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Continental resource and energy systems

Academy of Science recommendations drive new project

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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

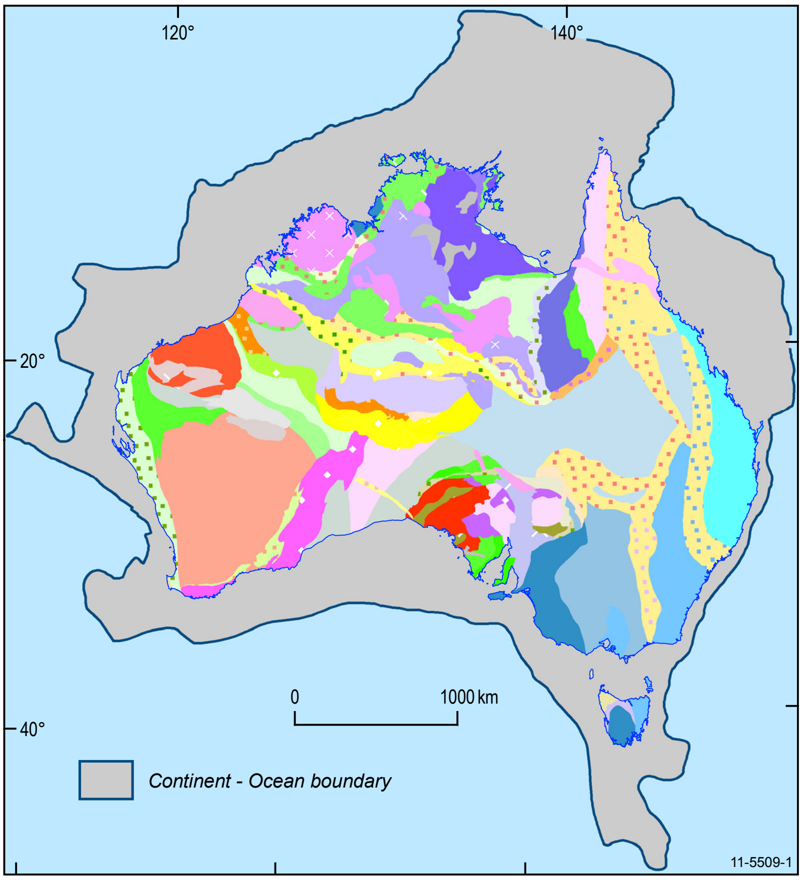

Figure 1. The 1995 Map of Australian Crustal Elements which interpreted the geometries of continent-scale geophysical domains under cover, based on magnetic and gravity datasets available at that time. See Shaw et al (1995, 1996) for the colour legend and explanation.

- 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.

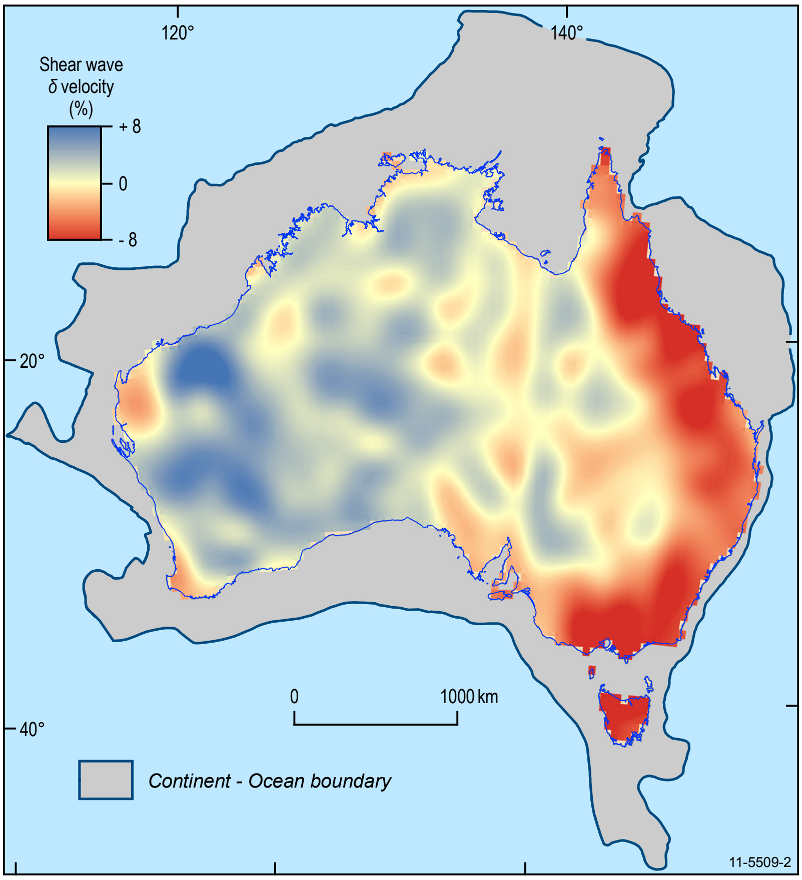

Figure 2. Isotropic shear wave inversion at 100 kilometres depth from Fishwick and Reading (2008). The cool and warm colours denote relatively fast and slow wave velocities, respectively, plotted as percentage perturbations from global reference model ak135.

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.

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.

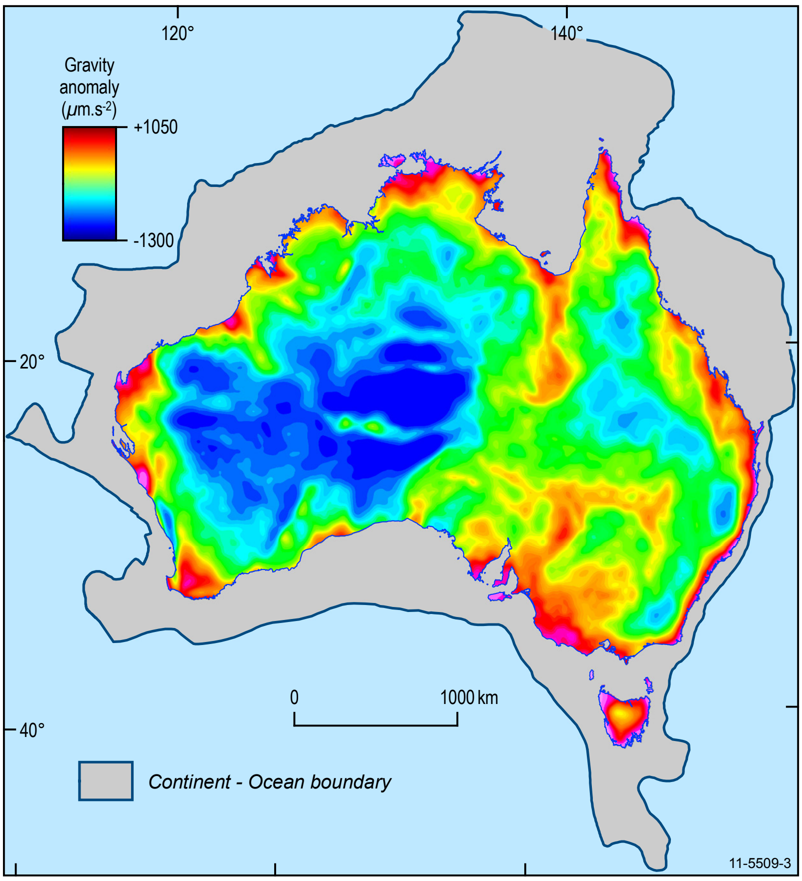

Figure 3. Bouguer gravity anomaly map of Australia, with data upwardly continued to 25 kilometres. The cool and warm colours, respectively, denote lower and higher density crustal rocks.

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 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.

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).

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 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.

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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

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