ASEG-PESA 2015
Geophysics and Geology together for Discovery
24th International Geophysical Conference and Exhibition
15 – 18 February 2015 Perth, Western Australia

Interpretation and modelling of new Browse Basin airborne magnetic data for igneous rocks and basement

Ron Hackney
Geoscience Australia
GPO Box 378
Canberra ACT 2601
Ron.Hackney@ga.gov.au

Rowan Romeyn
Geoscience Australia
GPO Box 378
Canberra ACT 2601
Rowan.Romeyn@ga.gov.au

Claire Orlov
Geoscience Australia
GPO Box 378
Canberra ACT 2601
Claire.Orlov@ga.gov.au

SUMMARY

The Browse Basin on Australia's North West Shelf is a NE-trending Paleozoic to Cenozoic depocentre that contains more than 15 km of sediments. These sediments host significant hydrocarbon reserves, some of which are currently under development. The basin also has the potential to store large volumes of carbon dioxide. Recently-acquired aeromagnetic data over the Browse Basin provide new impetus for studies of the nature of basement, the role of structural inheritance and controls on the distribution of volcanic rocks.

Initial interpretation of the new magnetic data has utilised magnetic source polygons and depth estimates derived from the tilt-angle filter. Exploration wells that intersect mainly volcanic flows or tuffaceous rocks tend to lie on or adjacent to source polygons. Computed tilt depths show that these sources tend to coincide with the depth to the top of volcanics in wells and that tilt depths extend deep into the basin (up to ~10 km). The magnetic susceptibility distribution inferred from minimally-constrained, regional-scale inversion models also indicates that magnetic anomalies arise from features deep in the basin and within basement. These results highlight the importance of understanding the role of volcanic rocks in basin evolution and their influence on reservoirs that may host hydrocarbons or that may be suitable for CO_2 storage.

Key words: Browse Basin, volcanics, magnetics, inversion modelling, tilt depth.

INTRODUCTION

The Browse Basin (Figure 1) is a northeast-trending Paleozoic to Cenozoic depocentre located offshore in the Timor Sea region of Australia's North West Shelf. The basin contains a Paleozoic, Mesozoic and Cenozoic sedimentary succession in excess of 15 km thick (Struckmeyer et al., 1998) and also considerable volumes of breakup-related magmatic rocks (Symonds et al., 1998). The main structural elements of the basin include the Barcoo and Caswell sub-basins and the Leveque and Yampi shelves in water depths that reach about 2000 m. The outboard and frontier parts of the basin include the Scott Plateau and Seringapatam Sub-basin in water depths of up to 5000 m.

The Caswell Sub-basin hosts several large gas fields planned for Liquefied Natural Gas (LNG) and condensate development. Gas accumulations in the Browse Basin are naturally high in carbon dioxide (CO_2) and initial assessments indicated that the Browse Basin has the capacity to store more than 7 GT of CO_2 (Carbon Storage Taskforce, 2009).

Geoscience Australia's current focus on the Browse Basin as a potential area for CO_2 storage also involves a review of the sequence stratigraphic framework of the basin and analysis of data from marine sampling surveys conducted on the Leveque Shelf in 2013 (Picard et al., 2014) and in the Caswell Sub-basin during late 2014. The current work in the Browse Basin is the precursor to further regional studies of the northern and western margins of Australia that aim to identify, characterise and map structural events and the structural architecture of margin basins. This mapping will aid interpretations of the nature of basement, the role of structural inheritance and help to better understand the distribution of volcanic rocks.

BROWSE BASIN MAGNETIC DATA

Recognising the benefits of airborne magnetic data to regional basin studies, an airborne magnetic survey was conducted over the Browse Basin during 2013 (Figure 1). The survey was conducted as part of the National CO_2 Infrastructure Plan (2012–15) that aims to acquire, interpret and integrate new and existing pre-competitive data to assess the suitability of various basins for the geological storage of CO_2. Obtaining airborne magnetic data is a cost effective and relatively quick way to provide additional constraints on important characteristics of sedimentary basins that include sediment thickness, fault architecture, distribution of igneous rocks and basement composition. These characteristics influence the hydrocarbon prospectivity of a basin and its potential to store CO_2.

Thomson Aviation were contracted to acquire the new magnetic data over the Browse Basin. From late August to early November 2013, two aircraft acquired about 190,000 line kilometres of data along north-south traverses spaced 800 m apart and east-west tie lines spaced 4000 m apart, all at a nominal flying height of 80 m above sea level (Rogerson, 2014). The data are available for download from the Geophysical Archive Data Delivery System (http://www.ga.gov.au/gadds).

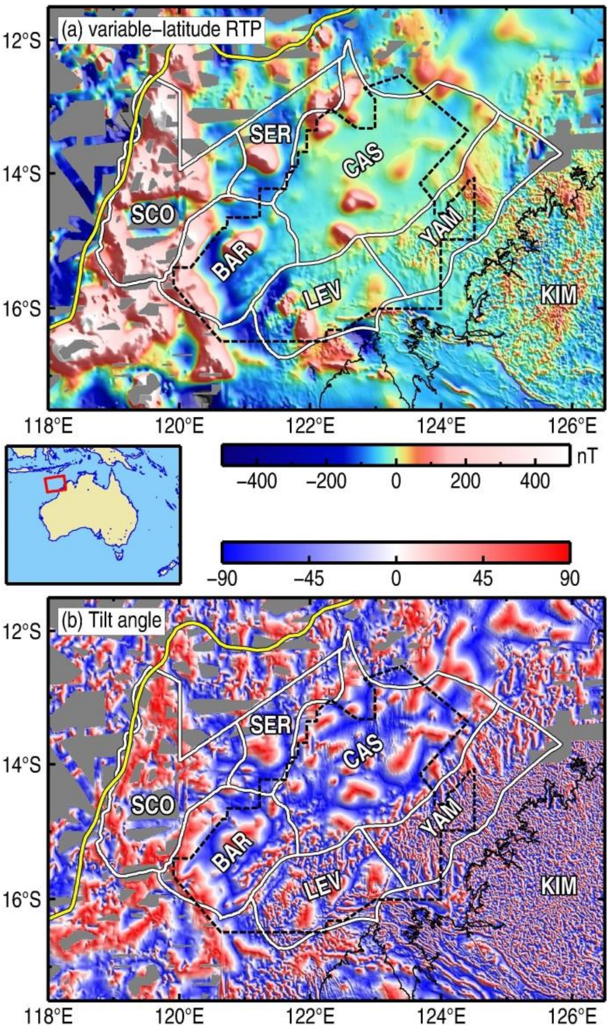

Figure 1. (a) Merged variable-latitude RTP grid of the new Browse Basin airborne magnetic data (dashed outline) with existing ship-track and airborne data after upward continuation to 1 km. (b) Tilt angle computed from the merged grid. The main structural elements of the basin and surrounding area are shown (SCO, Scott Plateau; SER, Seringapatam Sub-basin; BAR, Barcoo Sub-basin; CAS, Caswell Sub-basin; LEV, Leveque Shelf; YAM, Yampi Shelf; KIM, Kimberly Block). The yellow line marks the continent–ocean boundary.

The new data have been merged with existing ship-track and airborne data over the Browse Basin (Figure 1). Features evident in this merged dataset include:

- high-frequency anomalies, similar in character to the onshore Kimberley Block, that extend beyond the Yampi and Leveque shelves—this anomaly pattern is attributable to magnetic features in basement (e.g. dykes, magnetised basement rocks);
- ovate positive anomalies of various wavelengths in the Caswell and Barcoo sub-basins—these anomalies are attributed to Late Jurassic break-up related volcanic rocks (e.g. Jason et al., 2004);
- an extensive, long-wavelength high bound to the west by the continent–ocean boundary that coincides with the Scott Plateau and outer Barcoo Sub-basin—this broad anomaly can be attributed to flood basalts erupted around the time of breakup (Symonds et al., 1998).

INTERPRETATION AND MODELLING

Initial interpretation of the merged Browse Basin magnetic dataset has incorporated source depth estimation and mapping of source bodies from tilt-angle filtered data, as well as regional-scale inversion modelling. The initial results of this work are outlined below.

Tilt angle

The "tilt-angle" is a quantity derived from the ratio of vertical to total horizontal derivative and is defined by Miller & Singh (1994) as:

$$tilt\ angle = \tan^{-1}\left(\frac{vertical\ component\ of\ gradient}{horizontal\ component\ of\ gradient}\right).$$

The tilt angle tends to normalise anomaly amplitudes and also has the quality that it is positive over vertically-sided anomaly sources. This means that polygons enclosing positive tilt angle can be used to help identify source bodies irrespective of magnetisation direction (cf. Morse, 2010). In addition, Salem et al. (2007) show that the horizontal distance between the ±45º contours of the tilt angle is related to magnetic source depth. Tilt angle for the merged grid of Browse Basin magnetic data is shown in Figure 1b.

Magnetic source-body mapping

Magnetic source polygons derived from the tilt angle are shown in Figure 2a together with wells that intersect igneous rocks or basement. Information from well completion reports shows that many wells in the Browse Basin intersect Jurassic extrusive igneous rocks (Figure 2a). Intrusive rocks are intersected in a limited number of wells, while a number of wells on the shelf intersect crystalline basement.

Figure 2a shows that exploration wells in the outer Caswell Sub-basin that intersect extrusive igneous rocks mostly correlate with relatively narrow magnetic source polygons (width 20–30 km). This indicates that the igneous rocks are the source of the magnetic anomalies. In the central Caswell Sub-basin, wells that intersect tuffs and volcanic flows also coincide with broader magnetic source polygons (width ~50 km) that most likely reflect magnetisation within the deeper parts of the basin or within basement.

Wells in the Barcoo Sub-basin mostly intersect volcanic flows. These intersections coincide with broad source polygons that are similar to those in the Caswell Sub-basin and also suggest that the volcanic flows are the source of the magnetic anomalies. On the Leveque and Yampi shelves, the association between source polygons and wells that intersect basement is consistent with magnetic anomalies in these areas arising from magnetisation within basement.

The overall correlation between igneous rocks in exploration wells and source polygons derived from tilt angle means that the source polygons can be used to help map the distribution of igneous rocks within the basin.

Tilt depth

Source depths estimated using the tilt depth approach described by Salem et al. (2007) are shown in Figure 2b together with the depth to the shallowest igneous rocks or basement in petroleum exploration wells. Tilt depths lie in the range 0–10 km. The seismically-inferred sediment thickness in the Browse Basin reaches around 15 km (Figure 2b), which means that the magnetic source bodies are located primarily within the sedimentary section.

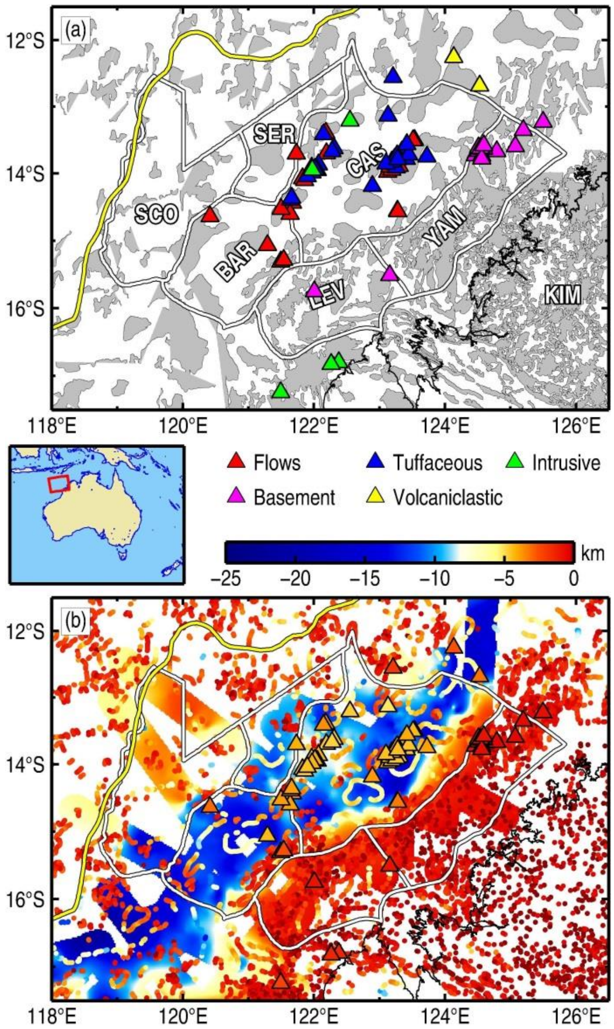

Figure 2. (a) Magnetic source polygons derived from the tilt angle (Figure 1b) plotted with wells that intersect various types of igneous rocks or basement. (b) Tilt-depth estimates (dots) and the depth to shallowest igneous rocks (or basement) in exploration wells (triangles). Gridded depth to basement interpreted from seismic reflection data (AGSO, 2001) is also shown (depth converted using stacking velocity data from the Caswell Sub-basin). The outlines of Browse Basin structural elements and the continent–ocean boundary are as in Figure 1.

Tilt depths are shallowest over the Leveque and Yampi shelves where water depth is shallow (<100 m) and sediment is thinnest. Wells in shelf areas intersect basement at 0.7–1 km depth and tilt depths in this area are generally <1 km (Figure 2b). The largest tilt depths are evident in the central Barcoo Sub-basin, in the Seringapatam Sub-basin, and through much of the inboard Caswell Sub-basin. In these areas, the tilt depths are deeper than Jurassic extrusive igneous rocks that are intersected in exploration wells at ~4–5 km depth (Figure 2b). This broad range of depths suggests the presence of substantial volumes of igneous material in the deeper parts of the basin that are either temporally related to magmatic activity associated with breakup or are representative of older igneous rocks that pre-date breakup.

Regional-scale inversion modelling

In order to help constrain the nature of basement to the Browse Basin and to help delineate the distribution of magmatic rocks within the basin, regional-scale 3D inversion modelling was undertaken using Mag3D v5.0 from the University of British Columbia's Geophysical Inversion Facility (UBC-GIF). The inversion models cover a large area (750×500×25 km, plus 50 km padding in the x-y direction) with a cell size of 2×2×1 km and comprise ~3.2 million cells. These regional models aimed to capture the whole of the Browse Basin as well as the continent–ocean boundary and the onshore Kimberley Block. The depth of the models was selected to capture basin and basement geology down to the Curie depth.

The inversion models were constrained by surfaces representing seafloor and topography, a depth-converted basement horizon previously interpreted from seismic reflection data (Figure 2b; AGSO, 2001), and a Curie depth at 23 km that was inferred by assuming a geothermal gradient of 25°C/km. In this way, the magnetic susceptibility of basin rocks and basement could be treated separately and sea water could be fixed to zero magnetic susceptibility.

The results of the regional-scale inversion modelling suggest that the regional magnetic field of the Browse Basin can be explained by:

1) Magnetisation entirely within basement (i.e. it is not necessary to invoke magnetisation within the sediments); or
2) Dominant magnetisation within basement and a component of magnetisation in the deeper parts of the sedimentary succession (Figure 3).

At this regional scale, these models do not indicate a dominant component of magnetisation within the sedimentary succession that could be related to magmatic rocks (Figure 3). This is despite the fact that well and seismic information shows that, in parts of the basin, igneous rocks are abundant in the Jurassic succession. However, due to the horizontal cell size in these regional models (2 km), the magnetic data used in the inversion were upward continued to 2 km. This has resulted in the loss of higher frequency magnetic signal potentially attributable to shallower igneous bodies within the basin. Higher resolution models of smaller volumes are therefore required to further constrain and understand the distribution of magnetised intra-sedimentary igneous sources. Remanence will also need to be considered, but can't be accounted for using the UBC-GIF inversion code.

CONCLUSIONS

Newly-acquired airborne magnetic data vastly improves the coverage and resolution of magnetic data over the Browse Basin. These data provide fresh impetus for studies of sediment thickness, fault architecture, distribution of extrusive and intrusive igneous rocks and basement composition. Whilst the existence of extrusive volcanic rocks and related intrusive rocks in the basin is well known from seismic reflection data, the new magnetic data provide additional constraints that help to map the distribution of these rocks within the basin. Source polygons and tilt depths confirm that magnetic anomalies arise from Jurassic breakup-related igneous rocks that are intersected in exploration wells. However, tilt depths as deep as 10 km suggest the existence of considerable volumes of igneous rocks in pre-breakup (i.e. pre-Jurassic) strata of the inboard Caswell Sub-basin as well as in the Seringapatam and Barcoo sub-basins. In addition, regional-scale inversion models indicate that magnetic sources are also prevalent in basement.

ACKNOWLEDGMENTS

We thank Jennie Totterdell and Tony Meixner for reviewing this abstract, Marina Costelloe and Murray Richardson for facilitating data acquisition and processing, Peter Milligan for computing tilt depths and James Goodwin for help with UBC-GIF inversion modelling. This paper is published with the permission of the Chief Executive Officer of Geoscience Australia.

REFERENCES

AGSO, 2001, Line drawings of AGSO–Geoscience Australia's Regional Seismic Profiles, Offshore Northern and Northwestern Australia. Australian Geological Survey Organisation Record 2001/36.

Carbon Storage Taskforce, 2009, National Carbon Mapping and Infrastructure Plan - Australia: Full Report, Department of Resources Energy and Tourism, Canberra, 126pp.

Jason, R., McMurtrie, G. and Keall, J., 2004, Hydrocarbon potential of the outer Browse Basin, NW Australia, Proceedings, IPA–AAPG Deepwater and Frontier Exploration in Asia and Australasia Symposium, December 2004, 11pp.

Miller, H.G. and Singh, V., 1994, Potential field tilt—a new concept for location of potential field sources, Journal of Applied Geophysics, 32, 213–217.

Morse, M., 2010, Potential field methods prove effective for continental margin studies, AusGeo News 98.

Picard, K., Nichol, S., Hashimoto, T., Carroll, A.G., Bernardel, G., Jones, L.E.A., Siwabessy, P.J.W., Radke, L.C., Nicholas, W.A., Carey, M., Howard, F.J.F., Tran, M. and Potter, A., 2014, Seabed Environments and Shallow Geology of the Leveque Shelf, Western Australia SOL5754 (GA0340) Post Survey Report, Geoscience Australia Record 2014/10.

Rogerson, P., 2014, Geoscience Australia Project 1258 (G2023AM) Airborne Geophysical Survey Operations and Processing Report: Browse Basin, Thomson Aviation Geophysical Survey, 41pp.

Salem A., Williams, S., Fairhead, J.D., Ravat, D. and Smith, R., 2007, Tilt-depth method: A simple depth estimation method using first-order magnetic derivatives, The Leading Edge, 26, 1502–1505.

Struckmeyer, H.I.M., Blevin, J.E., Sayers, J., Totterdell, J.M., Baxter, K. and Cathro, D.L., 1998, Structural evolution of the Browse Basin, North West Shelf: New concepts from deep-seismic data, In: Purcell, P.G. and Purcell, R.R. (Editors), The Sedimentary Basins of Western Australia 2: Proceedings, Petroleum Exploration Society of Australia Symposium, Perth, 1998, 345–367.

Symonds, P.A., Planke, S., Frey, O. and Skogseid, J., 1998, Volcanic evolution of the Western Australian continential margin and its implications for basin devclopment, In: Purcell, P.G. and Purcell, R.R. (Editors), The Sedimentary Basins of Western Australia 2: Proceedings, Petroleum Exploration Society of Australia Symposium, Perth, 1998, 33–53.

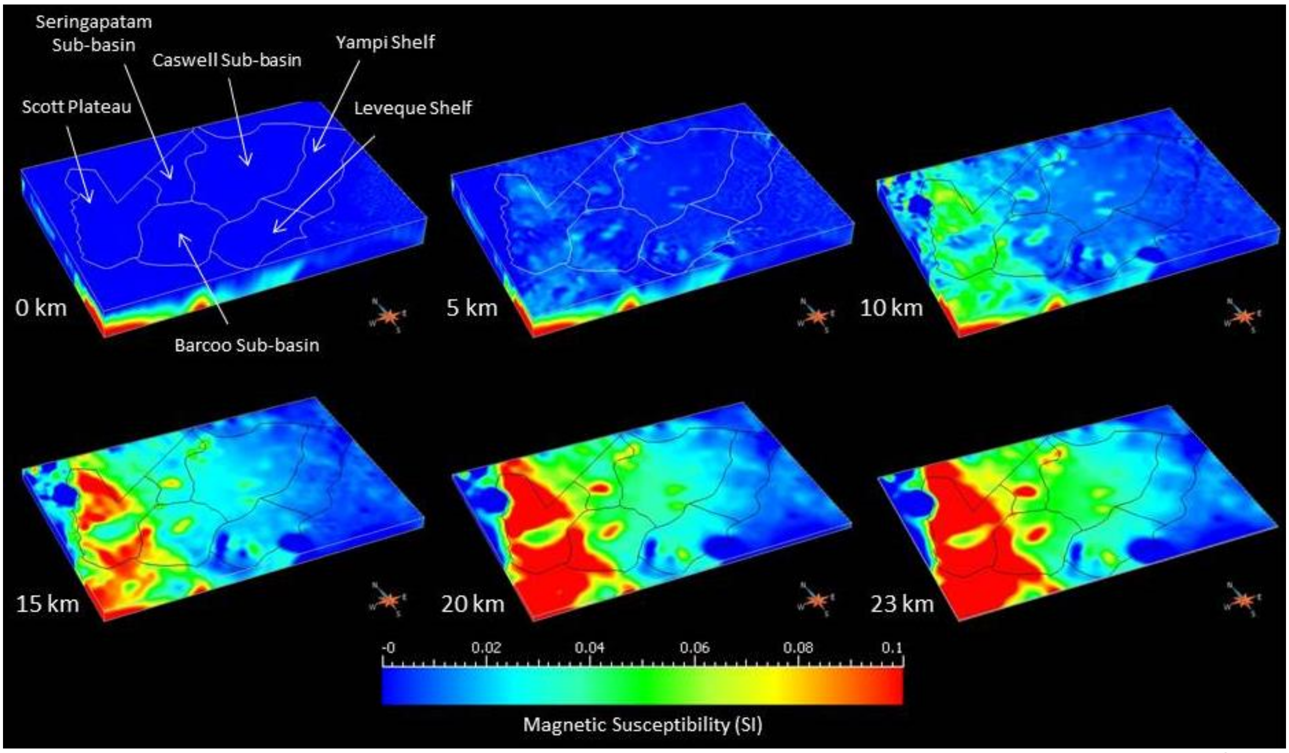

Figure 3. Depth slices showing magnetic susceptibility within and beneath the Browse Basin and surrounding regions from a regional-scale inversion model. This model was constrained to allow magnetic susceptibility variations of 0–1 SI within basement and 0–0.2 SI within the sediments.