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Understanding Australia's Southwest Margin

Basement architecture as a framework for predictive basin analysis

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The Southwest Margin is a section of the continental margin off Australia's western coast. It includes the Paleozoic to Mesozoic Southern Carnarvon, Perth and Mentelle basins, as well as the Naturaliste and Wallaby plateaus. While several smaller hydrocarbon discoveries have been made onshore, the offshore region remains underexplored. Recent studies, however, indicate there is potential for new petroleum discoveries in many of these frontier areas (Nicholson et al 2008; Borissova et al 2010; Jones et al 2011).

Despite the new geological insights gained from these studies, depth-to-basement and basement structure and composition beneath the Southwest Margin sedimentary basins remain poorly understood. The extent of exposed basement outcrop is limited, only a few wells intersect basement and, in many areas, the basement horizon cannot be resolved using seismic data. An understanding of basement is however important when conducting basin studies, as the basement of any basin provides the foundation onto which sediment fill is deposited. As tectonic stresses are applied to a region, the rheology and mechanical behaviour of the basement influences how the crust deforms. Hence, variations in basement strength, composition and structure significantly influence the resulting basin geometry, patterns of sediment deposition and basement derived heatflow. All of these factors fundamentally affect the generation and preservation of hydrocarbon resources.

Geoscience Australia is currently engaged in a study to improve our understanding of the basement in the Southwest Margin region, which will generate the following products:

- regional gravity and magnetic datasets
- a map of interpreted basement terrane distribution
- maps of interpreted basement composition and structure
- a depth-to-basement model.

This work develops alternative technical methodologies to define the basement architecture so it can be used as a framework for predictive basin analysis when other datasets are unavailable. Although this study will primarily complement offshore petroleum exploration studies along a rifted margin, the methodologies described here are applicable to other exploration activities in many different geographic and tectonic settings.

New data

Geoscience Australia has assessed the prospectivity of the frontier areas of the Southwest Margin basins as part of the Australian Government's Offshore Energy Security Program (Geoscience Australia 2011; *AusGeo News* 103). This work included the acquisition of 7300 kilometres of new 2D seismic reflection data in 2008–09 and re-processing of 11 700 kilometres of open-file industry seismic data (*AusGeo News* 94). Whilst regional-scale interpretation of these data provided important new insights into the structural framework of the basins along this margin, the lack of a clear basement reflector makes it very difficult to resolve basement geometry and structure.

In addition, 26 000 line kilometres of new potential-field data were acquired as part of the Offshore Energy Security Program. These new data were merged and levelled (Hackney and Morse 2011; Hackney et al 2012) and combined with an existing Australia-wide dataset of levelled marine data (Petkovic et al 2001). The data were subsequently combined with onshore data from the 5th Edition of the Magnetic Map of Australia (Milligan et al 2010) and the 2010 release of the Australian National Gravity Database. The final compilation (figure 1) provides a consistent onshore/offshore dataset that covers the entire Southwest Margin of Australia, and is the primary dataset used for this study where seismic data is unavailable or no basement reflector can be resolved.

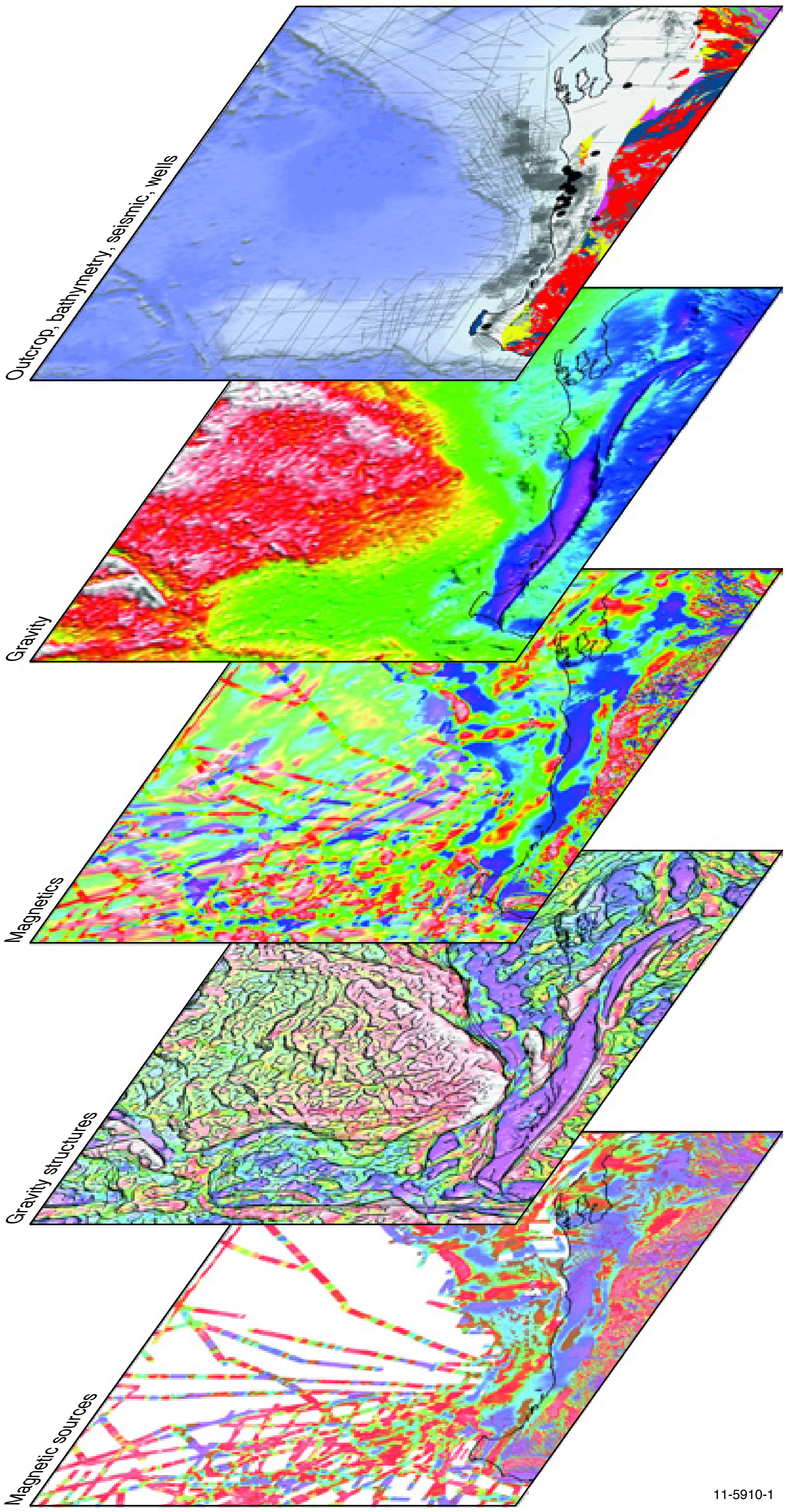

Figure 1. Datasets used for basement architecture interpretation of the Southwest Margin basins.

Insights into basement composition are provided from limited basement outcrop onshore, basement intersections in wells, and dredge samples (figure 1). Basement outcrop is restricted to the Northampton, Mullingarra and Leeuwin Complexes (figure 2), and approximately 30 basement penetrating wells have been identified across the Perth and Southern Carnarvon Basins which provide information on basement composition. In addition, sampling surveys conducted across the region over the last five years have obtained additional samples from basement rocks in the southern part of the study area (Halpin et al 2008; *AusGeo News* 94).

Basement terranes, structure and composition

New interpretive maps of basement terrane distribution, composition and structural fabric for the Southwest Margin will better characterise the nature of basement across the region. For this study, basement is defined as the economic basement for petroleum systems and represents all igneous and metamorphic rocks of Late Neoproterozoic/Early Cambrian age and older, as well as any younger plutonic intrusions and Mesozoic oceanic crust (Nicholson et al 2008; Borissova et al 2010; Jones et al 2011). The maps extend from the Naturaliste Plateau in the south to the Southern Carnarvon Basin and Wallaby Plateau in the north. In addition, they link the Archean Yilgarn Craton and surrounding Proterozoic mobile belts in the east through to the Early Cretaceous oceanic crust of the Indian Ocean to the west, and are therefore not constrained by the coast line or crustal type.

The basement terrane, structure and composition layers have been constructed through the integrated interpretation of all available geological and geophysical datasets, including outcrop, wells, geochronology, seismic, gravity, magnetic and bathymetry datasets (figure 1). The interpretation methodology is adapted from Shaw et al (1995, 1996) and FrOG Tech (2005). Direct geological observations (outcrop, wells or dredge samples) are compared with potential field characteristics to identify any relationships between observed basement composition and rock properties (density or magnetic susceptibility). There are also correlations between observed structural fabrics and equivalent trends in the potential field data. In addition, along the continent–ocean transition zone, a similar relationship is established between the observed seismic characteristics and potential field data.

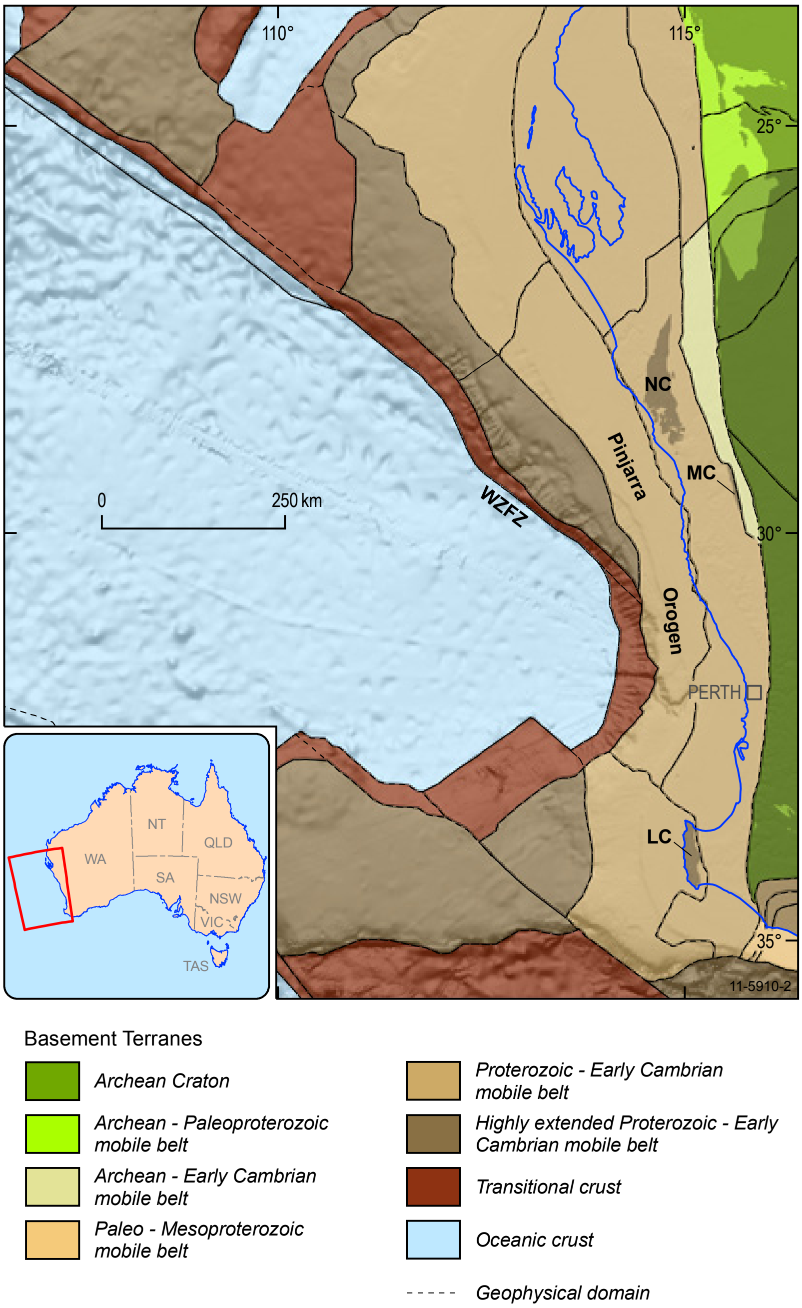

Figure 2. Basement terrane map showing terrane type (abbreviations: NH-Northampton Complex; LC-Leeuwin Complex; MC-Mullingarra Complex; WZFZ- Wallaby–Zenith Fracture Zone).

The potential field data are then used to predict basement terrane distribution, basement composition and structural fabric in areas where no other datasets are currently available. In addition, the Proterozoic to Mesozoic geological history of each basement terrane is assessed using all available geochronological data from the literature. Continental basement evolution is reviewed in the context of regional Proterozoic plate reconstructions (Collins and Pisarevsky 2005).

The basement terrane map shows regions of similar geological history, and is useful as a predictive tool for determining the likely generic geological history, composition and structural fabric of basement (figure 2). The terrane map provides new insights into the nature and distribution of terranes within the Neoproterozoic–Early Cambrian Pinjarra Orogen, and suggests that rocks with a strong affinity to the Northampton complex terrane may extend much further south than previously mapped. This has implications for sediment provenance studies in the Perth Basin and on the North West Shelf. The terrane map also includes an update of the continent–ocean boundary and associated continent–ocean transition zone which developed during the Mesozoic separation of Australia from India and Antarctica. This boundary effectively marks the limit of any potential petroleum occurrence.

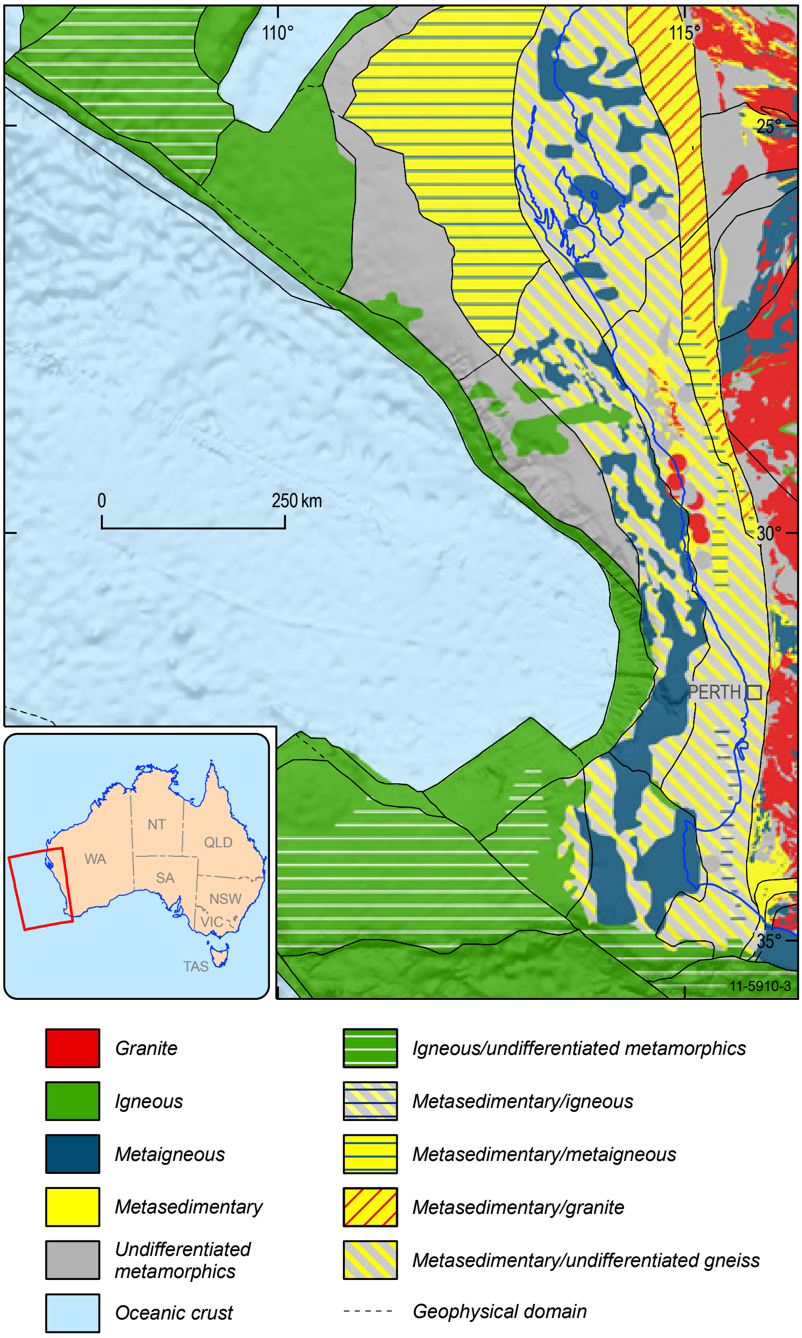

Figure 3. Basement composition map showing simplified primary rock type.

Major basement structures are mapped using basement outcrop, potential field and bathymetry data. The mapped structures include basement faults, dykes and general structural trends that can be identified in the potential field data. Basement trends associated with the Neoproterozoic Pinjarra Orogen appear to have had a profound affect on Late Jurassic–Early Cretaceous margin development. For example, the inception of the Wallaby–Zenith Fracture Zone correlates with a significant change in basement structural trend (figure 2). In addition, a linkage is evident between basement fabric orientation and basin geometry implying basement structures have significantly influenced basin evolution and hence patterns of sediment deposition through time.

The basement composition map (figure 3) is derived from all direct observations of basement composition, seismic basement characteristics and the potential field datasets. This map highlights potential variations in radiogenic basement-derived heatflow due to composition changes which may in turn influence the thermal evolution of the basin and hence petroleum source rock maturation.

Depth-to-basement

Sediment thickness is a fundamental factor in assessing the architecture, evolution and petroleum prospectivity of a basin. While seismic reflection data is an important tool for investigating sedimentary basins, deep basin architecture may be difficult to resolve in some seismic datasets. Because parts of the northern Perth Basin are susceptible to this problem, this study used magnetic methods to estimate the depth to major magnetic susceptibility contrasts, such as the sediment-basement interface or magmatic bodies, to resolve depth-to-basement in areas of limited seismic resolution.

Depth to magnetic basement was estimated using the spectral method of Spector and Grant (1970), which relates the wavelength of the magnetic grids to magnetic source depths (Johnston and Petkovic 2012). While many magnetic methods estimate depth-to-basement (Gunn 1997), the spectral method allows additional geological and geophysical data (such as well information, surface outcrop, gravity and seismic interpretations) to be integrated into the workflow. This results in a more geologically plausible depth-to-basement model. As part of this project, software has been developed which has allowed rapid implementation of this workflow.

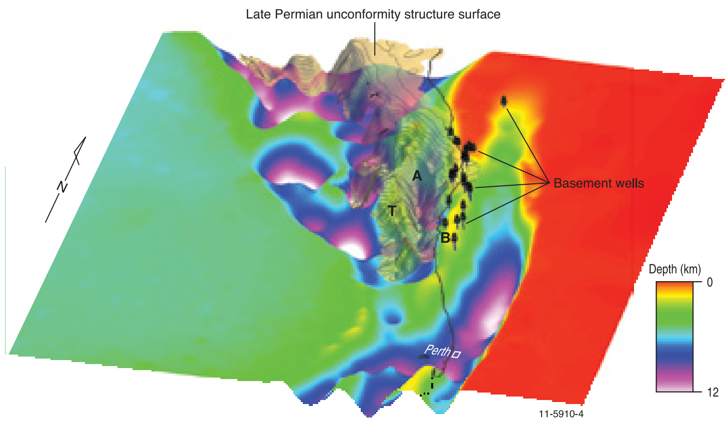

Figure 4. Perspective view of depth-to-magnetic basement map, derived from magnetic power-density spectrum, well depths and depth-converted seismic interpretation (abbreviations: A-Abrolhos Sub-basin; B-Beagle Ridge; T-Turtle Dove Ridge). Basement is overlain by the top Permian unconformity structure surface (Jones et al 2011).

The depth to Precambrian basement for the Perth Basin highlights the main sub-basins and structural highs and gives an indication of total sediment thickness (figure 4). For example, the Abrolhos Sub-basin is clearly delineated as a 32 kilometre-wide, elongate, north-northwest trending depocentre, located between the Beagle Ridge to the east and the Turtle Dove Ridge to the west. A comparison of the depth-to-basement map with the topography of the overlying Late Permian unconformity (see figure 7 in Jones et al 2011) gives further insight into the total thickness of early syn-rift/pre-rift sediments, beyond what may be resolved using seismic data alone.

Two-dimensional magnetic cross sections (forward models) were used to independently test the spectral depth-to-basement model and overall a good correlation was observed between the two methods (Johnston and Petkovic 2012). In addition, the modelled magnetic susceptibility variations across the Turtle Dove Ridge and Abrolhos Sub-basin are consistent with the interpreted basement composition variations described in the previous section.

Conclusions

This study provides a regional view of the simplified basement lithology, geometry and variation of basement across Australia's Southwest Margin based on the integration of numerous geophysical and geological datasets.

The spatial variation of basement terranes, composition and structural fabric is captured through a series of data products and interpreted maps, which can be used to predict regional-scale changes in basin geometry and patterns of sediment deposition over time. The depth-to-basement model integrates both geological and geophysical data to provide a new 3D view of total basin architecture, not obtainable from the seismic data alone, which better constrains the possible thickness of pre- and early syn-rift sediments. Future work will involve integration of new geochronological data and plate reconstructions to provide new insights into the timing and nature of the tectonic events controlling both the Proterozoic basement and the Mesozoic margin evolution.

The Southwest Margin basement architecture framework defined in this study demonstrates the application of basement studies for predictive basin analysis in the context of petroleum exploration in rifted margin settings. These workflows are equally applicable to studies on the adjacent Southern Margin and North West Shelf. In addition, the methodologies described here may be applied to other regional geological and exploration activities in many different geographic and tectonic settings.

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