Potential-field data for structural interpretation in the northern Perth Basin, Australia

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SUMMARY

New compilations of levelled marine and onshore gravity and magnetic data are facilitating structural and geological interpretations of the offshore northern Perth Basin. Multi-scale edge detection applied to these data helps the mapping of structural trends within the basin and complements interpretations based on seismic reflection data. Together with edge detection, magnetic source polygons determined from tilt angle aid in extrapolating exposed basement under sedimentary basins and, therefore, assist in the mapping of basement terranes. Three-dimensional gravity modelling of crustal structure indicates deeper Moho beneath the onshore and inboard parts of the Perth Basin and that crustal thinning is pronounced only under the outboard parts of the basin (Zeewcyk Sub-basin).

Key words: gravity, magnetics, Perth Basin, structure.

INTRODUCTION

The northern Perth Basin is an under-explored region of the southwest continental margin of Australia that formed from the Paleozoic to Mesozoic within an obliquely-oriented extensional rift system (Quaife et al., 1994; Mory and Iasky, 1996; Norvick, 2004). Onshore and inboard parts of the Perth Basin have proven hydrocarbon potential (e.g. Buswell et al., 2004). Work by Geoscience Australia as part of the Australian Government's Energy Security Program (2006–2011) sought to assess the prospectivity of the deep water parts of the basin. This new prospectivity assessment utilised 7300 km of new 2D seismic reflection data acquired in late 2008/early 2009 and re-processing of 11 700 km of open-file industry seismic data. The results of this work demonstrated significant prospectivity in the deep water regions of the northern Perth Basin and culminated in the release of a large new exploration acreage area (Jones et al., 2011).

Whilst regional-scale interpretation of new and existing 2D seismic reflection data has provided important new insights into the structural framework of the basin, a number of outstanding issues remain which cannot be addressed using the seismic data alone. Depth to basement, basement architecture and composition remain poorly determined in deep water regions. Integrated modelling and interpretation of potential-field data with other available geological and geophysical datasets are being used to provide additional means to map basement architecture and geometry.

This paper describes the geophysical methods that were applied to new merged datasets of levelled ship-track and onshore gravity and magnetic data. Multi-scale edge detection has been used as an aid to quantifying structural trends and basement architecture within the basin. The tilt angle filter was used for automated mapping of magnetic source polygons and three-dimensional (3D) gravity modelling has been used to investigate crustal structure.

NEW GRAVITY/MAGNETIC COMPILATIONS

To improve the coverage of geophysical and geological data over the frontier parts of Australia's southwestern margin, two marine surveys conducted in late 2008/early 2009 acquired about 26 000 line km of new potential-field data. These data were merged and levelled with an existing Australia-wide dataset of levelled marine data (Petkovic et al., 2001) to generate a dataset comprising about 240 000 line km of marine gravity and magnetic data. The marine 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 provides a consistent onshore/offshore dataset that covers the southwestern margin of Australia in the area bound by 106–120°E and 19–37°S. The portions of this dataset covering the northern Perth Basin are shown in Figure 1 (magnetics) and Figure 2 (gravity). The data are available for free download from the Geophysical Archive Data Delivery System (http://www.geoscience.gov.au/gadds/).

DATA ENHANCEMENT

Several enhancement techniques were applied to the new levelled gravity and magnetic datasets. Together with spectrally-based depth to magnetic basement estimates (Johnston and Petkovic, this volume), these enhancements aid the delineation of major tectonic elements and facilitate the interpretation of basement structure and composition.

Multi-scale edge detection

Gravity and magnetic lineaments have been mapped using multi-scale edge detection. This approach maps anomaly edges ("worms") from the total horizontal derivative of gravity and magnetic data at various upward continuation levels (e.g. Archibald et al., 1999; Hornby et al., 1999). Straight lines can be fit to the edge curves and used to aid structural interpretation (e.g. Milligan et al., 2003).

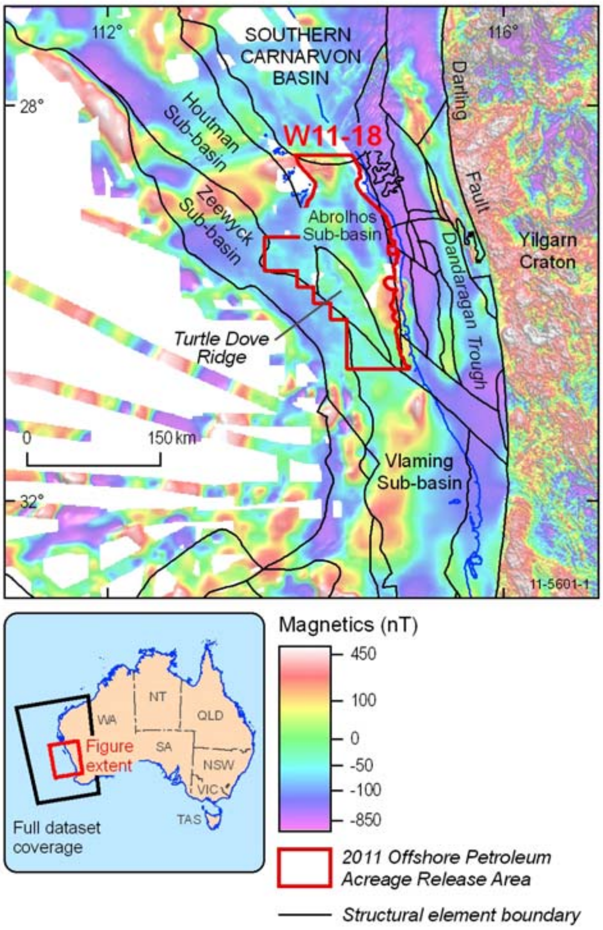

Figure 1. Magnetic anomalies for the Perth Basin region after variable-latitude reduction to pole. The grid includes levelled marine magnetic data merged with airborne data from the 5th Edition of the Magnetic Anomaly Map of Australia (Milligan et al., 2010). Structural element boundaries are revised from Jones et al. (2011).

Figure 3 shows gravity edges overlain by lineaments fit to the edge curves. The dominant trends are NW, NNW and NNE. The dominant magnetic trends (Figure 4) are similar to those in the gravity data, but an ENE trend is more prominent, particularly at long wavelengths through the northern Zeewyck and southern Houtman sub-basins.

Magnetic source bodies from tilt angle

To complement multi-scale edge detection, magnetic source bodies have been inferred from tilt angle, the angle whose tangent is the ratio between vertical and total horizontal derivatives (Miller and Singh, 1994). The magnetic source polygons are shown in Figure 4.

Interpretation

Multi-scale edge detection assists and corroborates interpretation of the structural fabric of the northern Perth Basin. Lineaments fit to worms highlight dominant gravity and magnetic trends and the relationships between them. As part of ongoing work, the dominant trends are being related to the main tectonic events that have shaped the southwestern margin (i.e. Rodinia assembly and break-up, separation of India and Australia during Gondwana break-up).

The magnetic source bodies allow the interpretation of basement terranes to be extended beyond areas of basement outcrop and areas with well control on basement character. The data also allow widely-separated areas with similar basement composition to be linked beneath the sedimentary cover. For example, there is a strong indication that source polygons through the Vlaming and Abrolhos sub-basins are linked (Figure 4). This apparent continuity of sources can be interpreted to suggest that the outboard parts of northern Perth Basin share a similar basement composition that is distinct from the onshore and near-shore parts of the Perth Basin where there is a lack of magnetic source bodies.

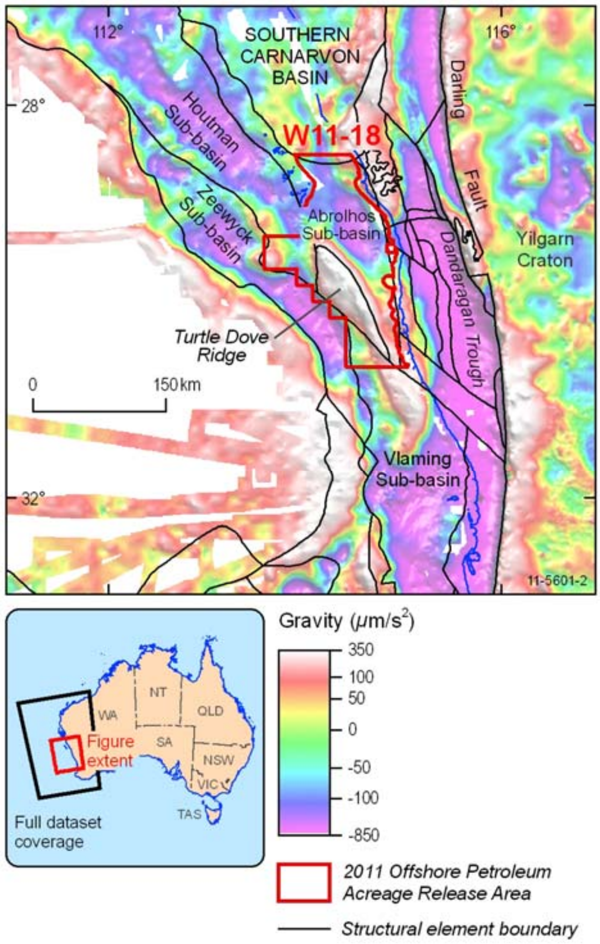

Figure 2. Residual gravity anomalies for the Perth Basin region derived by subtracting a 25 km upward-continued field from the Bouguer gravity. The grid includes levelled marine gravity data combined with data from the 2010 release of the Australian National Gravity Database.

CRUSTAL-SCALE 3D GRAVITY MODELLING

The aim of 3D gravity modelling of the northern Perth Basin is to test seismic interpretations of the sedimentary section and to provide interpretative guidance in areas with lower-quality seismic data or where the existing interpretation is inconsistent with the subsurface mass distribution reflected in the gravity field. This requires that the long-wavelength gravity signal of crustal structure also be accounted for, but constraints on crustal structure in this region are limited. To this end, initial 3D forward gravity models of the northern Perth Basin examined different models of crustal thickness to provide a crustal-scale framework for future modelling of the sedimentary section and underlying basement.

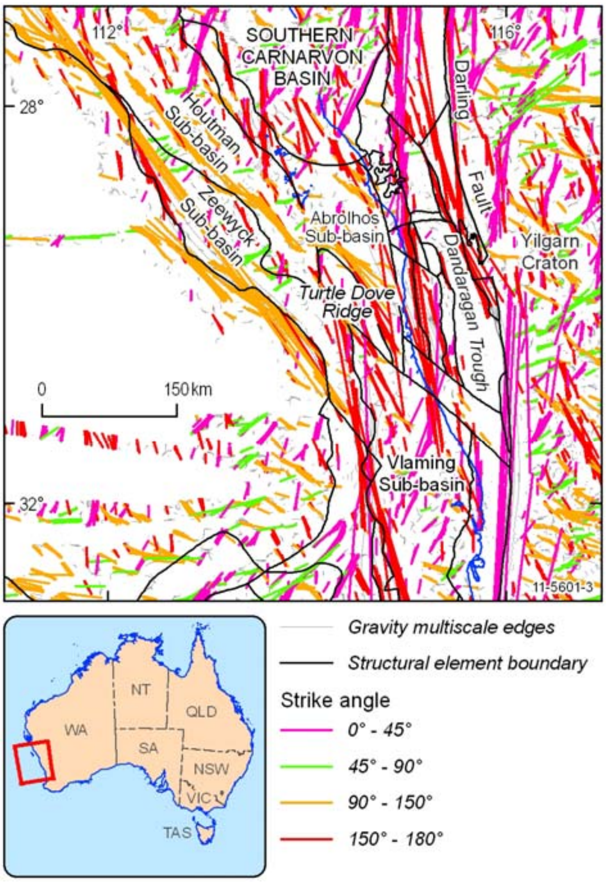

Figure 3. Gravity edges (grey) overlain by edge lineaments colour coded by strike. Edges were computed for 15 upward continuation levels (1.4– 155.6 km).

The models shown in Figure 5 incorporate the same sediment body defined by triangulating horizons interpreted from 2D seismic reflection lines to 3D. The sediments are divided into two layers defined by top basement and top Permian horizons (Mory and Iasky, 1996; Jones et al., 2011). The model densities are 3300 kg/m^3 for the mantle, 2800 kg/m^3 for the crust and 2650 kg/m^3 for the deeper (Permian) sedimentary layer. Based on well-log data, the post-Permian sediment layer has a density that increases linearly with depth from 2200 kg/m^3 to 2650 kg/m^3.

Two different crustal-scale models were considered. The first model (Figure 5a) incorporates a Moho computed under the assumption of local isostatic balance of water and sediment layers. This Airy-type model requires thinner crust under sedimentary basins and is more indicative of pure shear during extension. The gravity signature of the isostatically balanced crustal model fits poorly to observed data.

The second model (Figure 5b) incorporates data from an Australia-wide crustal thickness model (Aitken, 2010) derived from inversion of gravity data constrained by: 1) sediment thickness from the FrOG Tech Oz SEEBASE™ dataset; and 2) seismological estimates of Moho depth. The gravity computed for this model gives a better fit to observations in most areas, but this is not surprising given that the Moho used is itself derived from inversion of gravity data. Despite this, the model is significant because it suggests the thickness of crystalline crust is roughly constant across much of the northern Perth Basin.

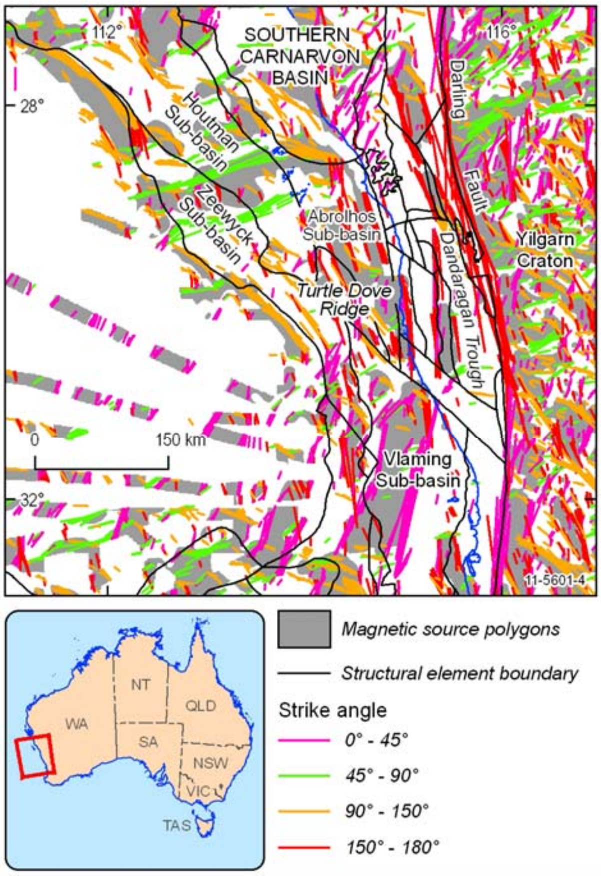

Figure 4. Magnetic anomaly edge lineaments, colour coded by strike, overlain on magnetic source polygons (grey) determined from positive tilt angle. Edge lineaments are shown for 12 upward continuation levels (4.0–159.5 km).

Taken together, the crustal geometries implied by the 3D gravity models indicate that pure shear stretching to form the northern Perth Basin is not compatible with the observed gravity signal. In contrast, the model with constant-thickness crystalline crust from the onshore Perth Basin to the South Turtle Dove Ridge suggests that the accommodation space for the onshore Perth Basin is dominantly generated by movement on a crustal-scale Darling Fault. Thinning of the crystalline crust only appears to become significant close to the edge of the margin under the Zeewyck Sub-Basin.

CONCLUSIONS

Geoscience Australia's efforts to better understand the structural architecture and petroleum prospectivity of the northern Perth Basin involves a comprehensive work program that incorporates constraints from a wide variety of data. Gravity and magnetic data are an integral part of this work program. The data are being used to: map anomaly trends for comparison with seismically-inferred structure maps; examine depth-to-basement in order to constrain maps of basement architecture; and to test or add to seismic interpretations using 3D gravity modelling. The combined interpretation highlights areas requiring further examination, but provides an enhanced understanding of the structure and basement architecture of the northern Perth Basin that underpins current and future releases of exploration acreage.

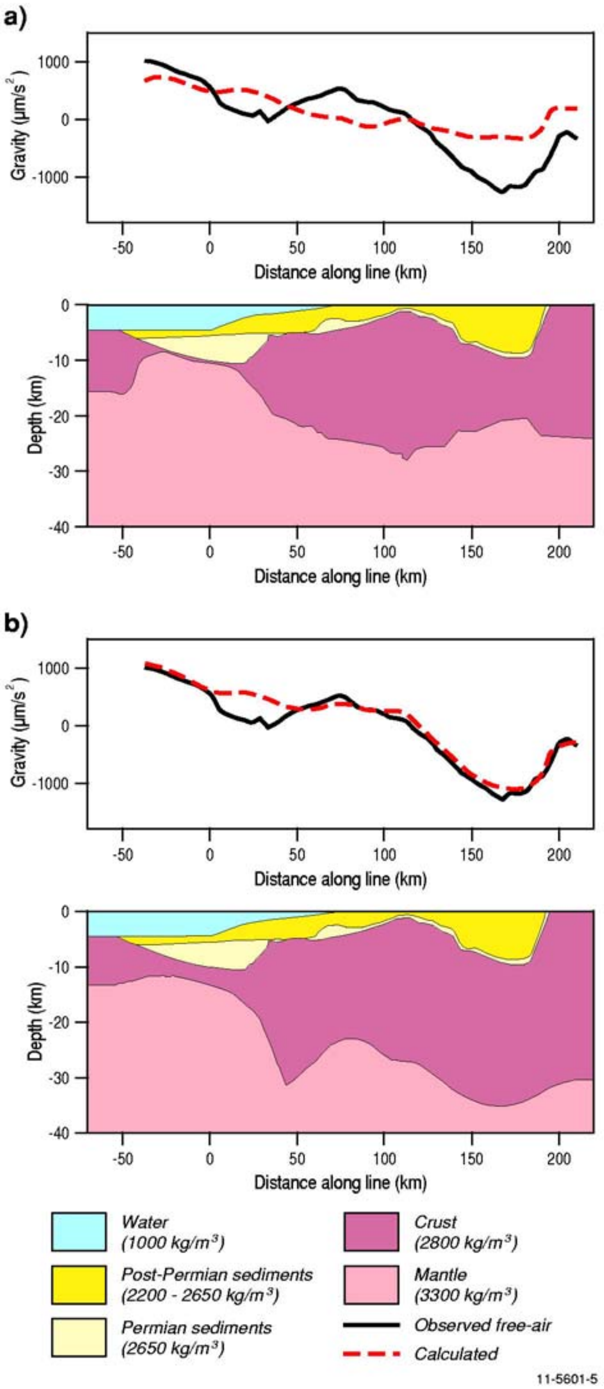

Figure 5. Example E–W profiles through two 3D gravity models of the northern Perth Basin. The Moho in the models is defined by (a) local isostatic balance of water and sediments and (b) a seismologically-constrained continent-wide gravity inversion (Aitken, 2010).

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