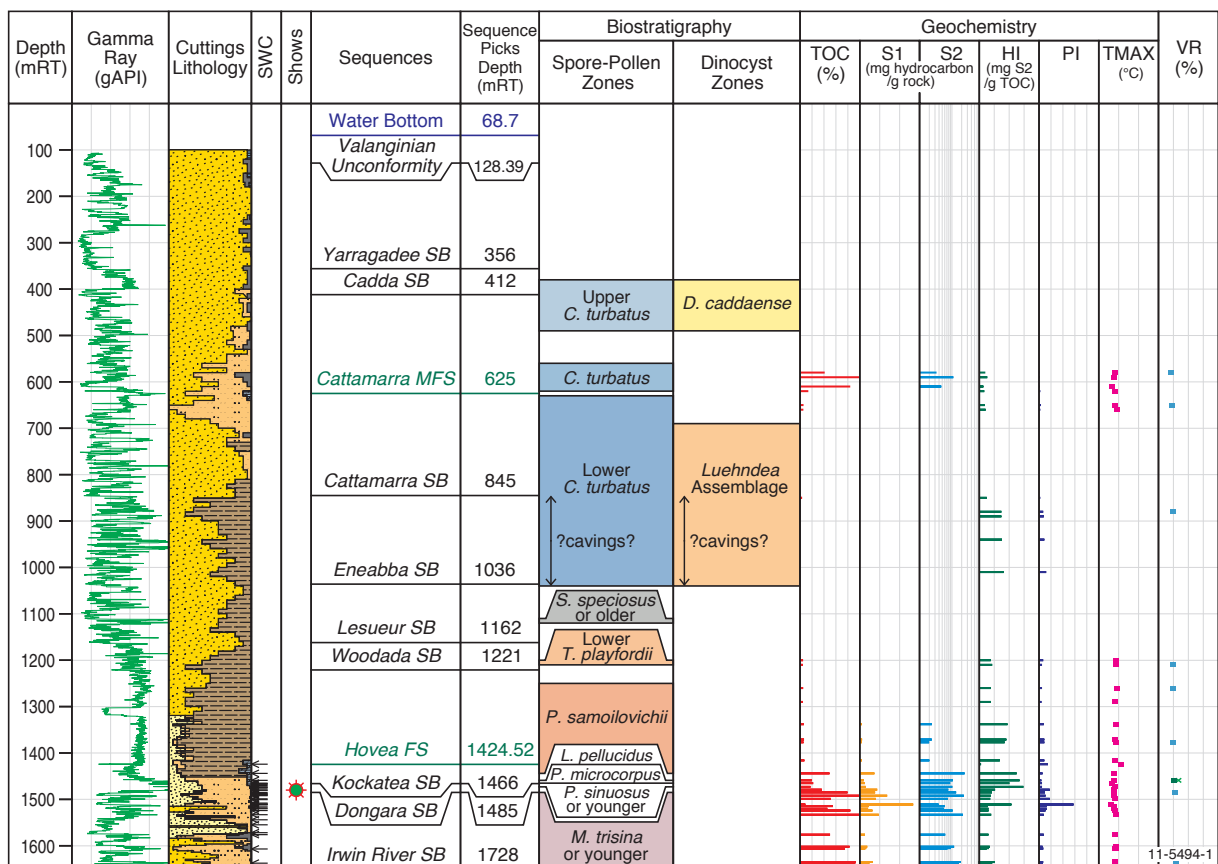


Figure 1. An example of the data included in the Dunsborough-1 well composite from the offshore northern Perth Basin well folio (location shown in figure 4). The Middle Jurassic to Permian stratigraphy in Dunsborough-1 was revised on the basis of sequence stratigraphic analysis that incorporated a review of open-file palynological data and new palynological analysis of cuttings samples over the interval 380-1210 mRT. Forty-one new geochemistry and 10 new Vitrinite Reflectance measurements were acquired from cuttings and side wall core samples over the interval 580-1725.4 mRT.

Oil is currently being produced from the offshore northern Perth Basin, specifically from the Cliff Head oil field that was discovered in 2001. Three more petroleum discoveries were made in this part of the basin in 2007, with oil and gas in Dunsborough–1, and gas in Frankland–1 and Perseverance–1. These accumulations are located in Permian sandstones and have primarily been sourced from the Triassic Hovea Member of the Kockatea Shale. This shale has also been the source of the majority of producing oil and gas fields of the onshore Perth Basin.

Depositional history

The biostratigraphic history of the offshore northern Perth Basin was revised through combining existing well data with interpretations of newly-acquired palynology data. This study also included the first published synthesis of data from 14 new exploration wells drilled

since the Cliff Head–1 discovery.

The new biostratigraphic data were reviewed and used in conjunction with well logs and lithological interpretations of cuttings, cores and sidewall cores to define a new chronostratigraphic sequence framework. Depositional sequences and key maximum flooding surfaces are correlated between wells to show the spatial and temporal distribution of these sequences. The main sedimentary succession in this part of the basin is Permian to Late Jurassic in age. Two regional unconformities were identified and they correspond to regional uplift in the Late Permian (Capitanian) and the breakup of Australia and Greater India in the Valanginian Stage.

The new data and interpretations for 23 of the petroleum exploration wells are included in the offshore northern Perth Basin well folio (figure 1). These new data include: 120 new palynological samples; 244 new geochemistry measurements; 100 new thermal maturity measurements; and a compilation of Grains with Oil Inclusions (GOI™) data. All data presented in the folio were either publicly available or newly derived. The composite 1:5000 scale well log summarises, in graphic form, the main stratigraphic features and hydrocarbon occurrences (figure 1). The folio also includes Offshore Perth Basin Biozonation and Stratigraphy 2011 Chart 38.

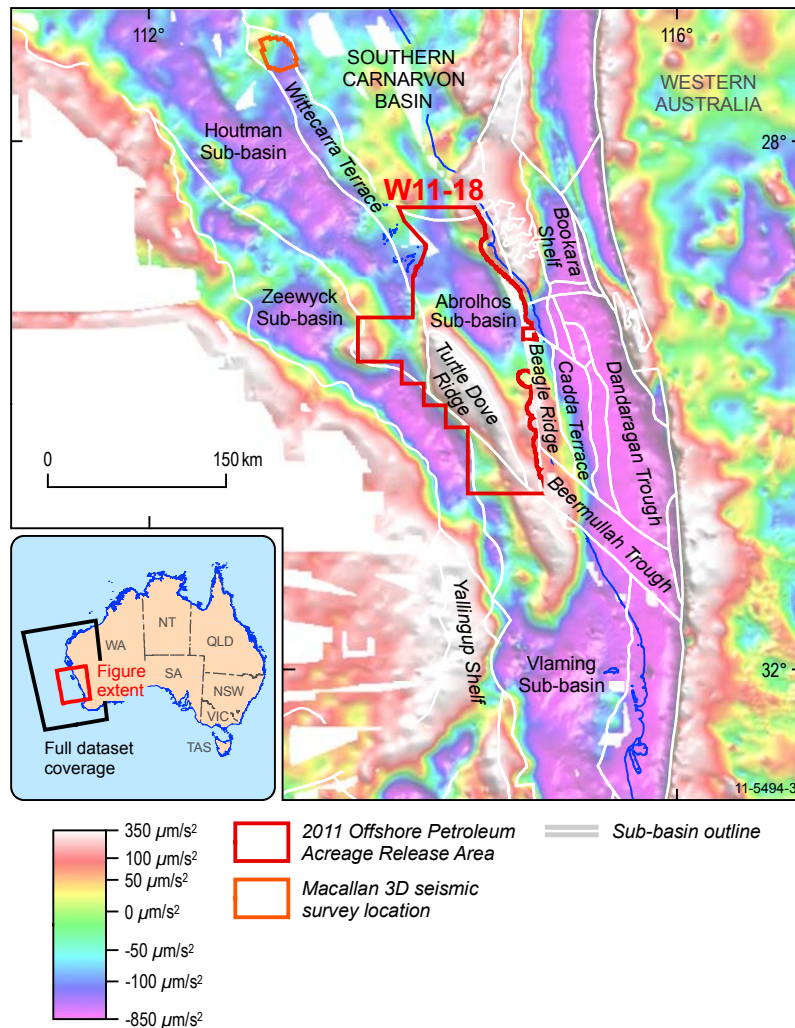


Figure 2. The levelled and merged gravity dataset for the northern Perth Basin and adjacent onshore areas overlain by structural elements of the offshore northern Perth Basin and the Release Area W11-18. The residual gravity image is computed from the Bouguer anomaly by subtracting its upward continuation to 25 kilometres.

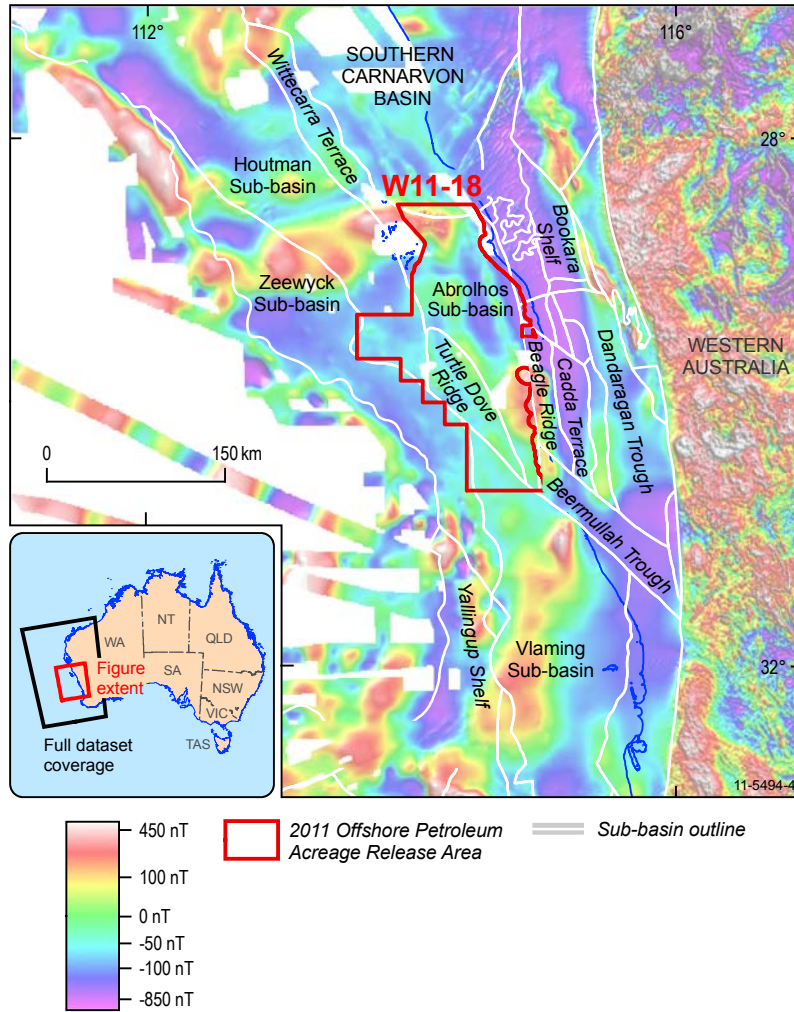


Figure 3. The levelled and merged, reduced-to-pole magnetic dataset for the northern Perth Basin and adjacent onshore areas overlain by structural elements of the offshore northern Perth Basin and the Release Area W11-18.

New geophysical datasets

A major output from the study is a data package which includes reprocessed seismic data, new seismic reflection data and new gravity and magnetic data. The new seismic, gravity and magnetic datasets were collected between October 2008 and February 2009 during two major surveys off the coast of Western Australia (surveys GA-310 and GA-2476). The datasets collected during these surveys have greatly improved the coverage over a large portion of Australia's southwestern margin. The data package covering this area was released to the petroleum industry by the Australian Government's Minister for Resources and Energy, the Hon Martin Ferguson AM MP, in April 2010.

The new gravity and magnetic data were merged and levelled with an existing Australia-wide dataset (Petkovic et al 2001) and combined with onshore data from the fifth edition of the Magnetic Anomaly Map of Australia (Milligan et al 2010) and the 2010 version of the

Australian National Gravity Database. The final compilations of gravity and magnetic data provide a consistent dataset that covers the southwestern margin of Australia (106–120°E and 19–37°S). This area includes the Mentelle, Perth and southern Carnarvon basins, as well as the Wallaby Plateau. Data covering the northern Perth Basin (figures 2 and 3), as well as the full dataset coverage of the area, are available for download through the Geophysical Archive Data Delivery System (see below).

The new compilations of levelled gravity and magnetic data covering marine and onshore areas are facilitating structural and geological interpretations of the offshore northern Perth Basin. Depth-to-basement and basement architecture in some parts of the basin are not well defined using seismic data. For these locations integrated modelling and interpretation of potential field data are being used to provide additional information. Several geophysical processing methods are being applied to the new datasets, including wavelet-based multi-scale edge detection to highlight the edges of anomalies. This method complements seismic reflection data for mapping structural trends. Spectrally-based depth-to-basement estimates and three-dimensional (3D) gravity modelling are being used to map basement architecture.

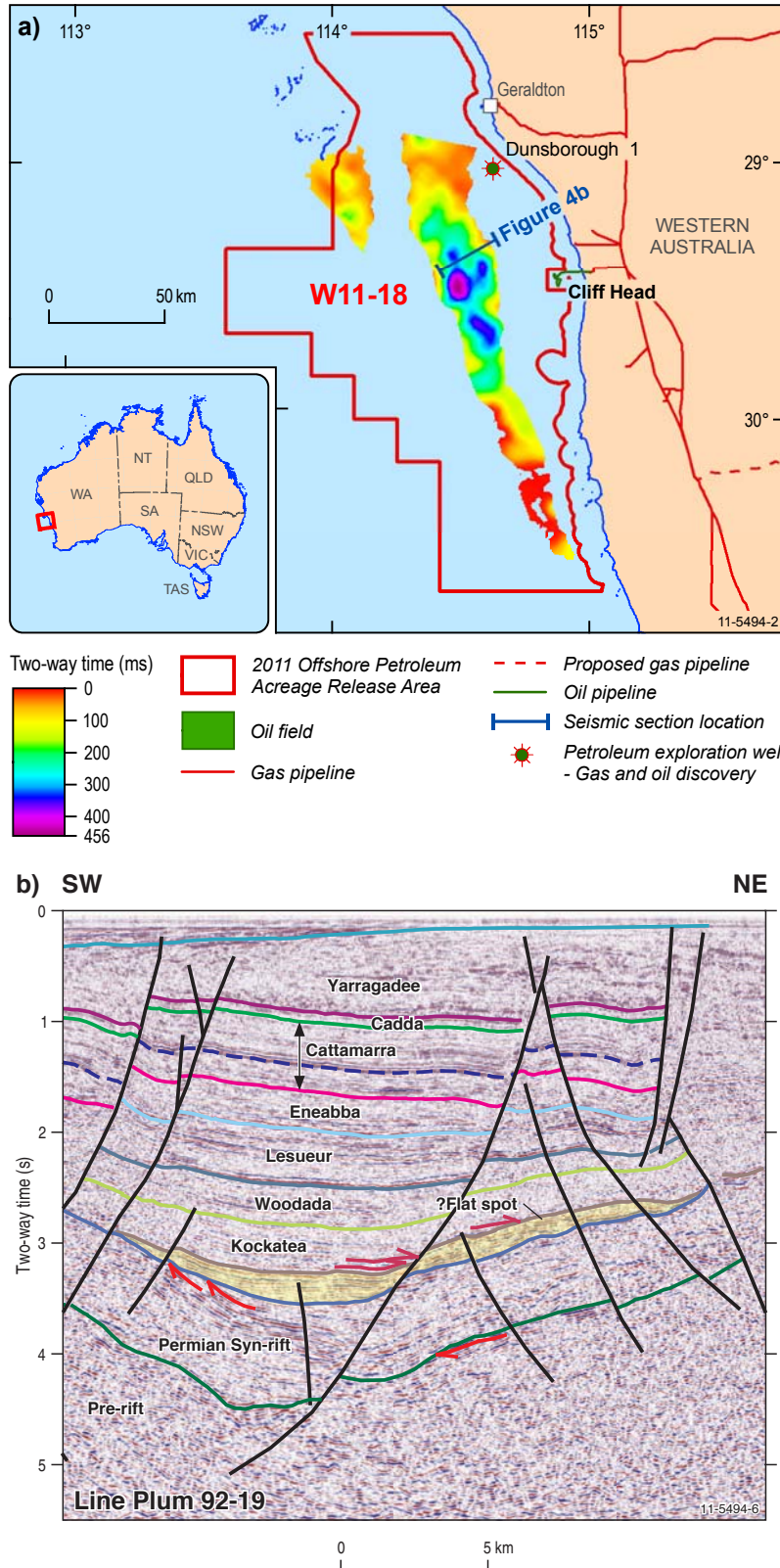


Figure 4a. The thickness and spatial distribution of a potential, large upper Permian stratigraphic play identified within Release Area W11-18.
b. Portion of seismic line Plum92-19, in the Abrolhos Sub-basin, displaying a thick basal succession of high amplitude continuous reflectivity interpreted as a potential reservoir. Hydrocarbons may have been preserved within this unit, when structural accumulations were breached through tectonic reactivation.

Petroleum prospectivity assessment

The new seismic data collected by Geoscience Australia show that Permo-Triassic strata which are stratigraphically equivalent to the productive onshore and nearshore Perth Basin petroleum system also occur within Permian half-grabens in the outer Abrolhos and Houtman sub-basins. Source rock, oil stain and fluid inclusion sampling from these strata indicate that the proven onshore-nearshore petroleum system is also effective and widespread offshore. There is also evidence for an active Jurassic petroleum system within the W11-18 Release Area. This assessment of petroleum prospectivity (Jones et al 2011) underpinned the release of offshore petroleum exploration area W11-18 in April 2011.

Reducing exploration risk

A major exploration risk in the offshore northern Perth Basin is loss of petroleum accumulations because of trap breach. In a joint CSIRO and Geoscience Australia collaborative study, palaeo-oil columns were detected in Permian reservoir sandstones below the Kockatea Shale regional seal in 13 of the 17 wells from the Abrolhos Sub-basin that were analysed. Further outboard, a palaeo-oil column in Houtman-1 demonstrates an effective oil-charge system in Jurassic strata in the Houtman Sub-basin. Breach

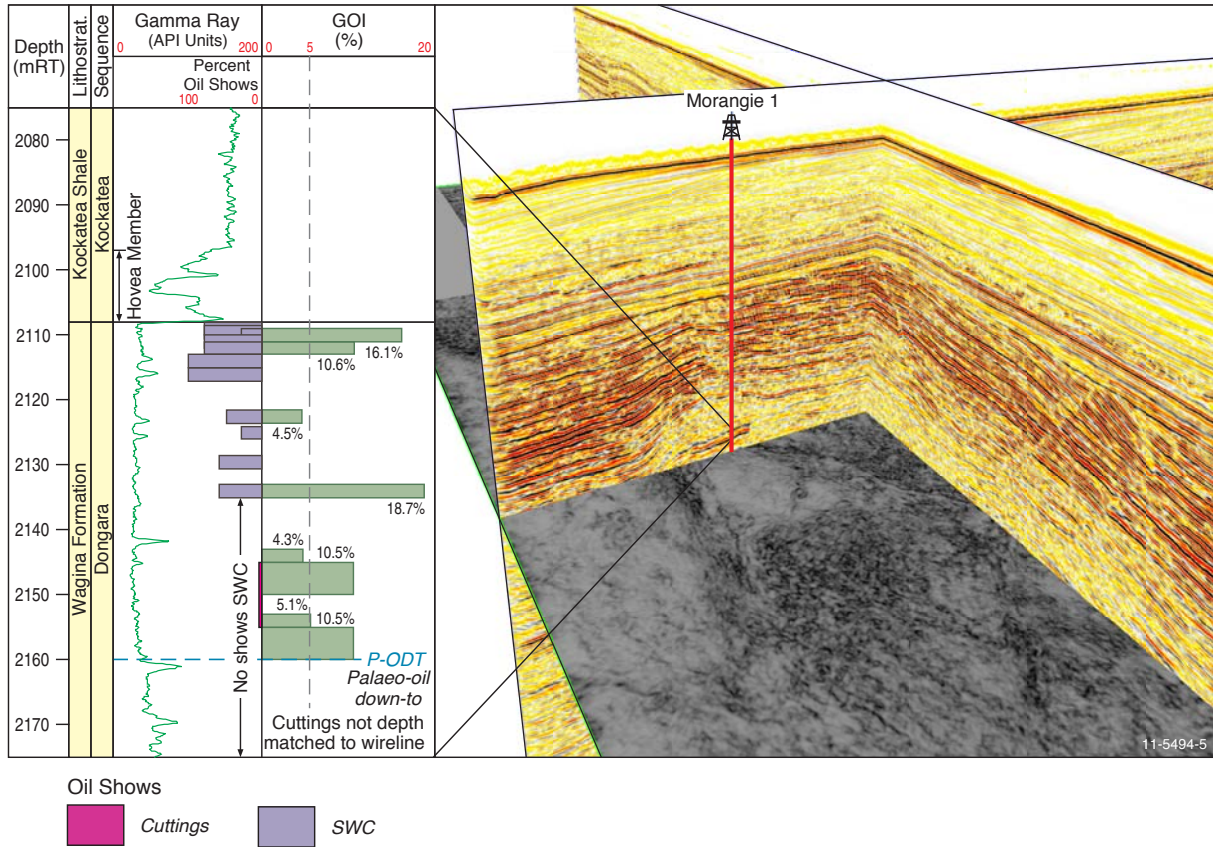


Figure 5. 3D seismic will be interpreted in 3D visualisation mode around prospects with oil-charge indicators (fluid inclusion GOI™) to aid understanding of the breached trap mechanism via later modelling. The Macallan 3D seismic data set is shown with vertical slices showing amplitude (red and yellow) and horizontal slices showing variance (shades of grey). The GOI™ log for Morangie-1 is reproduced from Kempton et al (2011).

of palaeo-accumulations in the offshore northern Perth Basin could be attributed to fault reactivation and structuring associated with Valanginian breakup, the tilting of the margin following the breakup, or inversion of faults during the Miocene (Kempton et al 2011).

Stratigraphic plays, which can accumulate and preserve hydrocarbons away from faults, were identified to address the risk of trap breach. A potential, large upper Permian stratigraphic play occurs within two depocentres (or areas of thick sediments) within Release Area W11-18 (figure 4a). These depocentres contain a thick basal unit with high seismic amplitudes and continuous reflectivity, which is overlain by the Kockatea Shale regional seal (figure 4b). Petroleum systems modelling indicates this potential reservoir was well positioned to receive oil-charge from the overlying Hovea Member.

A collaborative trap integrity study between CSIRO and Geoscience Australia, is underway and will focus on several drilled prospects which are covered by 3D seismic data and contain both breached and preserved oil columns (Kempton et al 2011; figure 5). Three-dimensional coupled deformation and fluid-flow numerical modelling will be used to simulate the response of trap-bounding

faults to extensional reactivation in these prospects and therefore investigate hydrocarbon preservation risk in the Abrolhos Sub-basin.

References

- Jones AT, Kennard JM, Nicholson CJ, Bernadel G, Mantle D, Grosjean E, Boreham C, Jorgensen DC & Robertson D. 2011. New exploration opportunities in the offshore northern Perth Basin. *The APPEA Journal* 51: 45–78.
- Kempton RH, Gong S, Kennard J, Volk H, Mills D, Eadington P & Liu K. 2011. Detection of Palaeo-Oil Columns in the offshore northern Perth Basin: Extension of the effective Permo-Triassic Charge System. *The APPEA Journal* 51: 377–396.



Milligan PR, Franklin R, Minty BRS, Richardson LM & Percival PJ. 2010. Magnetic Anomaly Map of Australia (Fifth Edition), 1:15 000 000 scale. Geoscience Australia, Canberra. Available at: https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=70282

Petkovic P, Fitzgerald D, Brett J, Morse M & Buchanan C. 2001. Potential Field and Bathymetry Grids of Australia's Margins. ASEG Extended Abstracts 2001 (1).

For more information

email ausgeomail@ga.gov.au

Related articles/websites

Geophysical Archive Data Delivery System (GADDS)
www.geoscience.gov.au/bin/mapserv36?map=/public/http/www/geoportal/gadds/gadds.map&mode=browse

Australian National Gravity Database
www.ga.gov.au/minerals/projects/current-projects/continental-geophysics/gravity.html#afgn

Frontier Basins of the West Australian Continental Margin: Post-survey Report of Marine Reconnaissance and Geological Sampling Survey GA2476 (Geoscience Australia Record 2009/38)

https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=69606

Offshore northern Perth Basin well folio (Geoscience Australia Record 2011/09)

https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=71568

AusGeo News 102: The 2011 Acreage Release for offshore petroleum exploration

www.ga.gov.au/ausgeonews/ausgeonews201106/acreage.jsp

AusGeo News 94: Southwest Margin surveys completed

www.ga.gov.au/image_cache/GA14028.pdf

AusGeo News 94: The geology and deep marine terrains of Australia's western region

www.ga.gov.au/image_cache/GA14029.pdf

Continental resource and energy systems

Academy of Science recommendations drive new project

Jon Claoué-Long

An influential Australian Academy of Science think tank has called for Australian geoscientists to cooperate in an innovative, well-defined and nationally-coordinated strategy to bring competitive advantage to Australian mineral exploration (Australian Academy of Science 2010). Because more than 80 per cent of the continent is covered by regolith and sedimentary basins, mineral and energy explorers need to prioritise search areas based on knowledge of:

- where the cover is relatively thin
- the characteristics in that cover which will either promote, or prevent, the sensing of buried resources

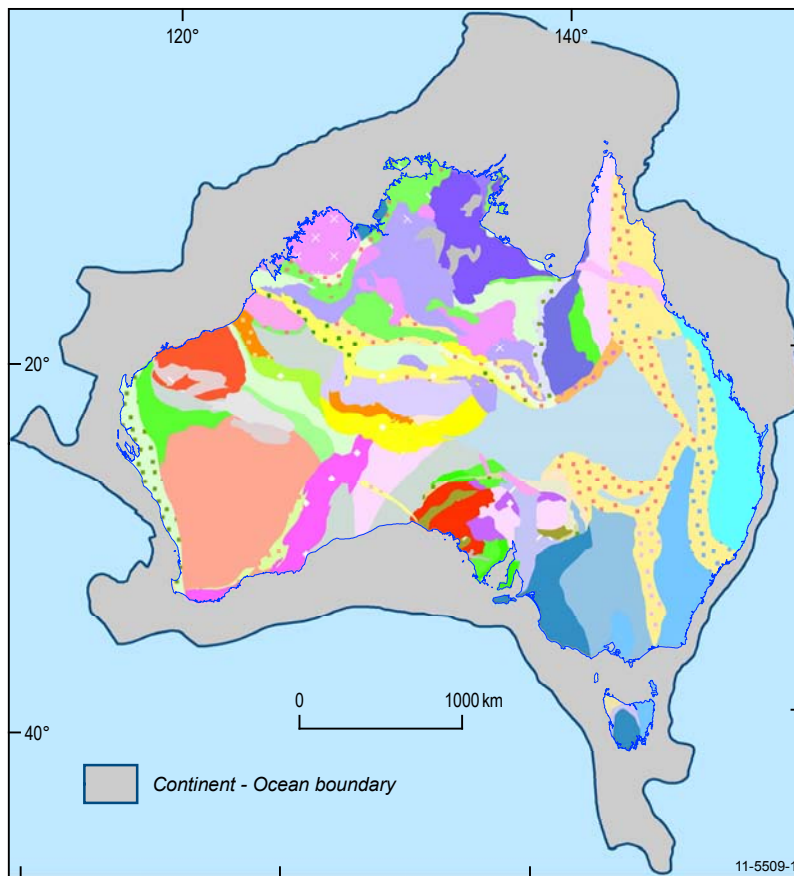


Figure 1. The 1995 Map of Australian Crustal Elements which interpreted the geometries of continent-scale geophysical domains under cover, based on magnetic and gravity datasets available at that time. See Shaw et al (1995, 1996) for the colour legend and explanation.

- the far-field chemical and physical signatures of resource systems that may be detected through cover
- the structuring of the deep crust and the mantle through time, which has generated the locations of resource and energy systems.

These factors are interrelated, so the strategy requires research groups to cooperate across institutional boundaries, and to foster collaborative links between the exploration and research communities that will promote fast uptake of new knowledge.

Geoscience Australia is responding by forming the 'Continental Resource and Energy Systems' (CRES) program. CRES will bring together research relating to the depth and character of the Australian cover, resource system indicators under cover, and Australian continental structures. This program is also integrating the contemporary evidence for the tectonic development of the lithosphere that underpins the Australian continent.

What is a tectonic map?

The geological mapping of the whole Australian continent, as distinct from regions within it, has proceeded in major landmarks. Each has taken the concept of the continent-wide map to a new level. The first was the publication of the ‘Geological Map of the Commonwealth of Australia’ by Edgeworth David (1931). It was the most detailed geological map developed for any continent at that time, and its release drew significant international interest in Australia. The lesson from that response is that making new data and understandings available will stimulate international research and exploration interest.

Successors to this pioneering map were developed after World War II by the Tectonic Map Committee of the Geological Society of Australia and published at 1:2 534 400 scale (in 1960) and at 1:5 000 000 scale (in 1971) by the Bureau of Mineral Resources (a predecessor of Geoscience Australia). These continent-wide maps were created through a compilation of the mapped geology at the land surface. They pre-date the plate tectonic paradigm, the role of geophysics in sensing the crust under cover, and the role of detailed geochronology in establishing temporal relationships. Nevertheless,

they were tectonic maps because they attempted to order the continent into major domains based on cratons, orogenic provinces, and platform cover.

The advent of continent-scale magnetic and gravity maps, and the development of views on how to interpret them, led the Australian Geological Survey Organisation (a later predecessor of Geoscience Australia) to develop a new concept of continental ‘geophysical domains’ recognised purely from geophysical characteristics. This concept attempted to link the magnetic signatures with maps of surface geology. The resulting 1:5 000 000 Map of Australian Crustal Elements (Shaw et al 1995) presented a detailed view of geophysically-defined domains within the shallow crust (figure 1). In an important development of thinking, the Australian Crustal Elements were not presented as a ‘tectonic’ map, but rather as a geometric framework of domains which would inform the debate about tectonic development (Shaw et al 1996).

Models of Australian tectonic evolution have been debated ever since, and numerous small sketch diagrams of alternative interpretations have been published in the academic literature. The Australian Crustal Elements map now needs to be updated in the light of the development of new datasets that image the deeper lithosphere, as well as advances in the interpretation of that data over the last 15 years.

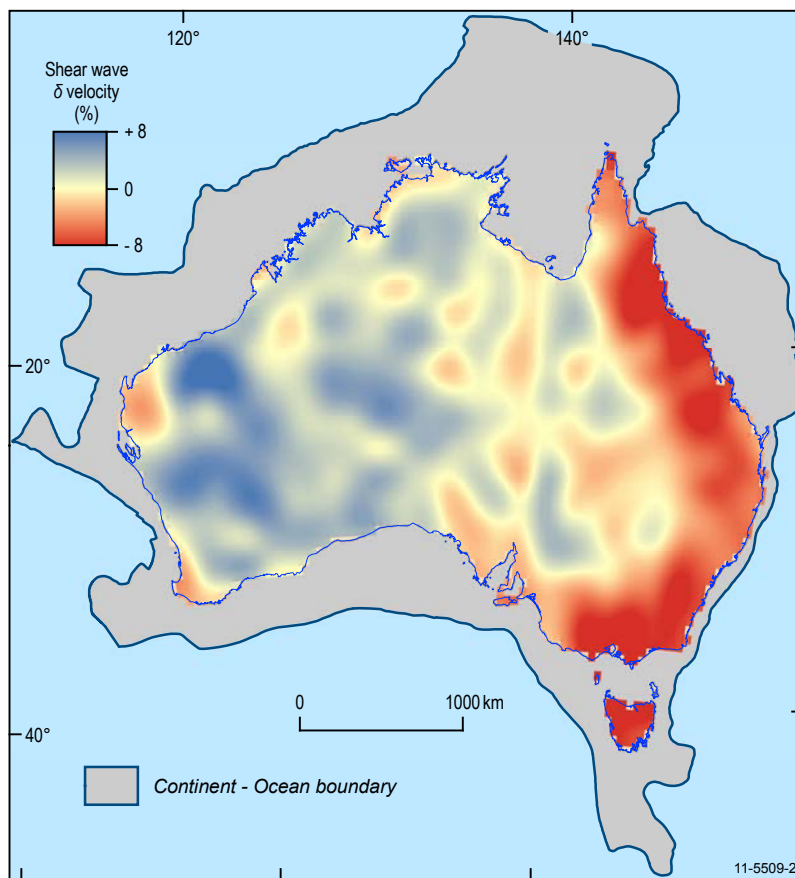


Figure 2. Isotropic shear wave inversion at 100 kilometres depth from Fishwick and Reading (2008). The cool and warm colours denote relatively fast and slow wave velocities, respectively, plotted as percentage perturbations from global reference model ak135.

Imaging the Australian lithosphere

Evidence for the structuring of the Australian lithosphere now extends beyond magnetic and gravity data, to include a rich array of geophysical and geological tools. At the widest scale, the most important geological tool is the plate tectonic paradigm, which informs our understanding of the offshore portion of the Australian plate and can also potentially guide approaches to the continental part. Another conceptual tool is the expectation of self-similarities of observations at vastly different scales (Mandelbrot 1982) which suggests that observations of structuring at the continent scale will carry testable predictions for regional and local scales of mapping and exploration.

New geophysical datasets include the inversion of earthquake wave speeds within the deep lithosphere, collected at receiver stations across the continent. Figure 2 shows one layer of this dataset, at 100 kilometres depth (Fishwick and Reading 2008). Blue colours in this image denote fast shear wave speeds in relatively rigid lithosphere, while warm colours denote slower speeds in less rigid lithosphere. The dataset shows that much of the west of the Australian continent is underlain by relatively rigid lithosphere, and indicates large scale

structures such as a prominent north-south linear discontinuity crossing under the continent from Adelaide to Mount Isa.

Another image of the lithosphere is provided by the long-wavelength gravity data in figure 3 (Bacchin et al 2008). Blue colours denote low densities and warm colours indicate higher densities, responding to compositional features. The image indicates mainly buoyant, low-gravity material in the west of the continent, whereas the eastern side is dominated by denser material. Large-scale structures are evident within these broad density zones, including prominent north-south trending zones in the east. There are many other new continent-scale geophysical views of the deep crust and upper mantle, including the collection of magnetotelluric and reflection seismic traverses across much of the continent as part of Geoscience Australia's Onshore Energy Security Program.

Complementing the geophysical evidence described above is an array of geological observations that image large scale, all-lithosphere features. One example shown in figure 4 (Claoué-Long and Hoatson 2009) is a Large Igneous Province—a belt of mantle-derived mafic and ultramafic magmatic rocks which bisected the continent as a linear extensional feature at around 825 million years. The locus of extension 400 million years later is indicated by mapping of

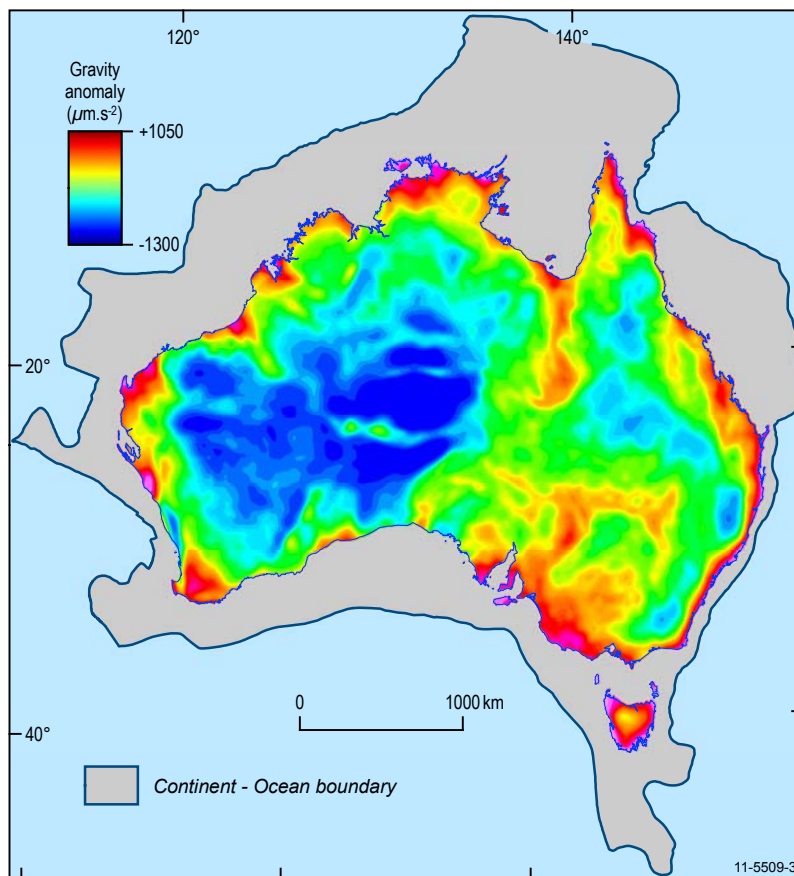


Figure 3. Bouguer gravity anomaly map of Australia, with data upwardly continued to 25 kilometres. The cool and warm colours, respectively, denote lower and higher density crustal rocks.

the marine sediments in the Larapinta Seaway that crossed Australia during the Ordovician (Cook and Totterdell 1991). This information can indicate the continent-scale geometry of mantle-tapping structures and, importantly, allow recognition of the time when particular structures were active. Supporting geological evidence can also come from the locations of kimberlite-related eruptions through time, and from mapping of isotopic compositions.

Putting the evidence together

There is a major task in collecting, managing, and then comprehending each of the wide array of evidence sets for the Australian lithosphere—geophysical, geochemical and geological data of very different origins and qualities, generated by a range of individuals and institutions. Geoscience Australia is developing a spatial database to make these datasets available in a consistent format and deploy them for viewing and access via the web. This will be a primary research tool for developing a dynamic understanding of the continent constrained with the original datasets. It will permit each

type of evidence to be viewed and appraised in context with all the other data in a consistent format in one location.

A parallel effort will work towards a ‘national cover map’ that presents the depth and character of surficial cover, regolith and onshore basins. Indications of depth rely especially on geophysical appraisal of a range of regolith and basin datasets. These datasets will be integrated with other continent-scale projects within Geoscience Australia such as the recent Weathering Intensity Map of Australia (Wilford 2011) and the National Geochemical Survey which has now completed the collection of samples from river catchment sediments over 80 per cent of the continent. This evidence will lead appraisal of the ease or difficulty of exploration in different areas, by providing information such as the depth and age of the cover, and whether it is *in situ* or transported.

Linking the knowledge from mapping the lithosphere, and constraints on the depth and character of the cover, will be the development of ‘distal resource footprint’ criteria. These are the indicators of resource and energy systems which may not be obscured by burial and so can be used as exploration tools once the region of interest has been selected. Geophysical methods may be important where buried mineral and energy resources have physical properties that contrast with their surroundings. Chemical indicators include

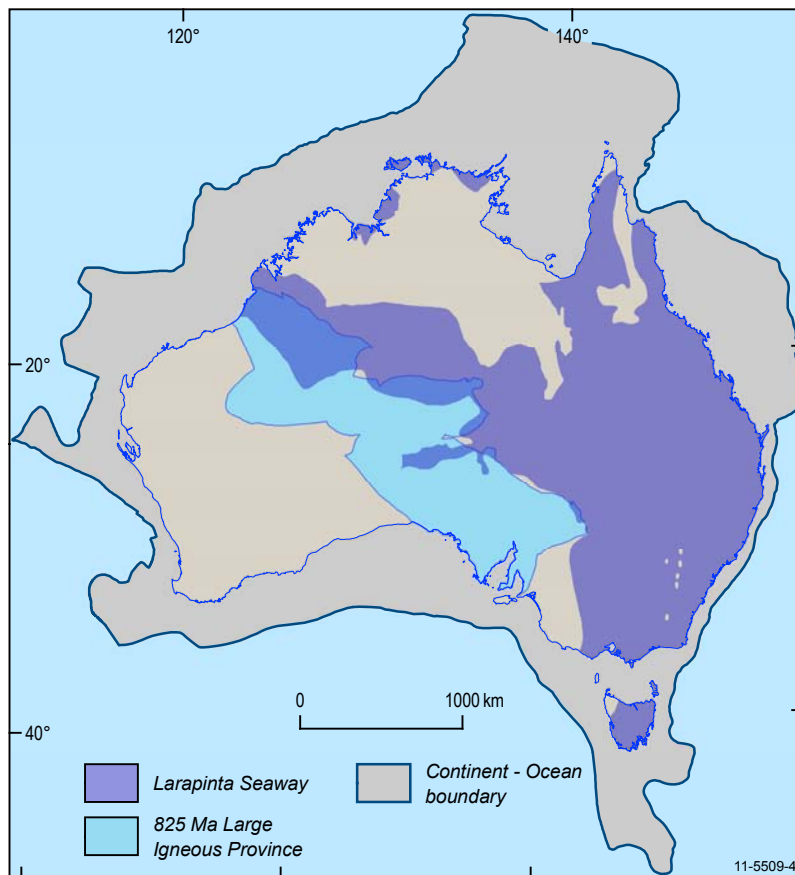


Figure 4. Two views of linear extensional belts across Australia. The pale blue zone is the extent of the 825 million years Gairdner Large Igneous Province (Claoué-Long and Hoatson 2009). The darker blue zone is the Ordovician maximum development of the Larapinta Seaway mapped from marine sediments across Australia (Cook and Totterdell 1991).

distal chemical footprints and the capacity of chemical evidence to migrate through cover to be accessible at the surface. An important criterion will be the definition of 'background' geochemical signatures.

Building a continent-scale understanding of metallogeny and energy resources, together with their relation to the Australian geodynamic framework, and their accessibility through cover, will be a long-term project. The aim is to provide a significant change in access to data and understanding of the Australian continent, which will guide and attract future minerals and energy exploration.

Re-issue of Australia's Crustal Elements map and digital dataset

To mark the commencement of the 'Continental Resource & Energy Systems' program, Geoscience Australia has re-issued the Map of Australian Crustal Elements (figure 1; Shaw et al 1995). This map was the major output of the last attempt to systematically map the crustal structure of Australia at a detailed scale. It delineates geophysical domains interpreted to extend within the shallow crust under the cover of later basins, based on the geophysical data available at that time. Originally produced as a paper map at 1:5 000 000 scale, the dataset has been edited and ported into digital format. One aim of the new Geoscience Australia program is to update this resource, and to extend mapping into the deeper lithosphere, in light of the new datasets and interpretations that have become available since 1995.

References

- Australian Academy of Science. 2010. Searching the deep earth: the future of Australian resource discovery and utilisation. Proceedings of the August 2010 Theo Murphy High Flyers Thinktank.
- Bacchin M, Milligan PR, Wynne P & Tracey R. 2008. Gravity anomaly map of the Australian region Third Edition, 1:5 000000 scale. Geoscience Australia, Canberra. Available at: https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=65682
- Claoué-Long JC & Hoatson DM. 2009. Australian Proterozoic Large Igneous Provinces 1:5 000 000 scale maps, Sheets 1 & 2. Geoscience Australia, Canberra. Available at: https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=69213
- Cook PJ & Totterdell J. 1991. Palaeogeographic atlas of Australia. Volume 2 – Ordovician. Bureau of Mineral Resources, Canberra.
- Edgeworth David TW. 1931. Geological map of the Commonwealth of Australia 1:3 000 000 scale. Council for Scientific and Industrial Research, Australia.
- Fishwick S & Reading AM. 2008. Anomalous lithosphere beneath the Proterozoic of western and central Australia: A record of continental collision and intraplate deformation? *Precambrian Research* 166: 111–121.

- Geological Society of Australia. 1960. Tectonic Map of Australia 1:2 534 400 scale. Bureau of Mineral Resources, Geology and Geophysics, Australia.
- Geological Society of Australia. 1971. Tectonic Map of Australia and New Guinea 1:5 000 000 scale. Bureau of Mineral Resources, Geology and Geophysics, Australia.
- Mandelbrot B. 1982. The fractal geometry of nature. WH Freeman and Co.
- Shaw RD, Wellman P, Gunn P, Whitaker AJ, Tarlowski C & Morse M. 1995. Australian Crustal Elements based on the distribution of geophysical domains, 1:5 000 000 scale; version 2.4, ArcGIS dataset. Geoscience Australia, Canberra.
- Shaw RD, Wellman P, Gunn P, Whitaker AJ, Tarlowski C & Morse M. 1996. Guide to using the Australian Crustal Elements Map. Australian Geological Survey Organisation Record 1996/30.
- Wilford J. 2011 (in press). A weathering intensity index for the Australian continent using airborne gamma-ray spectrometry and digital terrain analysis. *Geoderma*. doi geoderma2010.12.022

For more information

email ausgeomail@ga.gov.au

Related articles/websites

- Australian Crustal Elements (National Geoscience Dataset)
www.ga.gov.au/cedda/maps/1084
- AusGeo News 101*: Weathering intensity map of the Australian continent
www.ga.gov.au/ausgeonews/ausgeonews201103/weathering.jsp
- AusGeo News 97*: New map provides exploration pointers for nickel and platinum-group elements
www.ga.gov.au/ausgeonews/ausgeonews201003/productnews.jsp#product1

New 3D Model of Capel and Faust basins released

Geological model assists in the assessment of offshore frontier basins

Karen Higgins

Geoscience Australia has recently completed a study of the Capel and Faust basins, remote frontier basins located over the northern Lord Howe Rise, offshore eastern Australia (figure 1). The Lord Howe Rise is a continental fragment that broke away from what is now the Australian continent's east coast during the final break up of eastern Gondwana, commencing in the Cretaceous. The Capel and Faust basins cover an area of 210 000 square kilometres within Australian waters at water depths between 1500 and 3000 metres. The area of

the basins is comparable with a number of Australia's hydrocarbon producing provinces. Previous investigations hinted at deep basins that could be prospective for hydrocarbon resources, but new data was necessary for a more definitive assessment.

There is usually a high degree of uncertainty in the geological interpretation of frontier sedimentary basins because there is usually little pre-existing data or associated analysis. Consequently, Geoscience Australia acquired new data in this area during 2006–2007, including rock samples and high-quality reflection seismic, potential field and bathymetric data (figure 1). 2D analyses of these datasets were found to be inadequate in providing a satisfactory interpretation of the area's geology. This was the result of the combination of:

- a comparatively wide (15 to 40 kilometre) seismic line spacing
- lack of direct evidence (such as a deep drill hole) for the composition and age of basin sediments
- the widespread presence of volcanic and intrusive rocks masking features on seismic data
- the highly compartmentalised basin structure.

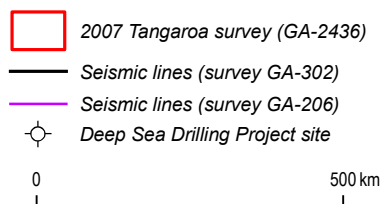
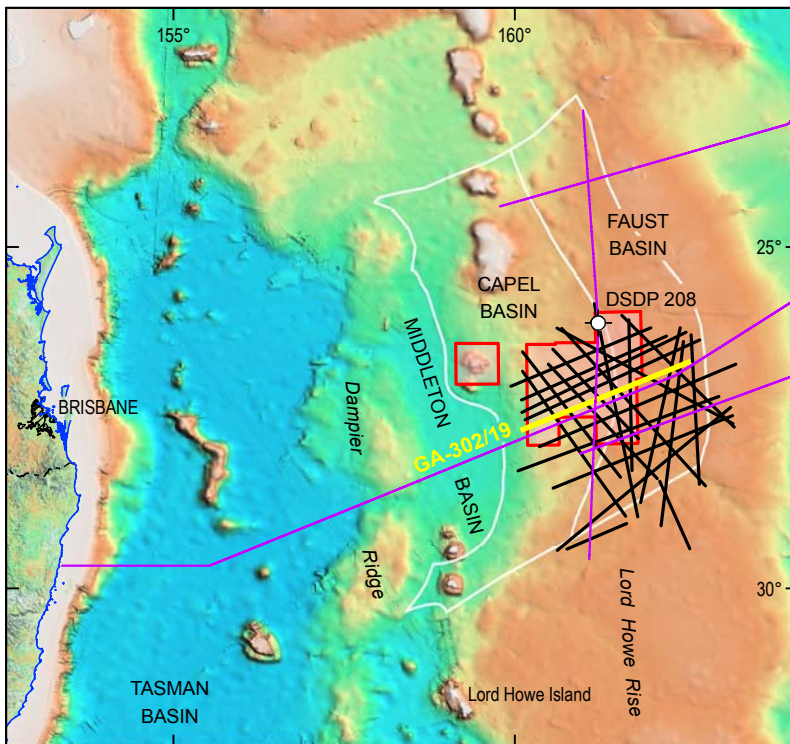


Figure 1. The location of data acquisition by Geoscience Australia in the Capel and Faust basins with Deep Sea Drilling Project holes on a bathymetric image (Colwell et al 2010). Seismic line GA-302/19 is highlighted in yellow.

3D modelling and petroleum exploration

Because of these challenges, effective data integration and analysis methods were essential. By using the 3D visualisation and modelling environment provided by GOCAD™, the diverse datasets were captured, processed and interpreted to create an integrated 3D geological model. This model enabled key geological and petroleum prospectivity questions to be answered. 3D geological analysis of offshore Australian areas at a basin-wide scale is a relatively new field of study. Usually petroleum exploration companies analyse basins at the scale of exploration prospects when undertaking detailed 3D mapping of hydrocarbon accumulations and modelling of fluid flow.

Geoscience Australia previously used basin-scale 3D geological modelling in a study of the Bremer Basin, located on the southern margin of Australia (Bradshaw 2005). However for this study

the model was produced at the end of the project to allow 3D visualisation of key interpretations and datasets. In the Capel and Faust basins study, the 3D visualisation environment was proactively used during the analytical workflow, as a workspace for data integration and testing of geological interpretations. This integrated 3D methodology is increasingly being used for petroleum prospectivity assessment at a basin scale.

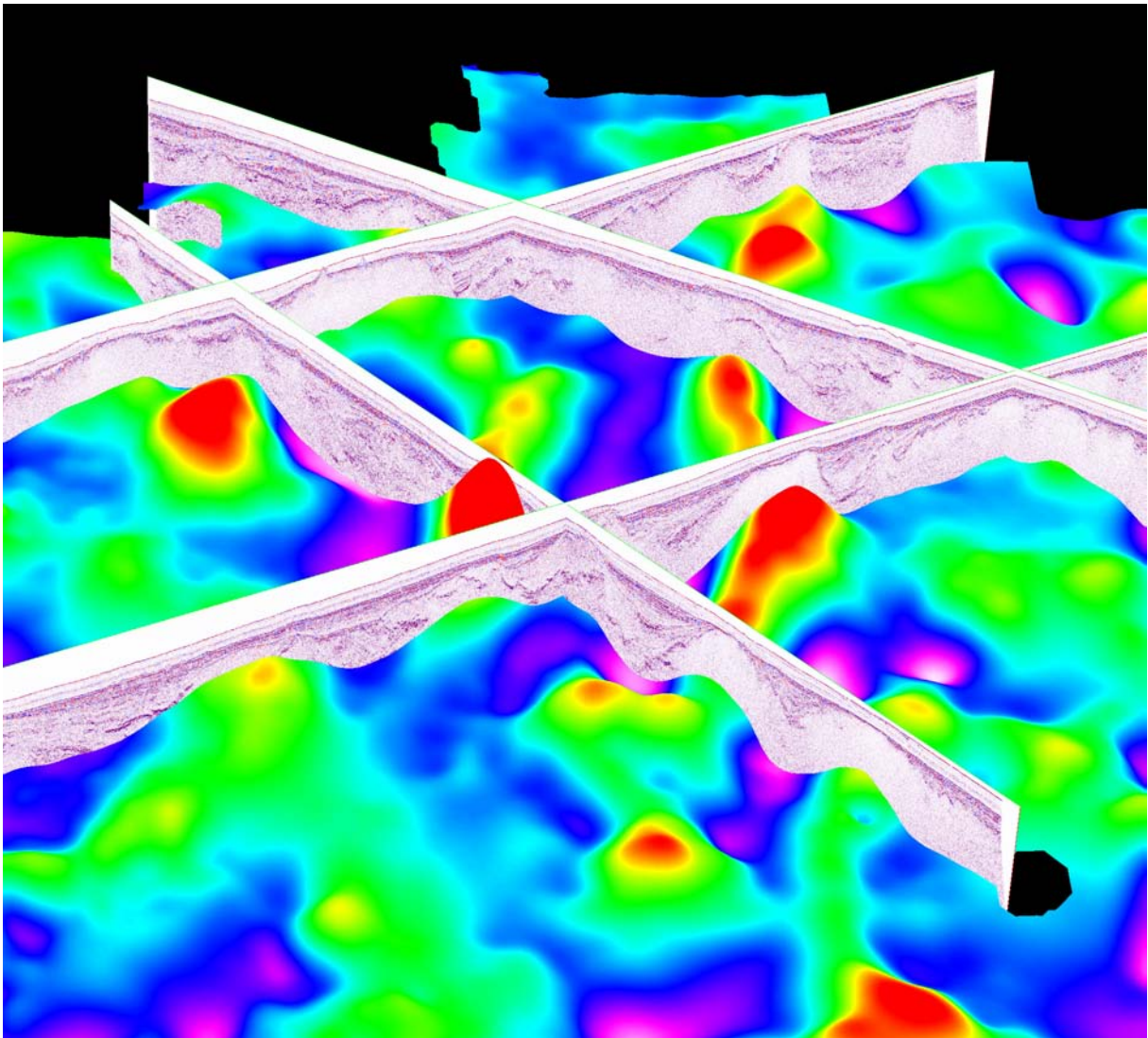


Figure 2. 3D visualisation of selected GA-302 seismic lines and grid of marine gravity data. The strong correlation between basement topography (revealed by seismic data) and gravity anomalies allowed gravity data to be used to interpolate structures between seismic lines.

Building an integrated 3D model

The Capel and Faust 3D geological model is composed of two fundamental components: horizon surfaces and fault surfaces. A number of horizon surfaces, based on 2D seismic interpretation, define key depositional and erosional events in the evolution of the basins (Colwell et al 2010). These surfaces bound major sedimentary units, which may source, host or trap petroleum accumulations. Seven key horizon surfaces were selected for the 3D geological model. Ages were assigned to most of the horizons by inference from major regional tectonic events (Colwell et al 2010). Fault surfaces represent fractures formed largely through tectonic movements that cut through

the basin sediments or form basin margins. Faults may also facilitate the trapping, migration and leakage of hydrocarbons potentially generated within the basin (figure 3). Two fault types were interpreted in the seismic datasets: major basin-bounding or basement offsetting faults, and minor intra-basin faults.

The seismic data was the primary dataset used for model

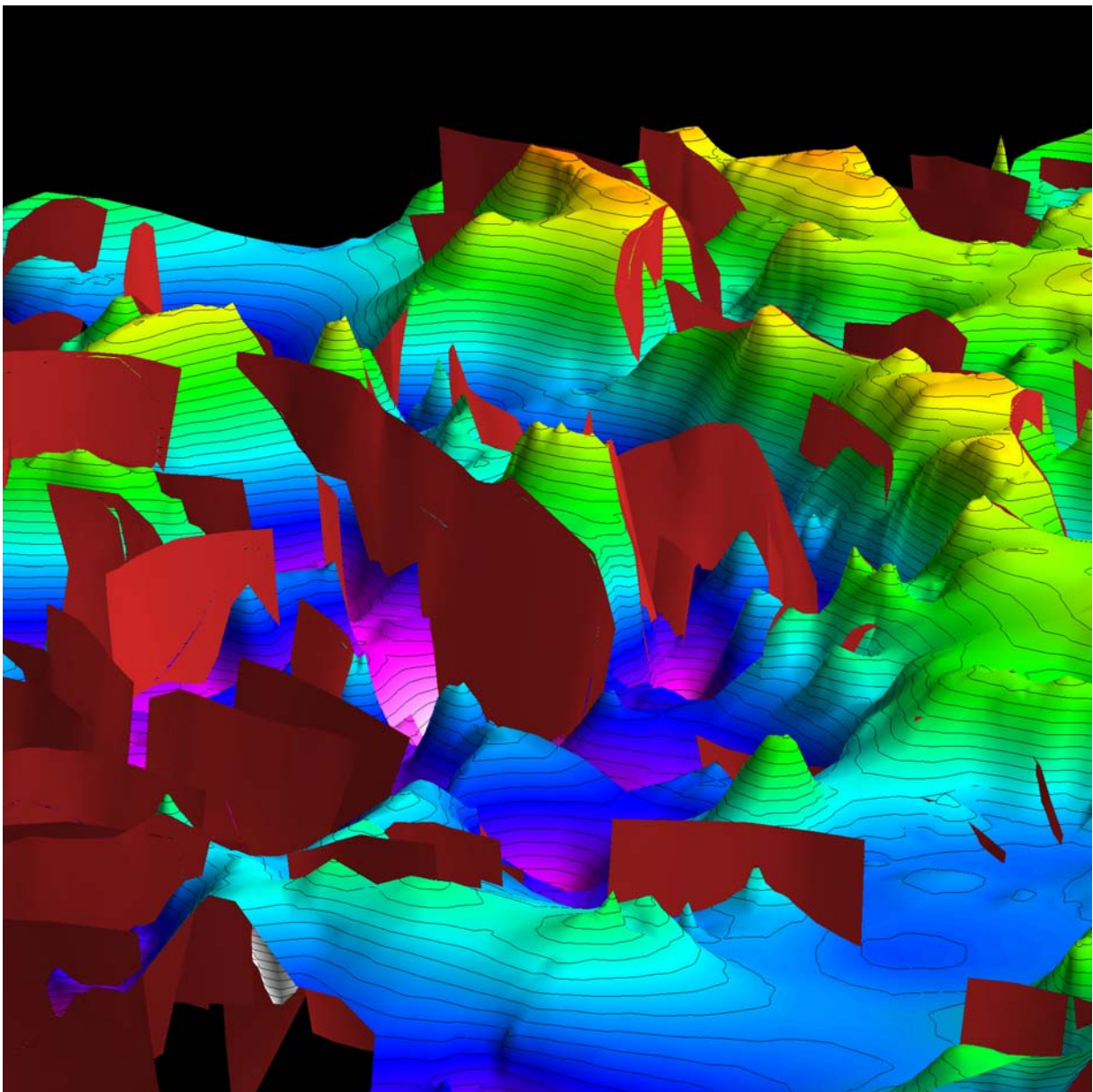


Figure 3. 3D basement architecture and faults (in red) of the Capel and Faust basins study area. The purple and blue colours delineate the base of the depocentres which have been filled with sediments. The green, yellow and orange colours represent the basement highs which border the depocentres.

building, but the comparatively wide spacing of the seismic lines required integration of other datasets to enable 3D surfaces to be generated (figure 1). Interpreted trends in gravity, magnetics and bathymetry datasets, which have a three kilometre line spacing in some areas, assisted in filling in the gaps in seismic coverage. The bathymetry data indicated many of the basin edges, particularly where fault movement is ongoing and has influenced the seafloor morphology. The gravity and magnetic data highlighted the location of basins and how they trend between seismic lines (figure 2). Areas of steep gradients in the gravity and magnetic data (Hackney 2010, Petkovic 2010, Petkovic et al 2011) were extracted as ‘worms’ and by upward continuation to highlight significant subsurface structures, their continuity and the regional structural trends. Maximising information extracted from the available datasets in this way, and their integration in 3D, allowed a robust geological model to be built.

Assessing petroleum prospectivity

The 3D horizon and fault surfaces were iteratively tested and modified as geologic interpretations evolved during the project lifecycle. The final horizon and fault surfaces were then seamlessly integrated to produce a complete 3D geological model (figure 3). This produced a series of horizon surfaces cut by fault surfaces, facilitating the display of the magnitude and sense of fault movement. The geometry of fault surfaces also revealed how the faults evolved over time; for example, faults exhibiting alternating segments of large and small displacement probably formed through the joining of multiple, but initially separate, short faults.

The end product is a 3D geological model that has vastly advanced our knowledge of hitherto poorly understood frontier basins. This model can be used to answer key petroleum prospectivity questions, such as the location of deepest depocentres, the likely location and type of hydrocarbon traps, and the nature of exploration risks. The model and the associated geological interpretations are now available from the Geoscience Australia Sales Centre as Record 2011/01 together with a range of other recently released Records and data products on the Capel and Faust basins (see below).

References

Bradshaw BE (Comp). 2005. Geology and Petroleum Potential of the Bremer Sub-basin, offshore southwestern Australia. Geoscience Australia Record 2005/21. Available at: https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=63730

Colwell JB, Hashimoto T, Rollet N, Higgins K, Bernardel G & McGiveron S. 2010. Interpretation of Seismic Data, Capel and Faust Basins, Australia's Remote Offshore Eastern Frontier. Geoscience Australia Record 2010/06. Available at: <https://www.ga.gov.au/products/servlet/>

controller?event=GEOCAT_DETAILS&catno=69190

Hackney R. 2010. Potential-field data covering the Capel and Faust Basins, Australia's Remote Offshore Eastern Frontier. Geoscience Australia Record 2010/34. Available at: https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=70711

Higgins KL, Hashimoto T, Hackney R, Petkovic P & Milligan P. 2011. Building a 3D GOCAD™ Model in offshore frontier basins for prospectivity assessment: Capel/Faust Basins, Lord Howe Rise. Geoscience Australia Record 2011/01. Available at: https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=70174

Petkovic P. 2010. Seismic velocity models of the sediment and upper crust of the Capel and Faust Basins, Lord Howe Rise. Geoscience Australia Record 2010/03. Available at: https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=69470

Petkovic P, Lane R & Rollet N. 2011. 3D gravity models of the Capel and Faust Basins, Lord Howe Rise. Geoscience Australia Record 2011/13. Available at: https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=70618

For more information

email ausgeomail@ga.gov.au

Related websites/articles

AusGeo News 99: Integrated assessment of the Capel and Faust basins, offshore eastern Australia
www.ga.gov.au/ausgeonews/ausgeonews201009/capel.jsp

AusGeo News 89: Survey of remote eastern frontier basins completed
www.ga.gov.au/ausgeonews/ausgeonews200803/survey.jsp

Exploring for calcrete-hosted uranium deposits in the Paterson region, Western Australia

Modelling points to prospective areas

Songfa Liu and Subhash Jaireth

Non-pedogenic calcretes are known to host many large uranium deposits such as Langer Heinrich in Namibia and Yeelirrie and Lake Maitland in Western Australia. In Australia there is an abundance of non-pedogenic calcretes. However many areas with such calcretes are yet to be systematically explored for uranium. Currently calcrete-hosted uranium deposits constitute only one per cent of known

uranium resources in Australia. Most known deposits are associated with Cenozoic drainage systems in the Yilgarn Craton, the Gascoyne Province (both in Western Australia) and the Ngalia Basin (in the Northern Territory).

In the Paterson region of the northern part of Western Australia, calcrete-hosted uranium mineralisation was reported in the Lake Waukarlyarly area but no major deposit of this type has been found. A recent airborne electromagnetic (AEM) survey in the Paterson region conducted by Geoscience Australia has mapped paleodrainage systems that have the potential to form calcrete-hosted uranium deposits (*AusGeo News* 101). The survey was part of the agency's Onshore Energy Security Program.

This article briefly outlines geological and geochemical factors which control the formation of calcrete-hosted uranium deposits. These factors provide the criteria necessary to map areas prospective for calcrete-hosted uranium deposits.

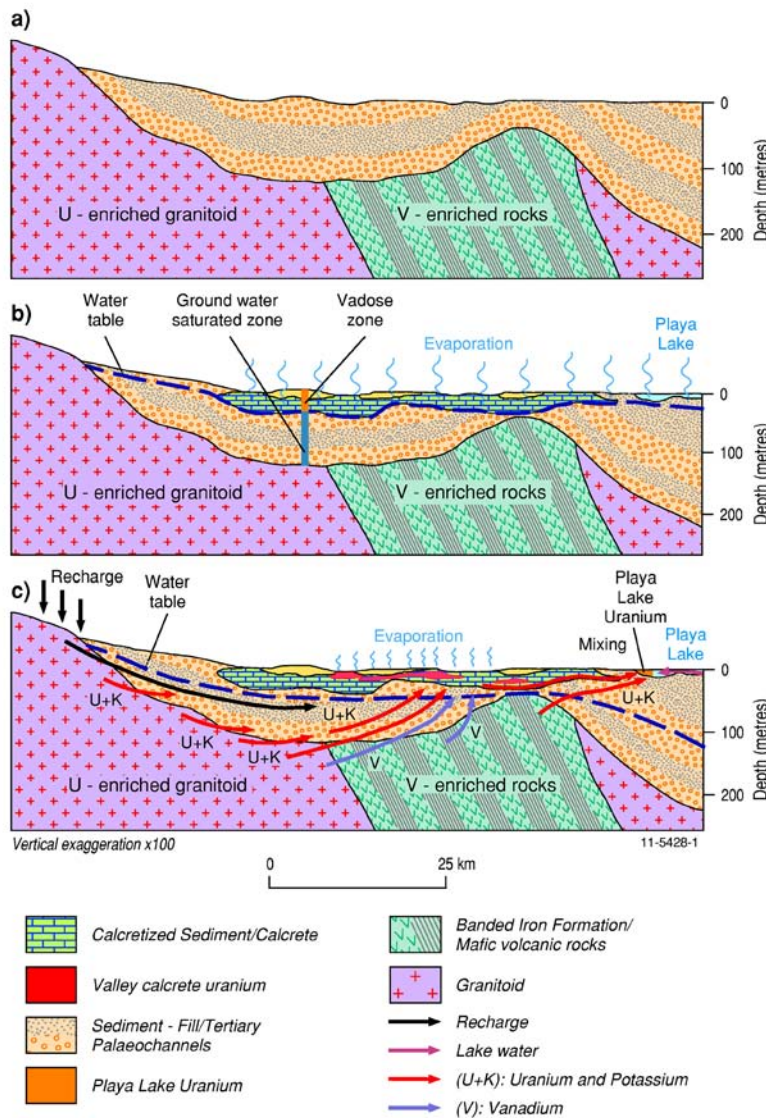


Figure 1. Model depicting the formation of calcrete-hosted uranium deposits.

Formation of calcrete-hosted uranium deposits

In the Paterson region the Archean Pilbara Craton and the Paleoproterozoic Rudall Complex are overlain by the Neoproterozoic Yeneena and Officer basins which are in turn overlain by the Paleozoic Canning Basin. The region is highly prospective for uranium deposits as it hosts a significant number of known uranium occurrences and deposits in the Rudall Complex, including the Kintyre deposit, which is the sixth largest uranium deposit in Australia.

Butt et al (1984) classified calcrete-hosted uranium deposits into three main types: valley, playa, and terrace deposits. Valley-type deposits, such as Yeelirrie, Hinkler–Centipede, Lake Way and Lake Raeside in the Yilgarn Craton, occur in calcretes and associated sediments in the central channels of major drainages, and in the platforms and chemical deltas where these drainages enter playas. Playa-type deposits, such as Lake Maitland and Lake Austin, occur in near-surface evaporitic and alluvial sediments. The calcretes near playas act as principal aquifers to the playas. The terrace deposits are less common and occur in calcrete terraces in dissected valleys, mainly in the Gascoyne Province of Western Australia. Uranium in calcrete-hosted deposits occurs entirely in the mineral carnotite.

As carnotite is a uranium-bearing vanadium oxide of potassium ($K[U^{+6}O_2][V^{+5}O_4] \cdot xH_2O$), its formation in calcrete is determined by geochemical processes that control the concentration of potassium, uranium and vanadium in groundwater and in playa lakes. Other important geochemical factors which may control the concentration of uranium in groundwater and playa-lake-water include the pH of the fluid and the concentration of dissolved carbonate and sulphate in the water (Bastrakov et al 2010).

The formation of calcrete-hosted uranium deposits can be illustrated in a three stage model (figure 1). The first stage represents the filling of paleovalleys with coarse-grained sediments of high permeability (figure 1a). This is followed by the initiation of an active groundwater drainage system. In arid zones dominated by intensive evaporation, the drainage system generates zones of calcrete near the water table (generally in the vadose zone, where the water is saturated with air, figure 1b). Intensive evaporation in the playa lakes causes deposition of evaporites and calcrete. Like other infill sediments, the calcrete also begins to act as an aquifer and is affected by evaporation and a fluctuating water table. Potassium and uranium are leached from felsic rocks (located upstream or in the incised bedrock of the palaeovalley) by saline, oxidised

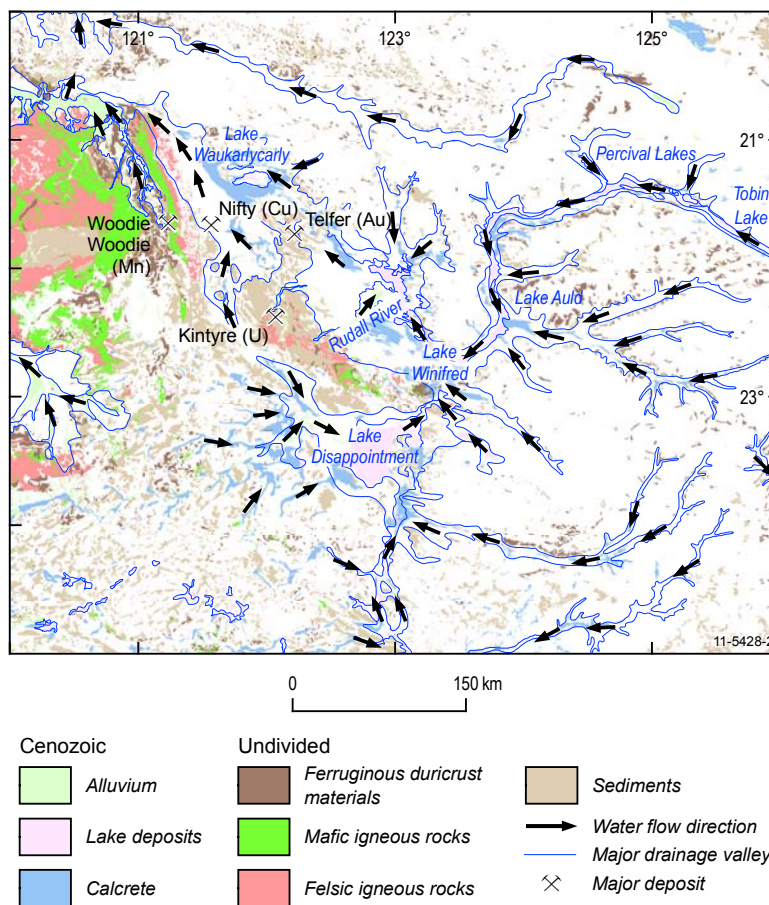


Figure 2. Distribution of key components of calcrete-hosted uranium mineral systems in the Paterson area.

groundwater, whereas vanadium is extracted from sources such as mafic rocks or iron rich (meta)sediments. Evaporation of groundwater can cause changes in the concentration of dissolved potassium, uranium, vanadium and carbonate, triggering precipitation of carnotite (figure 1c). In the vicinity of playa lakes, precipitation of carnotite can occur due to mixing of valley groundwater with potassium-rich saline lake water.

The above model of calcrete-hosted deposits shows that their formation is closely related to the evolution of the drainage system. Factors which favour uranium mineralisation include the presence of :

- source rocks of uranium (such as granites) and vanadium (such as mafic rocks and/or banded iron formations)
- paleovalleys / paleochannels that contain calcrete
- drainage systems of reasonable size with active recharge and discharge areas (such as playa lakes).

Table 1. Potential of calcrete–hosted uranium mineral systems in the Paterson region.

Criteria	Lake Waukarlycarly	Lake Dora – Lake Blanche	Lake Winifred
Groundwater flow system	Valley around Nifty–Kintyre – Telfer and from Lake Dora.	Lake Dora– Blanche.	Lake Disappointment–Lake Winifred.
Groundwater flow system size	Large.	Moderate to large.	Large.
Calcrete	Mapped around the Lake; southern part continuous 20 km x 60 km, northern part patchy.	Mapped around Lake Dora, and Lake Blanche.	Large area of continuous calcrete.
Source of uranium	Present. Felsic igneous rocks well exposed in Pilbara Craton west of the Lake. Felsic igneous rocks in the Telfer area. Felsic igneous rocks also exposed Rudall Complex.	Present. Felsic igneous rocks for west and south of Lake Dora–Lake Blanche. Ferruginous duricrust for north and east of Lake Dora.	Present. Felsic igneous rocks exposed in Rudall Complex.
Source of vanadium	Present. Mafic and ultramafic igneous rocks in Pilbara Craton and Rudall Complex.	Present. Mafic and ultramafic igneous rocks in Rudall Complex.	Present. Mafic and ultramafic igneous rocks in Rudall Complex.
Indication of uranium enrichment	Yes, as indicated by uranium anomalies in radiometric data around the lake area and Lamil Hill prospect.	No data	No data
Potential for calcrete-type uranium system (figure 3)	High in the rim of calcrete south of lake for valley- and playa-type (A). Moderate to high for (B), (C) and (D).	Moderate-high west of Telfer. Moderate south of Lake Blanche. Low north and east of Lake Dora.	Moderate–high potential for valley-type in palaeovalley near Lake Winifred (H).
Certainty (figure 3)	Moderate–high for (A), moderate for (B), (C) and (D).	Moderate for (E) & (G). Low to moderate for (F).	Moderate to low (H).

For other areas in the Paterson region see Table 7.13 in Liu and Jaireth (2010).

Potential of valley- and playa-type deposits in the Paterson region

The Paterson region contains abundant source rocks for uranium, which include Archean to Mesoproterozoic felsic igneous rocks of the Pilbara Craton, Rudall Complex and the Neoproterozoic Mt Crofton Granite Suite in the Telfer area (figure 2). Ferruginous regolith materials also have medium to high abundances of uranium (3.5 to 4 parts per million or ppm) although it may be less leachable

than uranium in felsic rocks. The region also contains source rocks of vanadium such as mafic and ultramafic igneous rocks in the Pilbara Craton and Rudall Complex (more than 300 ppm; Bagas and Smithies 1998, Hickman and Clarke 1994), and ferruginous duricrust (figure 2).

The region is characterised by well-developed current and paleo-drainage systems involving (paleo)valleys and lakes (figure 2). Flow directions of surface and groundwater have been determined from topographic maps, a digital elevation model and groundwater work. The Paterson AEM data defined a (paleo)drainage system which included a paleovalley over the Anketell Shelf from Lake Dora to Lake Waukarlyarly, and a palaeovalley connecting water flows from Lake Disappointment towards Lake Winifred and Lake Blanche (figures 5.30 and 5.31 of Roach 2010). The region also contains abundant valley-type calcrete and sulphate-rich sediments in the playa lakes.

The presence of appropriate source rocks, drainage systems and depositional environments makes the Paterson region prospective for calcrete-hosted uranium deposits. Prospective areas are shown on figure 3. Key features of the Lake Waukarlyarly, Lake Winifred, and Lake Dora–Lake Blanche prospective areas and levels of potential are summarised in Table 1. For other areas please see Liu and Jaireth (2010; Table 7.13).

These areas are divided on the basis of drainage systems including

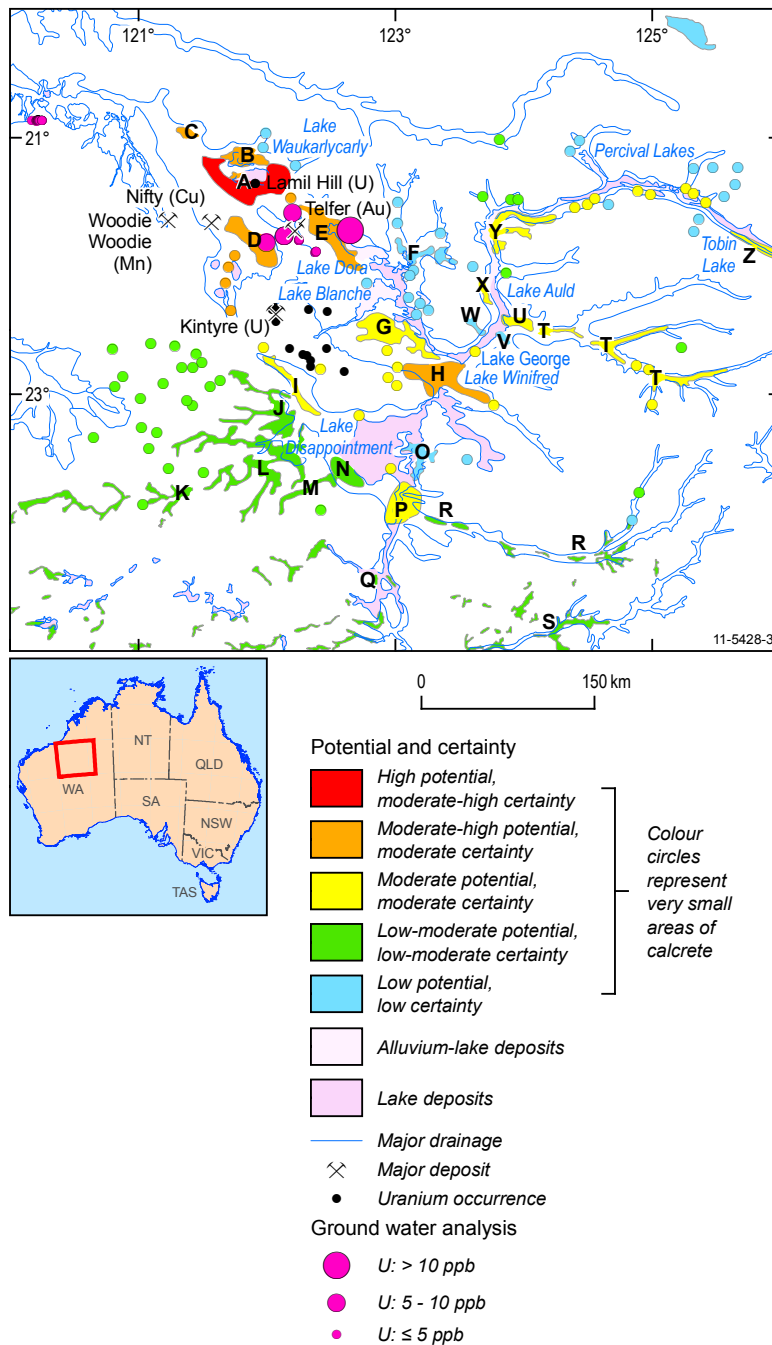


Figure 3. Prospectivity map for calcrete uranium mineral systems in the Paterson area. See Roach (2010) for detailed description of the method used for the assessment.



recharge and discharge areas, source areas for uranium and vanadium and water flow directions in drainage systems (figure 3): Lake Waukarlycarly (A to D); Lake Dora–Lake Blanche (E to G); Lake Winifred (H); Lake Disappointment west (I to N); Lake Disappointment southeast (P to S); and Lake Auld–Percival Lakes–Tobin Lake (T to W, X to Z).

Available information suggests that there is high potential for calcrete–hosted uranium mineral systems in the calcrete–rim area south of Lake Waukarlycarly (A). Potential is moderate to high in the area north and northwest of Lake Waukarlycarly (B and C), in the valley between Kintyre & Woodie Woodie–Nifty (D), east of Telfer (E) and south of Lake Winifred (H). Elsewhere the potential is low to low-moderate (figure 3).

Implications for exploration

The Paterson region contains several areas prospective for valley- and playa-type calcrete-hosted uranium deposits. The area with the highest level of potential is located to the south of Lake Waukarlycarly. A more detailed AEM survey (close line-spacing) may help map the paleochannels in greater detail to delineate more prospective areas. Geochemical surveys of sediment and groundwater can provide additional geochemical indicators (such as a saturation index with respect to carnotite) to map areas for detailed targeting. The presence of the Lamil Hills prospect shows that fertile calcrete mineral systems operated in the region.

For more information

email ausgeomail@ga.gov.au

References

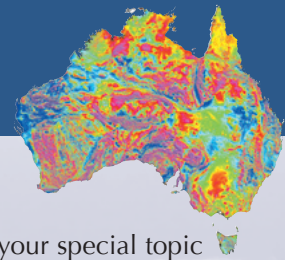
Bastrakov EN, Jaireth S & Mernagh TP. 2010. Solubility of uranium in hydrothermal fluids at 25°C to 300°C: implications for the formation of uranium deposits. *Geoscience Australia Record* 2010/29. Available at: https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=70633

Liu S F & Jaireth S. 2010. Implications for uranium systems. *In*: Roach IC (ed). *Geological and energy implications of the Paterson Province airborne electromagnetic (AEM) survey, Western Australia*. *Geoscience Australia Record* 2010/12. Available at: https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=70302

Stewart AJ. 2008. *Surface Geology of Australia 1:1 000 000 scale, Western Australia*. Geoscience Australia, Canberra.

AusGeoRef

Australian Geoscience References



Find

Information about:

- Australian geoscience
- Papers from Australian geoscience conferences and journals
- The latest research in your particular field
- An Australian geographic location or a geological feature

Annual subscription costs start from \$US95.00.

Try the 30 day free trial (www.ausgeoref.org)

For more information phone + 61 2 6249 9567
or email [Geoscience Australia's Library](mailto:Geoscience.Australia's.Library@ga.gov.au).
(Reference.Library@ga.gov.au)

Create

- A search on your special topic
- A customised bibliography
- An Alert profile for your particular field
- A document request



Australian Government
Geoscience Australia

in
collaboration
with



Towards future energy discovery

Completion of the Energy Security Program



William McKay, Edward Bowen, Narelle Neumann and Peter Southgate

A recent report by Geoscience Australia titled *Towards Future Energy Discovery* gives new impetus for energy and mineral exploration activity across the country and provides important input into Government policy making for Australia's energy future.

Launching the report in Canberra on 20 June 2011, the Minister for Resources and Energy Martin Ferguson AM MP, pointed out that 'Continued exploration for resources is fundamental to maintaining energy security'.

The report provides an overview of Geoscience Australia's Energy Security Program on completion of the program in mid-2011. Although data products and assessments have been released progressively, the report is the first unified compilation of the activities undertaken during the course of the program. It is designed to inform stakeholders of the new opportunities and key products embodied in a range of datasets, regional studies, assessments, maps and publications, most of which can be accessed online.

In 2006 the Australian Government expanded Geoscience Australia's program of seismic acquisition, data enhancement and

client access through the commitment of almost \$134 million over five years to the Energy Security Initiative. A total of \$75 million was allocated to focus on new frontier offshore areas and \$58.9 million was appropriated to identify potential for onshore energy resources such as petroleum, uranium and geothermal. The objective of the initiative has been to provide pre-competitive information to attract investment in offshore and onshore energy exploration by improving the chances of discovery and reducing risk to explorers.

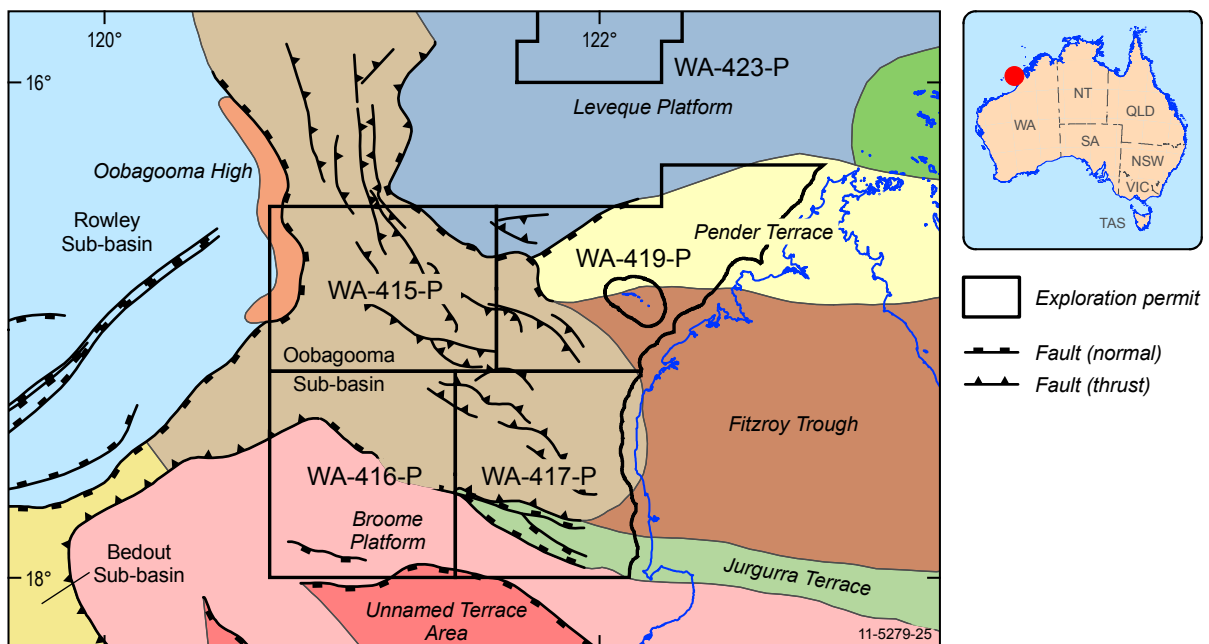


Figure 1. Structural map of the offshore Canning Basin showing newly-awarded exploration permits. The new data and pre-competitive knowledge for this area will continue to underpin future acreage releases and attract exploration attention.

Geoscience Australia engaged widely with the state and Northern Territory governments, industry, and other stakeholders to select frontier regions for pre-competitive data acquisition and investigation.

The offshore program targeted frontier basins with the long-term objective of attempting to locate a new hydrocarbon province for Australia. The program focused on the southern and southwest continental margin off Western Australia in the Mentelle, Vlaming, Perth, Southern Carnarvon, Canning and North Perth Basins and the Wallaby Plateau. The focus off eastern Australia was on the remote Capel and Faust basins and the Bass, deepwater Otway and Sorell basins west of Tasmania and south of Victoria.

In addition to the basin analysis and prospectivity assessment work, extensive seabed mapping was undertaken along the southern continental margin and the remote eastern parts of Australia's marine jurisdiction, in support of resource management.

As a result of the Offshore Energy Security Program, exploration companies have guaranteed expenditure of more than \$600 million

in the first three-year term of granted permits in the offshore Canning Basin (figure 1) and the Bremer and Bight basins. In addition, indicative expenditure approaching one billion dollars has been proposed during the second three-year permit period.

The focus of the onshore program was to stimulate exploration for energy resources, including non-renewable resources such as hydrocarbons, uranium and thorium as well as renewable geothermal energy resources. The Onshore Energy Security Program was

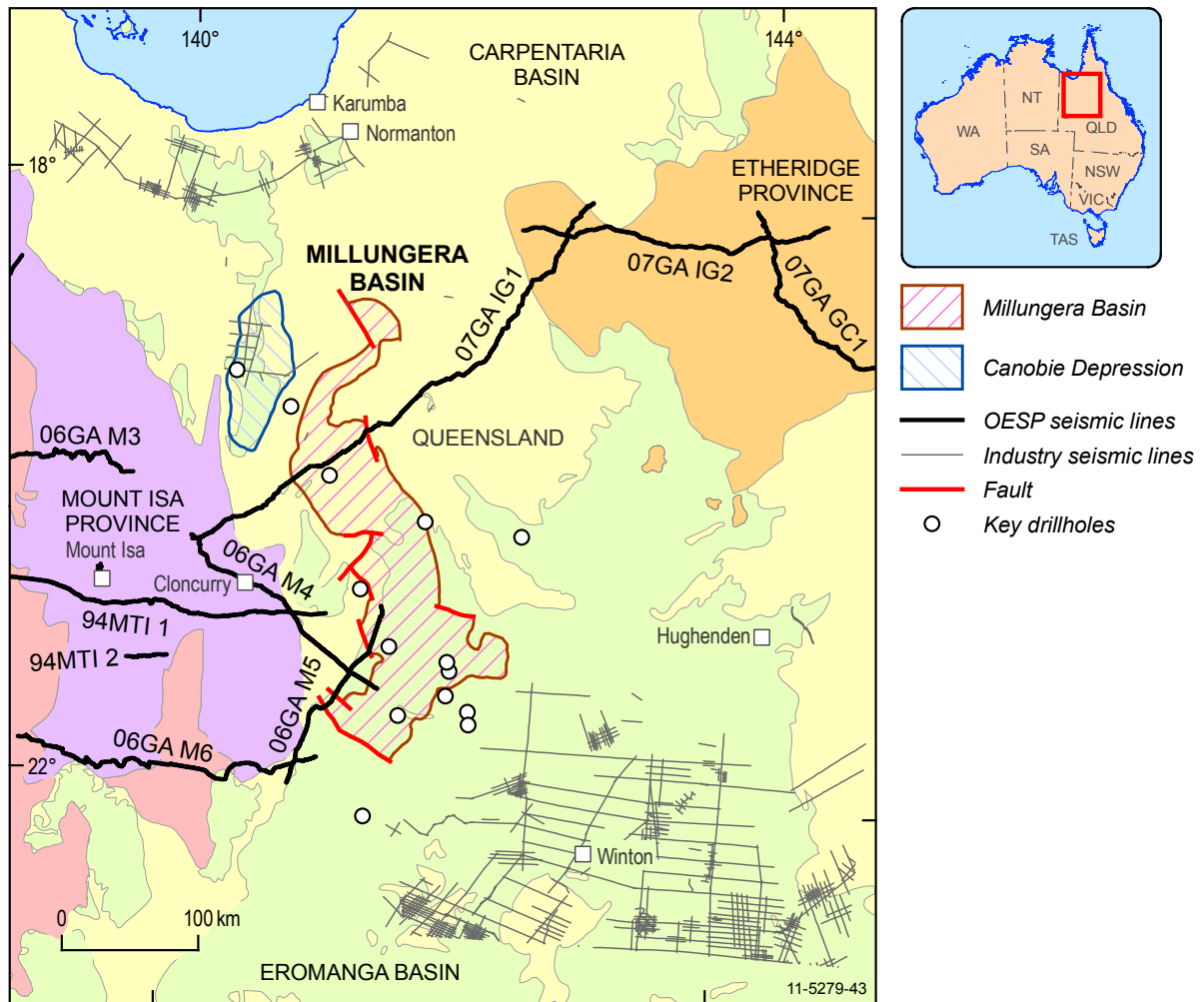


Figure 2. The recently discovered Millungera Basin, north Queensland. Modelling of the Millungera Basin indicates that potential hydrocarbon-bearing source rocks will be mature over large parts of the basin.



carried out under the National Geoscience Agreement between the Australian, state and Northern Territory governments. Australia-wide activities included acquisition and processing of airborne radiometric and magnetics data and the collection of more than 1300 geochemical samples. Deep seismic and airborne electromagnetic surveys were undertaken, on a regional basis, in most states and the Northern Territory.

The onshore program also produced the first national radiometric map of a continent, discovered a new sedimentary basin in North Queensland with the potential to host energy resources (the Millungera Basin in north Queensland; figure 2) and delivered a number of regional assessment studies and syntheses, which identified favourable areas for uranium, geothermal and mineral exploration.

Data and results from the Onshore Energy Security Program have stimulated tenement take-up, design of drilling programs and led to the discovery of mineralisation, as well as the development of new models and frameworks for energy exploration. The use of data and

products released by Geoscience Australia during the onshore program is estimated to have resulted in additional exploration expenditure by industry in excess of \$300 million.

For more information

email ausgeomail@ga.gov.au

Related articles/websites

Energy Security Program
Achievements—Towards Future
Energy Discovery

https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=71823

Review of rare-earth elements in Australia

Geoscience Australia has recently released a comprehensive review of Australia's rare-earth elements (REE) which describes their distribution, geological characteristics, and potential. Dramatically increasing prices for the REE reflect an expanding portfolio of applications and a narrow global supply base. Consequently, the REE are increasingly becoming more attractive commodity targets for the minerals industry. *The major rare-earth-element deposits of Australia: geological setting, exploration, and resources* will provide valuable information for mining companies, explorers, and investors.



Figure 1. Mount Weld in Western Australia is one of the richest rare-earth-element deposits in the world, with significant additional resources of niobium, tantalum, and phosphate. This aerial view shows the mine workings, in laterite developed above a ~2025 million year carbonatite intrusion. This image was kindly provided by Lynas Corporation Limited (<http://www.lynascorp.com/index.asp>).

Strategic importance

REE are a group of seventeen metals that comprise the lanthanide series of 15 elements and two closely related elements scandium and yttrium. The REE have unique catalytic, metallurgical, nuclear, electrical, magnetic, and luminescent properties. Their strategic importance is indicated by their use in a number of emerging and diverse technologies that are becoming increasingly more significant in today's society. Currently applications range from traditional (such as lighter flints, glass polishing mediums, car alternators) to high-technology (lasers, magnets, batteries, fibre-optic telecommunication cables). They are also important for developing technologies crucial to our future (including high-temperature superconductivity, safe storage and transport of hydrogen for a post-hydrocarbon economy, monitoring climate change and energy efficiency). Consequently, over the last two decades, the global demands for REE have significantly increased.

REE are relatively abundant in the Earth's crust, but discovered minable concentrations are less common than for most other exploited metals. In 1992 China surpassed the United States of America as the world's largest producer of rare-earth oxides and was responsible for 95.5 per cent of the world's output in 2009.

Production in Australia

Small-scale production of REE has taken place in Australia in the past with yttrium-rich minerals (gadolinite) first mined in 1913 from a pegmatite vein in the Cooglegong region of Marble Bar, Western Australia. Australia's REE industry attained a higher international profile when REE-bearing heavy minerals (monazite and xenotime) were obtained as by-products from beach sand mining activities in Western Australia, New South Wales, and Queensland. During the 1970s and 1980s, Australia's annual production was about 12 000 tonnes of monazite and 50 tonnes of xenotime. Australia became the world's largest producer of monazite when production peaked in 1985 with 18 735 tonnes of monazite.

During the past decade there has been increasing industry interest in hard-rock REE deposits as the demand and global prices for these strategic metals have significantly increased. A number of deposits with significant resources (such as Mount Weld in Western Australia, Nolans Bore in the Northern Territory, and Toongi in New South Wales) in different geological settings are now at advanced stages of development. Their planned production contributions (2011 for Mount Weld, around 2013 for Nolans Bore) are likely to have a discernible impact on the global supply of REE.

Scope and objectives of review

This monograph, which is the first national synthesis of the REE since 1997, has compiled public information and data from a range of domestic and international sources as well as the latest information held by Geoscience Australia and the state and territory geological surveys. An important component of this information was derived from various mining companies operating in Australia and elsewhere. Using a mineral-systems framework, the monograph examines the elements considered important for the formation of REE deposits and it should stimulate future research into the geological characteristics of REE in Australia. It also provides suggested exploration guidelines relevant to Australia. There is also a compilation of recent products and national databases produced by Geoscience Australia that could assist the exploration for REE deposits. The publication can be downloaded through the Geoscience Australia website and is also available in a DVD format from the Geoscience Australia Sales Centre.

For more information

email ausgeomail@ga.gov.au

Related articles/websites

The major rare-earth-element deposits of Australia: geological setting, exploration, and resources by Dean M Hoatson, Subhash Jaireth & Yanis Mieizitis
https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=71820

Hydrocarbon seepage survey in northern Perth Basin

Between mid-September and mid-October scientists from Geoscience Australia will be exploring the continental margin off Western Australia. The survey area is west of Geraldton in the vicinity of petroleum exploration acreage release area W11-18 in the northern Perth Basin (see article in this issue). The marine survey (SS05-2011) will be using the Australian Government's Marine National Facility, the RV *Southern Surveyor* (figure 1) and is part of the agency's Basin Studies and Marine research programs. Collaborators on this survey include representatives from CSIRO in Perth as well as marine researchers from the Royal Netherlands Institute for Sea Research and the University of Ghent in Belgium.

The aim of the survey is to investigate and sample potential natural hydrocarbon seepage sites in the offshore northern Perth Basin. Detecting sites of natural hydrocarbon seepage will help petroleum explorers assess the prospectivity of release area W11-18, as seeps are direct evidence of an active petroleum system. Since natural hydrocarbon seeps also support rich and diverse biological communities on the seafloor, the survey will assist in understanding the distribution of marine benthic communities along this part of Australia's continental shelf.

The survey will supplement techniques developed during previous surveys undertaken as part of Geoscience Australia's Seeps and Signatures Project (see below). It will utilise a hydrocarbon sensor array (which detects oil in seawater) and a remotely operated vehicle (ROV). Within selected survey areas the morphology (or shape) of the seabed will be mapped with multibeam swath and sidescan sonar while sediments below the seabed will be visualised with a sub-bottom profiler. The hydrocarbon sensor array will help determine if any



Figure 1. The Australian Government's Marine National Facility the RV *Southern Surveyor* which will be used for the survey.

interesting features on the seabed are potential seeps. Those features interpreted to be likely seeps will be targeted using precision underwater video and sediment sampling with the ROV. Sediment from these areas will also be collected with cores and grabs for post-survey assessment in Geoscience Australia's geochemistry laboratories.

For more information

email ausgeomail@ga.gov.au

Related articles/websites

AusGeo News 75: Hope surfaces with gas bubbles in seep detection trial
www.ga.gov.au/image_cache/GA5018.pdf

AusGeo News 81: The northern Arafura Basin—a shallow water frontier
www.ga.gov.au/image_cache/GA7746.pdf

AusGeo News 85: No evidence of seepage in central North West Shelf
www.ga.gov.au/image_cache/GA9323.pdf

Frome airborne electromagnetic data Phase 2 release

Geoscience Australia has recently released the Phase 2 data package for the Frome airborne electromagnetic (AEM) survey. The Phase 2 data release contains new inversion and interpretation products developed from data in the Phase 1 data package (contractor supplied data) released in March 2011 (see *AusGeo News* 102).

The Frome AEM survey was flown between May and November 2010 and covers 95 450 square kilometres in South Australia's outback. The survey aircraft acquired 32 317 line kilometres of data using Fugro Airborne Surveys' TEMPEST™ system. The aircraft flew along east-west lines spaced 2.5 kilometres and 5 kilometres apart at a nominal height of 100 metres above ground. The survey was a collaborative project involving Geoscience Australia, the Department of Primary Industries and Resources South Australia (PIRSA) and a consortium of exploration companies.

The Phase 2 data includes products developed from the Phase 1 data using Geoscience Australia's layered earth inversion algorithm (GA-LEI; Brodie and Sambridge 2006). These value-added products include two new inversions: a sample-by-sample (SBS) inversion of the whole data set; and, a line-by-line (LBL) inversion of the dataset which excludes the Olary Range and the Murray Basin. The SBS inversion, where each of the samples is inverted independently,

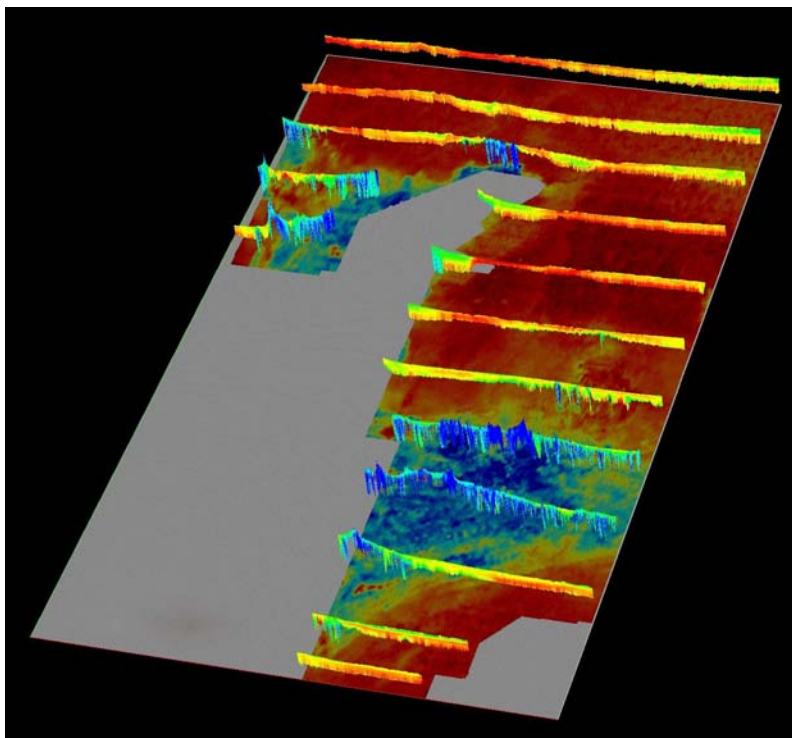


Figure 1. The Geoscience Australia layered earth inversion conductivity sections for some of the individual AEM survey lines, using 50X vertical exaggeration, over the 0 to 200 metre conductance grid for the Frome AEM survey.

is particularly useful in areas where the geology is not flat-lying, such as the Olary Range and northwestern Flinders Ranges. The LBL inversion, where a whole line is inverted simultaneously, favours laterally continuous geological models and is particularly useful in the Cenozoic stratigraphy of the Frome Embayment area. Together, they represent a powerful way to present and interpret AEM data (figure 1).

The Phase 2 data release includes ASCII datasets of the two inversions together with PDF format multiplots of each survey line, geolocated JPEG images of each survey line for both inversions (for easy display in a GIS package), GOCAD™ triangulated surfaces of each survey line for both inversions, ER Mapper™ format and geolocated JPEGs of gridded data (depth slices, elevation slices, conductance and depth of investigation) and ancillary data including ArcGIS shape files, metadata and explanatory notes.

A workshop to discuss the data will be held in the Mawson Theatre, Department of Geology and Geophysics, University of Adelaide, between 9:00 am and 3:00 pm on 30 November 2011. Scientists from Geoscience Australia and PIRSA as well as invited industry personnel will present interpretations based on the dataset and discuss the implications for the uranium, gold, copper and lead-zinc mineral potential of the Frome Embayment-Murray Basin

region. This workshop will coincide with the Sprigg Symposium (1 December) and the South Australian Explorer's Conference (2 December). An interpretation report, highlighting geological features and written by staff from both agencies will be published in late 2012.

The data are available for free download through the Geoscience Australia website or on DVD ROM for \$99.00 from the Geoscience Australia Sales Centre.

References

Brodie R & Sambridge M. 2006. A holistic approach to inversion of frequency domain airborne EM data. *Geophysics* 71: G301–313.

For more information

email ausgeomail@ga.gov.au

To reserve a seat at the Frome AEM survey interpretation workshop on 30 November 2011

email aem@ga.gov.au

Related articles/websites

Frome Embayment TEMPEST AEM Survey: Inversion Report and Data Package (Phase 2 data)

https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=72589

Frome Embayment TEMPEST AEM Survey, South Australia, 2010 Final Data (Phase 1 data)

https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=71624

Geoscience Australia's Airborne Electromagnetics Project

www.ga.gov.au/energy/projects/airborne-electromagnetics.html

Heat flow determinations for the Australian continent

Geoscience Australia has recently released the second and third reports in a planned series of reports of heat flow determinations across Australia. The second report contains data for seven boreholes including four in the Eastern Goldfields region of Western Australia and three in the Lake Frome region of South Australia. The third report contains an additional 24 heat flow determinations from across Australia including: Western Australia (Boddington, Kalgoorlie, Kambalda, Southern Cross), Victoria (Benambra), New South Wales (Braidwood, Cobar, Nyngan, Trangie), Queensland (Cloncurry, Maryborough) and the Northern Territory (Tennant Creek).



Currently heat flow data across the Australian continent are very sparse with the latest publicly available compilation containing less than 150 data points. To date, Geoscience Australia has increased the number of publicly available heat flow determinations across Australia by 41.

Geoscience Australia's Geothermal Energy Project has been recording temperature logs in existing boreholes across Australia as well as collecting drill core samples for laboratory analysis. Temperature logging is performed downwards in each hole with temperature recorded at 20 centimetre intervals. Drill core samples taken from the boreholes are measured using a divided bar thermal conductivity instrument in the Geoscience Australia laboratory.

The data and samples are used to calculate vertical heat flow, or the amount of heat energy passing vertically through the earth at any point, which helps to determine geothermal potential at each sample location. Heat flow is calculated by the product of the thermal gradient (change in temperature with depth) and

the thermal conductivity of the rock. Thermal conductivity varies as a result of a range of factors such as rock type and grain size.

These ongoing releases of new temperature and heat flow data are designed to support the emerging geothermal energy industry and encourage the development of a new low emission power generation technology.

For more information or to download a copy visit

Heat Flow Determinations for the Australian Continent: Release 2

https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=71773

Heat Flow Determinations for the Australian Continent: Release 3

https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=71774

Geoscience Australia's Geothermal Energy Project
www.ga.gov.au/energy/geothermal-energy-resources.html

New Isostatic Residual Gravity Anomaly Map of Australia (First Edition)



Figure 1. The new Isostatic Residual Gravity Anomaly Map of Australia.

A new printed version of the Isostatic Residual Gravity Anomaly Map of Australia at 1:5 million scale was recently released by Geoscience Australia. The map shows isostatic residual gravity anomalies across onshore Australia. Analysis of gravity anomaly values shows a relationship between terrain-corrected Bouguer anomaly values and the terrain height. This relationship is less evident after the isostatic correction which improves the resolution of anomalies.

The dataset is derived from observations recorded at approximately 1 500 000 gravity stations (or reference points) held in the Australian National Gravity Database (ANGD) by Geoscience Australia. The onshore data were acquired by the federal, state and territory governments, the mining and exploration industry, universities and research organisations over the six decades since the 1950s.

Continental Australia has a basic station spacing coverage of 11 kilometres; South Australia, Tasmania and part of New South Wales are covered at a spacing of 7 kilometres while Victoria has station coverage of approximately 1.5 kilometres. Recent government initiatives at state and federal level have funded systematic infill at a grid station spacing of 2, 2.5 or 4 kilometres to provide improved coverage in areas of scientific or economic interest. Other areas of detailed coverage have been surveyed by private companies for exploration purposes.

The depth-to-mantle model and subsequent isostatic

corrections were produced using a modified version of the United States Geological Survey program AIRYROOT (Simpson et al 1983) provided by Intrepid Geophysics. Geoscience Australia's 2009 Bathymetry and Topography Grid (Whiteway 2009) was used to calculate the depth-to-crustal bottom following the Airy-Heiskanen crustal-root model. The isostatic corrections were then applied to the complete Bouguer anomalies (Tracey and Nakamura 2010) to produce the Isostatic Residual Gravity Anomaly Grid of Australia. The gravity anomalies are based on the Australian Absolute Gravity Datum 2007 and the 1994 Geodetic Datum of Australia (Tracey et al 2008).

A crustal density of 2670 kilograms per cubic metre (kg/m^3) was used for the calculation, with an assumed density contrast between the crust and mantle of 400 kg/m^3 . A depth-to-mantle at sea level of 37 kilometres was used in the calculation. This was derived from the average Australian depth to the Mohorovičić discontinuity (Moho) at sea level using data from seismic studies around Australia (Goncharov et al 2007). The depth-to-Moho at sea level determined by the seismic velocities showed variations from 23.4 kilometres to 50.0 kilometres. This variability suggests that the assumption of isostasy may not be valid in certain areas. This is certainly the case in the Mount Isa region where seismic studies show a depth to Moho greater than 55 kilometres which does not occur in the Airy-Heiskanen model. However, the two models are broadly similar and the seismic data is too sparse for a national-scale crustal root model.

The complete Bouguer anomalies were gridded using a nearest neighbour gridding technique provided by the Intrepid Geophysics software package. The data were gridded to a cell size of 800 metres using Lambert Conic Conformal Projection Coordinates with standard parallels of 18° and 36° south and a central meridian of 134° east.

The geodetic version of the grid and the original onshore point located data can be downloaded free-of-charge in ERMMapper format from the Australian governments' Geophysical Archive Data Delivery System (GADDS).

References

- Goncharov A, Deighton I, Tischer M & Collins C. 2007. Crustal thickness in Australia: where, how and what for? Extended Abstracts, 19th International Geophysical Conference and Exhibition. Australian Society of Exploration Geophysicists.
- Nakamura A, Bacchin M, Milligan PR, Wynne P & Tracey R. 2011. Isostatic Residual Gravity Anomaly Map of Onshore Australia, scale 1:5 000 000. Geoscience Australia, Canberra. Available at: GEOCAT 69878
- Simpson RW, Jachens RC & Blakely RJ. 1983. AIRYROOT: A FORTRAN program for calculating the gravitational attraction of an Airy isostatic root out to 166.7 km. United States Geological Survey Open File Report 83–883.
- Tracey R, Bacchin M & Wynne P. 2008. AAGD07: A new absolute gravity

datum for Australian gravity and new standards for the Australian National Gravity Database. Extended Abstracts, 19th International Geophysical Conference and Exhibition.

Australian Society of Exploration Geophysicists.

Tracey R & Nakamura A. 2010. Complete Bouguer Anomalies for the Australian National Gravity Database: Extended Abstracts, 21st International Geophysical Conference and Exhibition. Australian Society of Exploration Geophysicists.

Whiteway TG. 2009. Australian Bathymetry and Topography Grid. Geoscience Australia Record 2009/21.

For more information

email ausgeo@ga.gov.au

Related articles/websites

Geophysical Archive Data Delivery System (GADDS).

www.geoscience.gov.au/gadds

INTREPID geophysical processing software

www.intrepid-geophysics.com/ig/index.php?lang=EN&menu=products-intrepidsoftware

New geophysical datasets released

Data from eighteen airborne magnetic/radiometric, electromagnetic and gravity surveys have been released since December 2010. These datasets can be interpreted to reveal the sub-surface geology of the survey areas and will be a valuable tool in assessing their mineral potential. The marine gravity and magnetic data over the Capel and Faust basins and the southwest margin (table 4) will greatly improve the understanding of Australia's marine jurisdiction.

Table 1. Details of the airborne magnetic, radiometric and elevation surveys.

Survey	Date	1:250 000 map sheets	Line spacing/ terrain clearance/ orientation	Line km	Contractor
AWAGS Magnetic Line Data	March– December 2007	Not applicable	75 km/ 80 m/ north–south	156 763	Aeroquest Airborne Pty Ltd
South Canning 1 WA	July 2010– February 2011	Runton (pt), Morris (pt), Madley (pt), Warri (pt), Herbert (pt)	400 m/ 60 m/ north–south	95 592	Aeroquest Airborne Pty Ltd
Eucla Basin 5 (North) WA	June 2010– February 2011	Forrest (pt)	200 m/ 50 m/ north–south	73 472	Fugro Airborne Surveys Pty Ltd
Eucla Basin 5 (South) WA	July 2010– April 2011	Eucla (pt), Noonaera (pt)	200/400 m/ 50 m/ north–south	80 247	Fugro Airborne Surveys Pty Ltd
Eucla Basin 2 WA	June 2010– April 2011	Loongana (pt), Forrest (pt), Madura (pt), Eucla (pt)	200 m/ 50 m/ east–west	114 562	Fugro Airborne Surveys Pty Ltd
Eucla Basin 4 WA	July 2010– April 2011	Naretha (pt), Madura (pt), Eucla (pt), Burnabbie (pt), Noonaera (pt)	200 m/ 50 m/ east–west	103 420	Fugro Airborne Surveys Pty Ltd
SE Lachlan NSW	March 2010– October 2010	Canberra (pt), Bega (pt), Mallacoota (pt)	250/500 m/ 60 m/ east–west	107 533	Fugro Airborne Surveys Pty Ltd
South Canning 2 WA	July 2010– April 2011	Morris (pt), Ryan (pt), Warri (pt), Cobb (pt)	400 m/ 60 m/ north–south	130 033	Aeroquest Airborne Pty Ltd
East Canning 3 WA	August 2010– January 2011	Lucas (pt), Stansmore	200/400 m/ 50 m/ north–south	122 591	Thomson Aviation Pty Ltd
Offshore East Tasmania	February–June 2011	Not applicable	800 m/ 90 m/ east–west	30 895	Fugro Airborne Surveys Pty Ltd

Table 2. Details of the gravity surveys.

Survey	Date	1:250 000 map sheets	Station spacing/ orientation	Stations	Contractor
West Arunta NT	June–October 2010	Mount Solitaire (pt), Lander River (pt), Highland Rocks (pt), Mount Theo (pt), Mount Peake (pt), Lake Mackay, Mount Doreen (pt), Napperby (pt) Mount Rennie (pt), Mount Liebig (pt) Hermannsburg (pt)	1, 2 & 4 km/ north–south, east–west grid	12 427	Atlas Geophysics Pty Ltd
Albany–Fraser North WA	October 2010– March 2011	Rason (pt), Neale (pt), Minigwal (pt), Plumridge (pt), Cundeelee (pt), Seemore (pt)	2.5 km/ north–south, east–west grid	9255	Atlas Geophysics Pty Ltd
Sandstone WA	August 2010– April 2011	Glengarry (pt), Sandstone (pt), Youanmi (pt), Barlee (pt)	2.5 km/ north–south, east–west grid	5760	Integrated Mapping Technologies Pty Ltd
South Gascoyne WA	August 2010– April 2011	Turee Creek (pt), Mount Egerton (pt), Glenburgh (pt), Robinson Range	2.5 km/ north–south, east–west grid	8932	Integrated Mapping Technologies Pty Ltd

Table 3. Details of the airborne electromagnetic surveys.

Survey	Date	1:250 000 map sheets	Line spacing/ terrain clearance/ orientation	Stations	Contractor
Frome (TEMPEST®) SA	May 2010– April 2011	Marree (pt), Callabonna (pt), Copley (pt), Frome (pt), Curnamona, Olary, Chowilla (pt)	2500 & 5000 m/ 120 (aircraft), 90 (sensor)/ east–west	32 730	Fugro Airborne Surveys Pty Ltd

Table 3 continued over page

Survey	Date	1:250 000 map sheets	Station spacing/ orientation	Stations	Contractor
Pine Creek– Kombolgie	August– November 2008; April 2009	Cobourg Peninsula (pt), Junction Bay (pt), Alligator River (pt), Millingimbi (pt), Mount Evelyn (pt), Katherine (pt).	1600 and 5000 m/ 80 (aircraft), 45 (sensor)/ east–west.	8780	Geotech Airborne Pty Ltd

Table 4. Details of the marine magnetic and gravity surveys.

Survey	Date	1:250 000 map sheets	Station spacing/ orientation	Km	Contractor
Capel and Faust Basins	November– December 2006	Not applicable	Ship track	9126	CGG Marine
Southwest margin surveys	1960–2009	Not applicable	Ship track	241 000	Various

For more information

email ausgeomail@ga.gov.au

Related articles/websites

Geophysical Archive Data Delivery System (GADDS)

www.geoscience.gov.au/gadds

Airborne electromagnetic survey data Kombolgie Phase-2 VTEM AEM survey final inversion data and conductivity models

https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=71372

Frome Embayment Phase-2 TEMPEST™ AEM survey final inversion data and conductivity models

https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=72589

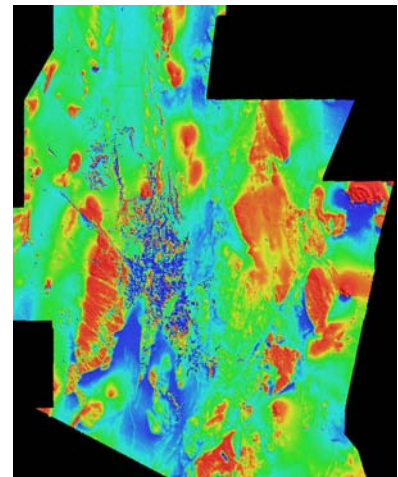


Figure 1. Total Magnetic Intensity image of a section of the southeast Lachlan airborne survey area.



Mining 2011 Resources Convention	26 to 28 October
Brisbane Convention and Exhibition Centre, Brisbane, Queensland Contact: Vertical Events, PO Box 1153, Subiaco WA 6904	P +61 8 9388 2222 f +61 8 9381 9222 e info@verticalevents.com.au www.verticalevents.com.au/ mining2011/
China Mining Congress and Expo	6 to 8 November
Ministry of Land and Resources, China Tianjin Meijiang Convention and Exhibition Centre, Tianjin, China Contact: China Mining Organising Committee	P +86 10 6446 6855 f +86 10 5885 7006 e info@china-mining.org www.china-mining.org/en/
IMTA (Asia Pacific) Global Conference and Trade Show 2011	10 and 11 November
International Map Trade Association Bangkok, Thailand Contact: Noleen Zander, IMTA (Asia Pacific), PO Box 1112, Unley SA 5061	P +61 8 8357 1777 f +61 8 8357 3001 e imtaaspac@chariot.net.au www.imtamaps.org/events/ displayevent.php?id=117
spatial@gov 2011 Conference & Exhibition	15 to 17 November
National Convention Centre, Canberra, ACT Contact: CeBIT Global Conferences, 80 Buckingham Street, Surry Hills NSW 2010	P +61 2 9280 3400 f +61 2 9280 1977 e cebit@hannoverfairs.com.au www.cebit.com.au/2011/conferences/ spatial-at-gov
Australian Geothermal Energy Conference	16 to 18 November
Australian Geothermal Energy Association and Australian Geothermal Energy Group Sebel Albert Park, Melbourne, Victoria Contact: Rob Bulfield, Sapro Conference Management	P +61 8 8274 6063 e agec2011@sapmea.asn.au www.ausgeothermal.com/
Surveying and Spatial Sciences Conference 2011	21 to 25 November
New Zealand Institute of Surveyors and Surveying and Spatial Sciences Institute Wellington Conference Centre, Wellington, New Zealand Contact: Conference Works Ltd, PO Box 1449, Wellington, New Zealand	P +64 21 2599 816 e convenor@sssc2011.org www.sssc2011.org
NAPE Expo 2011	22 to 24 February
American Association of Professional Landmen GBR Convention Center, Houston, Texas, USA Contact: NAPE, 4100 Fossil Creek Boulevard, Fort Worth, Texas 76137 USA	P +1 817 306 7171 f +1 817 847 7703 e info@napeexpo.com www.napeexpo.com/

For more information on Geoscience Australia's involvement in the above events email ausgeomail@ga.gov.au