Depth to magnetic sources in the offshore northern Perth Basin

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SUMMARY

During 2009-11 Geoscience Australia completed a petroleum prospectivity study of the offshore northern Perth Basin. Basement in the northern Perth Basin is deep and generally not resolved in the reflection seismic data. Recent improvements to the magnetic ship-track database and magnetic anomaly grid allowed an assessment of depth to magnetic sources, and estimation of sediment thickness, providing new insight into basement depth and trends. 2D models along seismic transects and analysis using spectral methods indicate that penetration of the deepest sediments by high-susceptibility bodies is probable. The reflection seismic evidence for these bodies is not clear, though in some cases they may be associated with faults and structural highs. Where the modelled bodies penetrate the sediments they are mostly below or within the Permian strata. A moderate positive magnetic anomaly (the Turtle Dove Ridge) is modelled by massive bodies whose tops are 5-15 km below sea floor. The depth to magnetic basement map highlights sub-basins and structural highs within the northern Perth Basin, with up to 12 km of sediment in the Zeewyck sub-basin.

Key words: Northern Perth Basin, magnetic models, basement, sediment thickness

INTRODUCTION

The northern Perth Basin is located onshore and offshore on the southwestern margin of Australia. The initial basin forming event took place during the Paleozoic to Mesozoic within an obliquely oriented extensional rift system (Quaife et al., 1994; Mory and Iasky, 1996; Norvick, 2004). It has proven petroleum potential (e.g. Jones et al., 2011) but is under-explored.

In late 2008/09, as part of the Australian Government's Energy Security Program (2006–2011) Geoscience Australia acquired 2D reflection seismic data to assess the prospectivity of deep water frontier regions. The survey, GA-310, acquired 7300 km of 2D reflection recorded to 12 s two way time, off the southwestern margin of Australia. This acquisition together with existing industry data, has enhanced our understanding of the basin geology and structure (Jones et al., 2011; Hackney et al., this volume). However, due to the thick sediments and high degree of structuring of the basin, reflection seismic data did not image the geologic basement throughout most of the region, defined here to be Precambrian. Our study uses magnetic data, constrained by gravity and reflection seismic data, to investigate the northern Perth Basin basement geology and geometry.

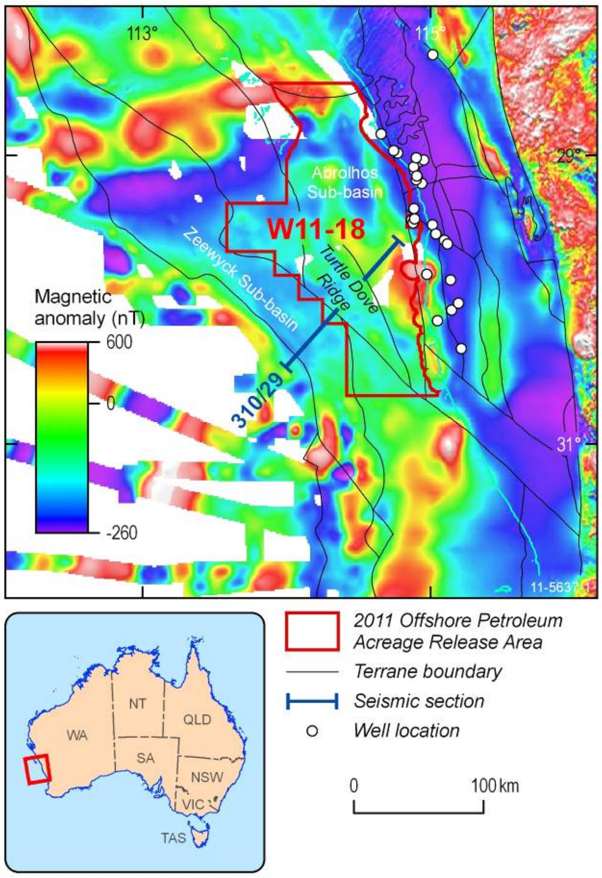

Figure 1. Location of study area in the northern Perth Basin showing the seismic line modelled, well locations, petroleum exploration permit release area W11-18 (red) and terrane and basin boundaries (black). The base image is the magnetic anomaly with a variable latitude reduction to pole (VRTP) (Hackney et al., this volume).

DATA

A new compilation of magnetic and gravity data from the southwestern margin of Australia (Hackney et al., this volume) was used in this study (Figure 1). This dataset is available from the Geoscience Australia Geophysical Archive Data Delivery System (http://www.geoscience.gov.au/gadds/). Depths to Precambrian units from wells were obtained from the Western Australian Petroleum and Geothermal Information Management System. Onshore interpretation of depth to basement from seismic data was taken from Mory and Iasky (1996).

METHODOLOGY

We used two approaches to estimate the depth to magnetic sources and the basement: 2D modelling along profiles and power spectrum analysis of the gridded magnetic anomaly map. Independently of this, an estimate of the seismic acoustic basement was interpreted on GA-310 seismic lines, though typically this was a depth representing the base of seismic resolution of the sedimentary section (BRS). This was used as an initial constraint on depth to basement in the 2D magnetic models, as there were no geological features identified in the reflection seismic data at depths that could explain the magnetic anomalies. The strategy for 2D magnetic modelling was to place magnetised bodies near the BRS depth to achieve a best fit between observed and computed magnetic field, regardless of the geological plausibility of the bodies. In recognition of their non-uniqueness, two sets of models were developed, placing bodies at shallow and deep locations (above and below BRS), in an attempt to identify their likely distribution.

A spectrally derived depth to magnetic basement model was developed independently of the 2D magnetic models. Our spectral method was based on previous methods where the azimuthally averaged power spectrum of a windowed magnetic grid is analysed for straight line segments (Spector and Grant, 1970; Connard et al., 1983; Blakely, 1996; Araña et al., 2000; Chiozzi et al., 2005). Spector and Grant (1970) showed that the gradient of straight line segments observed in the power spectra of magnetic grids are proportional to the depth to top of a random ensemble of magnetic sources of various geometries. Random, or uncorrelated, magnetisation of the crust is assumed in the Spector and Grant (1970) method, with the power spectrum following an exponential decay. This exponential decay is in disagreement with various other authors, who suggest that a power-law rate of decay is inherent in the power spectrum, which is the result of the fractal nature of magnetisation distribution in the crust (e.g. Pilkington and Todoeshuck, 1993). Fedi et al. (1997) introduce a correction factor, or β value, into the Spector and Grant method to account for this power law decay. However, the effect of this fractal correction factor has been shown to decrease with depth (e.g. Figure 7 of Fedi et al., 1997). We assume random crustal magnetisation because the fractal scaling parameter is unknown in this offshore continent-ocean transition zone. Also, the depths we are looking at are up to 15 km and uncorrected spectrally derived depths correspond well to depth to Precambrian basement from wells and depth converted seismic. Models that take the full power- spectrum into account have been developed for determining depth to top and bottom of magnetised layers (e.g. Bouligand et al., 2009), but as we are only interested in the top of basement, these models were not used.

Azimuthally averaged power spectra were calculated for 60 km x 60 km windows spaced with an 80% overlap throughout the study area. The power spectra were analysed using software developed by us. In some cases it is difficult to understand the geological significance of depths that are produced by modelling the magnetic power spectrum. For instance, if a magnetic power spectrum indicates the presence of ensembles of magnetic sources at multiple depths, how does one distinguish the top of magnetic basement from magnetic sources in the sedimentary section, or from deeper sources within basement? To deal with this uncertainty, wells and onshore seismic interpretation were employed to constrain top of magnetic basement depths, with Bouguer gravity being used to aid interpretation of power spectra showing multiple depth levels. For instance, where multiple depth levels were identified in a power spectrum located over a Bouguer gravity high, the shallowest depth level was interpreted as top basement, while the deeper points were inferred to be sourced from a deeper magnetic source ensemble. An example of this situation is given in Figure 2. The depth to magnetic basement map was integrated with depths to Precambrian strata from wells and depth converted seismic interpretation from both onshore (Mory and Iasky, 1996) and offshore.

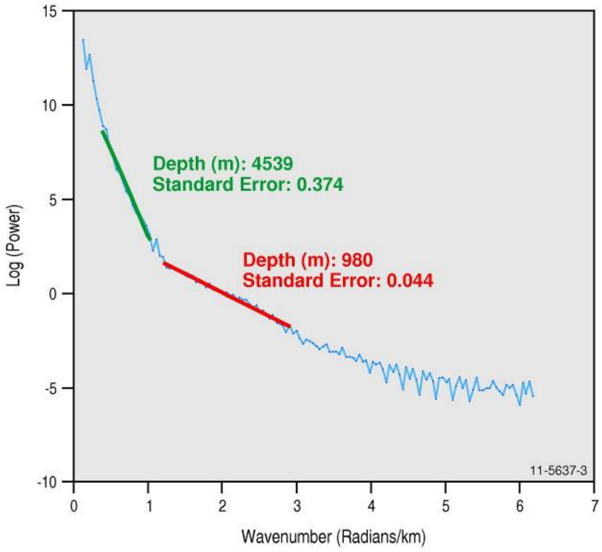

Figure 2: An example of a power spectrum containing multiple sources: one at ~ 980m, the other at ~ 4539m. As this power spectrum is located over a Bouguer gravity low, interpreted to be a sedimentary basin, the magnetic basement was interpreted to be related to the lower of the two magnetic source ensembles.

RESULTS

The depth to magnetic basement map, derived from magnetic power spectra, well and seismic data is given in Figure 3. Figure 4 shows a magnetic model for reflection seismic line GA-310/29 (Figure 1 and Figure 5).

The 2D models show magnetised bodies lying at 5 – 15 km depth and generally below the limit of seismic resolution. Where the bodies are modelled within seismic resolution, they are located stratigraphically at or below the Late Permian regional unconformity surface.

Sensitivity analysis of the models indicates that a range of acceptable depths can be modelled with only slight changes to magnetic susceptibilities. Horizontal locations of the bodies, however, are better defined. Zones of relatively higher magnetic susceptibilities are required beneath the Turtle Dove Ridge, which consists of a northwest trending structural high corresponding to a gravity high and a low magnetic signal along its axis. Seismic reflection data image the eastern flank of the Turtle Dove Ridge well, but the internal structure and western flank are poorly imaged (Figure 5). Our 2D magnetic model indicates that the flanks of the Turtle Dove Ridge are of higher magnetisation than the interior, perhaps due to magnetised dykes intruding along flanking faults. The relatively high magnetisation below the Turtle Dove Ridge may signal a distinct basement terrane whose origin differs from that of the surrounding lower magnetised basement. Bodies of lower magnetic susceptibility are modelled to the east and west of the Turtle Dove Ridge.

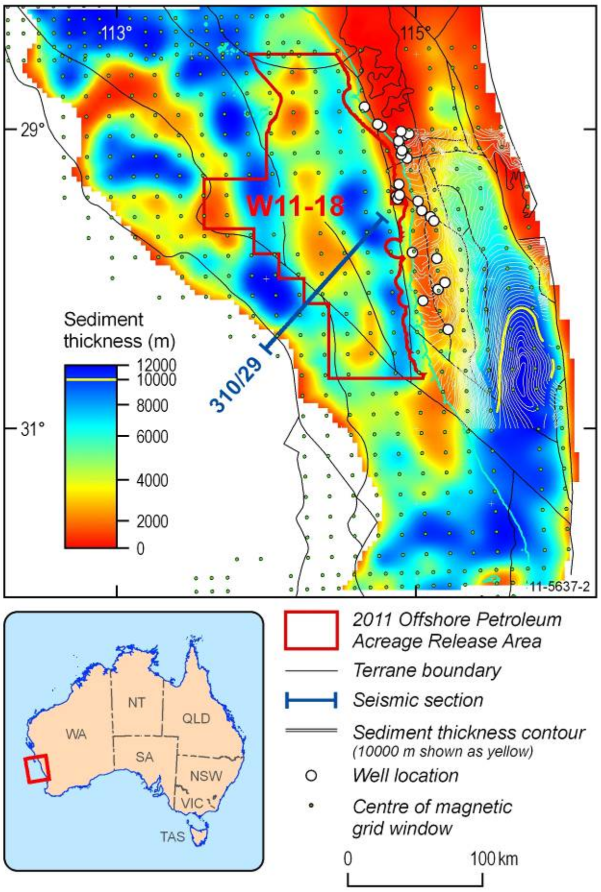

Figure 3. Depth to magnetic basement map, derived from magnetic spectrum depths and depth to Precambrian strata from wells and seismic interpretation. The blue line is the location of the 2D magnetic model shown in Figure 4 and respective seismic reflection line of Figure 5.

The depth to magnetic basement map (Figure 3) corresponds with the known sedimentary sub-basins and structural highs of the northern Perth Basin (cf. Figure 7 of Jones et al., 2011). The basement map shows up to 12 km of sediment indicated in the Zeewyck sub-basin west of the Turtle Dove Ridge where reflection seismic imaging does not resolve the base of the sediments. These thick sediments have encouraging implications for petroleum exploration in the area. The ~ 10 km of calculated sediment fill in the Abrolhos sub-basin correspond well with seismic reflection data.

The depth to magnetic basement determined using the spectral method is shallower than our 2D modelling of magnetised bodies, and may indicate that a significant component of the measured magnetic signal is derived from intra-basement sources.

CONCLUSIONS

Two dimensional magnetic modelling of the northern Perth Basin has shown that basement is generally composed of low susceptibility lithologies, with the Turtle Dove ridge comprising higher susceptibility lithologies. This may represent either magnetised intrusions or a separate basement terrane. Magnetic power spectra were used to create a depth to basement map of the northern Perth Basin. This map highlights structural highs and sub-basins of the region giving indications of sediment thickness where reflection seismic imaging does not resolve depth to basement.

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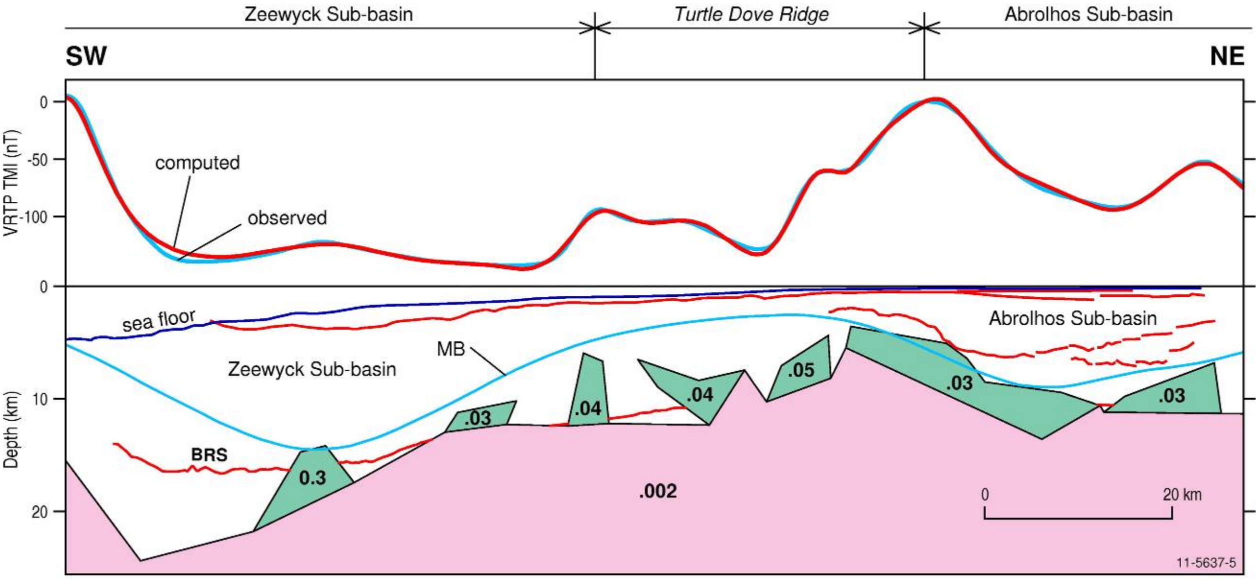

Figure 4. Two dimensional magnetic model for the GA-310-29 transect shown in Figure 1. MB is the projected depth to Precambrian basement by the spectral method (Figure 3). 'BRS' is 'base resolvable section'. The magnetic susceptibilities are SI units.

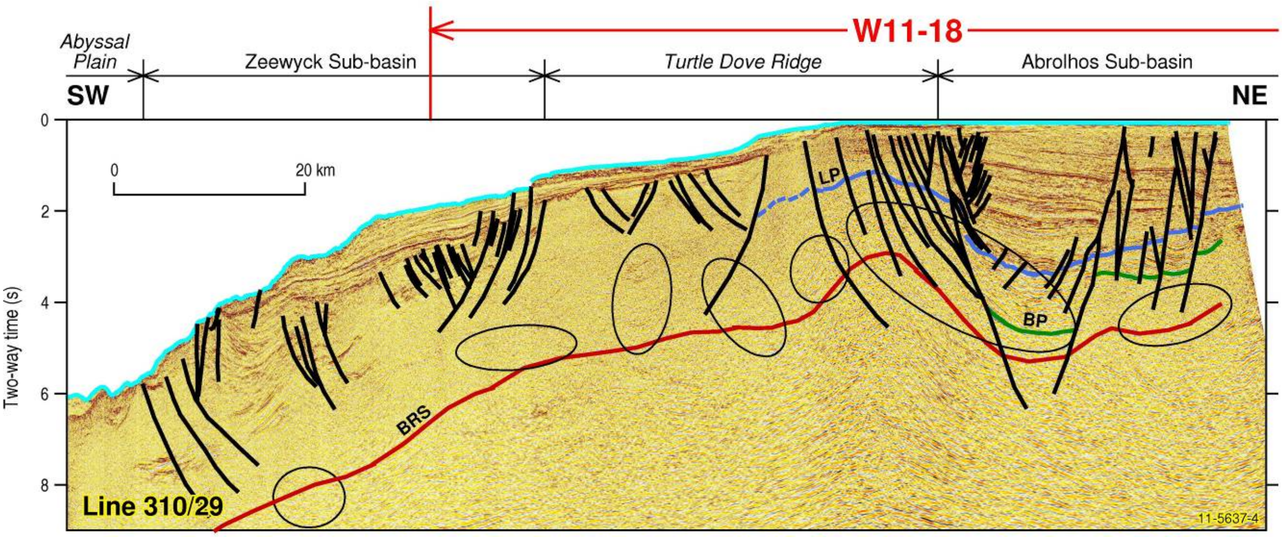

Figure 5. Reflection seismic data for line GA310-29 showing 0-9 s TWT and 125 km line length. Ellipses denote regions where magnetic bodies are modelled (Figure 4). 'BRS' is 'base resolvable section', BP is Base Permian and LP is Late Permian Unconformity.