Macquarie Arc and the Lachlan Orocline hypothesis: Magnetic analysis and development of geologically constrained forward model of lithospheric magnetisation

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SUMMARY

A comprehensive magnetic analysis of the Lachlan Orocline and Macquarie Arc, both located in the Lachlan Orogen, eastern Australia has been undertaken to test the potential relative rotation of this block to the surrounding units. These results are compared with palaeomagnetic data from the region and a series of geologically constrained crustal-scale forward models of lithospheric magnetisation for the area, with focus on the large-scale structural components of the Lachlan Orocline.

The forward model method treats each geological unit present in both the Macquarie Arc itself and the surrounding areas as independent parameterised stratigraphic units. Using a Geographical Information System (GIS) approach, known geological, structural and physical properties are used to produce a series of vertically integrated value grids. These grids are then used as input to model the regional magnetisation in the global scale magnetic field forward model.

Key words: magnetic modelling, Tasmanides, Lachlan, rock and mineral magnetism, tectonics.

INTRODUCTION

The Tasmanides are an orogenic belt consisting of geologically and temporally distinct terranes ranging in age from late Neoproterozoic to Triassic. The belt is ~4000 km long, ~1500 km wide (Coney et al. 1990), lies adjacent to the Achaean to Proterozoic basement to the west, and makes up approximately the eastern third of the Australian continent (Burton 2010). As seen in Figure 1, the belt consists of four blocks, with the oldest, the Delamarian Orogen (~515 – 490 Ma) located at both the south western boundary of the Tasmanides along proposed Tasman Line and making up the western two thirds of Tasmania. The Thomson and Lachlan Orogens (~485 – 340 Ma) make up the bulk of Tasmanides, extending through Queensland, New South Wales, Victoria, Tasmania, and potentially South Australia. The youngest, the New England Orogen (~305 – 230 Ma) making up much of the north east Australian coast (Kemp et al. 2009).

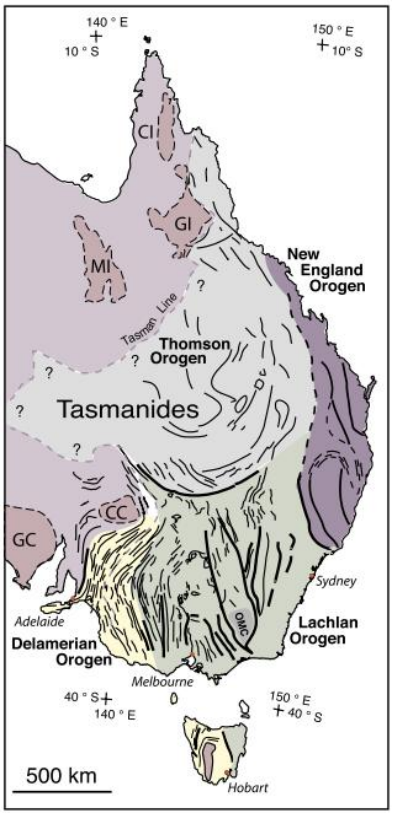

Figure 1. Composite map of the Tasmanides, eastern Australia (taken from D. R. Gray & Foster 2004). Heavy lines represent major faults, light lines represent aeromagnetic trends. CI: Coen Inlier, GI: Georgetown Inlier, MI: Mount Isa Inlier, CC: Curnamona Craton, GC: Gawler Craton.

The tectonic histories of the Tasmanides, although quite recent, are very complex and involve many different stages of deposition with subsequent deformation and alteration phases. Much of the region is under Cenozoic sedimentary cover and there is little or no outcrop over much of the belt. Geological, geophysical and tectonic interpretations of the region are difficult, and the subject of geological debate (Scheibner & Veevers 2000; Gray & Foster 2004; Glen 2005).

The eastern Lachlan, including the Molong-Monaro terrane and the Macquarie Arc are the focus of this project (see Figure

2). Magnetic and palaeomagnetic methods are used to quantitatively determine the proposed relative oroclinal rotation of the Molong-Monaro terrane in 3D as well as the potential megafold that exists beneath the sediment cover of the Murray Basin (Musgrave & Cayley 2011). These results aid in the tectonic interpretation of the Lachlan's geological history, which as it stands has no clear geological provenance linkage (Glen et al. 2011).

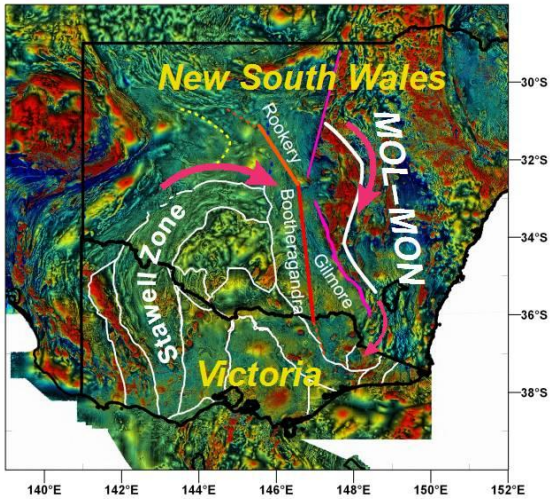

Figure 2. Aeromagnetic map of project area. Pink arrows indicate areas and direction of potential block rotation (Musgrave & Cayley 2011).

To investigate this existing geological problem, we utilise potential field analysis with a focus on long-wavelength magnetic, palaeomagnetic, and forward modelling techniques. These identify both the surface and deep crustal tectonic elements that form the eastern Lachlan to define the tectonic structures present and interpret their tectonic histories.

Potential field analysis, with focus on magnetic interpretation is ideally suited to problems of this nature, when magnetised rock units are under cover or have limited outcrop available for mapping or sampling. In these scenarios understanding the location, orientation and relationships between deep geological structures is the key to developing a clear picture of an areas tectonic history.

Australia has one of most complete and high-resolution continental magnetic datasets in the world, comprising of both aeromagnetic and satellite data, both of which are freely available through the Geoscience Australia Magnetic Anomaly Grid Database of Australia (MAGDA) (Milligan & Franklin 2004). The current continental magnetic map is compiled by stitching together each of the regional near-surface aeromagnetic surveys, with the aid of special-purpose long wavelength traverses. This data is high resolution at a regional level, focussing on the short wavelength data to delineate shallow structures. The satellite data on the other hand is measured far above the Earth's surface, and captures the longest wavelength information, which relates to the deepest structures present. It is these data that are used in this study to aid the development of the lithospheric magnetisation forward model.

METHOD AND RESULTS

To develop the magnetic forward model, a combination workflow was developed that comprised of palaeomagnetic analysis, a geographical information system modelling approach (Hemant & Maus 2005), and a global lithospheric magnetisation forward modelling algorithm (Masterton et al. 2012).

We completed a full palaeomagnetic analysis of samples collected from the Lachlan Orocline including the surrounding Cambrian Bendigo (Heathcote Belt) and Tabberabbera zones. Routine laboratory methods were used (Butler 1991), with initial results suggesting evidence of block rotation. Each of the measured rock properties, along with the existing known geological information of the units is used as input to generate the GIS style vertically integrated value grids (see Figure 3). The value grids are derived by integrating spatially related values such as the crustal thickness, crustal structure, and rock properties to calculate a single representative value at a resolution of 0.25° x 0.25°. A full description of the technique can be found in Hemant & Maus 2005.

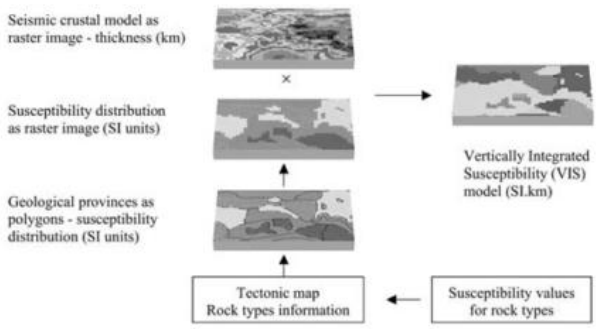

Figure 3. Flow chart diagram describing how different layers of discrete information can be combined using the GIS method to compute vertically integrated value grids (Hemant & Maus 2005).

The grids were then used as data input into the forward modelling algorithm to produce a lithospheric magnetisation grid at a resolution 0.25° x 0.25° for the globe. This global magnetisation grid is then cropped for the Australian continent. These initial models defined the long-wavelength anomalies well, but higher resolution models require development to define the finer structures present.

Aeromagnetic analysis of the region was also completed (Figure 4), with focus on the comparison between the shorter wavelengths representing the near-surface structures and the long wavelengths representing the deeper structures. Long-wavelength grids were computed using upward continuation filtering at specific reference elevations. These analyses were compared with the forward models to identify common anomaly patterns present in the Orocline. Persistence of the Stawell Zone (megafold) at depth was tested with upward continuation techniques. Results defined the fold structures at depth, at an upward continuation height of 30km. Also visible was the Molong-Monaro terrane, persisting through all upward continuation steps to 60km where it was still clearly visible.

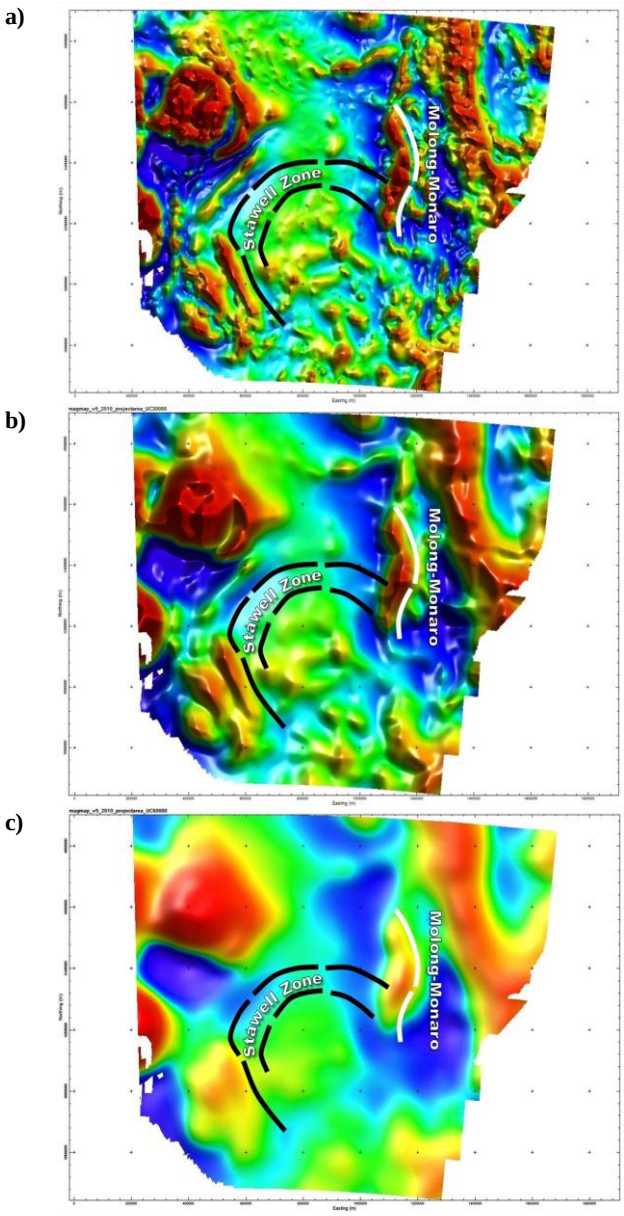

Figure 4. Upward continuation of total field aeromagnetic data (TMI) at reference heights of: a) 10km, b) 30km, and c) 60km. The proposed megafold located around the Stawell Zone can be seen at both 10km and 30km, but is difficult to define at 60km. The Molong-Monaro terrane is present through all reference continuation heights.

CONCLUSIONS

By combining magnetic modelling and palaeomagnetic studies a more comprehensive tectonic interpretation is possible. Although the Lachlan and Thomson Orogens are largely magnetically overprinted, some pre-folding remanent magnetisations are identifiable which assist in constraining relative rotations. As this is the first phase of a larger study, further palaeomagnetic and magnetic analyses will be undertaken, the forward models will undergo further geological refinement, and tectonic reconstructions will be developed to support the proposed block rotation of the Stawell Zone.

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REFERENCES

Burton, G.R., 2010. New structural model to explain geophysical features in northwestern New South Wales: implications for the tectonic framework of the Tasmanides. *Australian Journal of Earth Sciences*, 57(1), pp.23–49.

Butler, R.F., 1991. *Paleomagnetism: Magnetic Domains to Geologic Terranes*, Blackwell Science.

Coney, P.J. et al., 1990. The regional tectonics of the Tasman orogenic system , eastern Australia. *Journal of Structural Geology*, 12(5), pp.519–543.

Glen, R., Quinn, C. & Xiao, W., 2011. Island Arcs: Their role in growth of accretionary orogens and mineral endowment. *Gondwana Research*, 19(3), pp.567–570.

Glen, R.A., 2005. The Tasmanides of eastern Australia. *Geological Society, London, Special Publications*, 246(1), pp.23–96.

Gray, D.R. & Foster, D.A., 2004. Tectonic evolution of the Lachlan Orogen, southeast Australia: historical review, data synthesis and modern perspectives. *Australian Journal of Earth Sciences*, 51(6), pp.773–817.

Hemant, K. & Maus, S., 2005. Geological modeling of the new CHAMP magnetic anomaly maps using a geographical information system technique. *Journal of Geophysical Research*, 110(B12), p.B12103.

Kemp, a. I.S. et al., 2009. Isotopic evidence for rapid continental growth in an extensional accretionary orogen: The Tasmanides, eastern Australia. *Earth and Planetary Science Letters*, 284(3-4), pp.455–466.

Masterton, S.M., Gubbins, D. & Hemant, K., Forward modelling of oceanic lithospheric magnetisation. , pp.1–24.

Milligan, P.R. & Franklin, R., 2004. A new generation Magnetic Anomaly Grid Database of Australia (MAGDA). *Preview*, (December), pp.25–29.

Musgrave, R.J. & Cayley, R., 2011. Unfolding an Orocline Restores Australian Siluro-Devonian Poles to the Gondwana APWP. *AGU Fall Meeting Abstracts*, -1, p.0991.

Scheibner, E. & Veevers, J.J., 2000. Tasman Fold Belt System. In J. J. Veevers, ed. *Billion-year earth history of Australia and neighbours in Gondwanaland*. Gemoc Press, pp. 154–234.