Tectonic analysis of regional potential field data

Peter Betts*
Monash University
9 Rainforest Walk, Clayton Campus
Peter.Betts@monash.edu

Robin Armit
Monash University
9 Rainforest Walk, Clayton Campus
Robin.Armit@monash.edu

Caroline Tiddy
University of South Australia
Mawson Lakes Boulevard, Mawson Lakes, SA 5095
Caroline.Tiddy@unisa.edu.au

Sheree Armistead
University of Adelaide
Department of Earth Sciences
Sheree.Armistead@adelaide.edu.au

Laurent Ailleres
Monash University
9 Rainforest Walk, Clayton Campus
Laurent.Ailleres@monash.edu

SUMMARY

This contribution uses several case studies to illustrate how regional aeromagnetic and gravity data is used to undertake tectonic analysis. Regional aeromagnetic and gravity data is a powerful tool for tectonic analysis because it can be interpreted and modelled at different scales, and it is very effective at imaging different crustal levels. The signal in the data can also be linked to geological features and processes, and importantly, it is amenable to structural analysis, which can be used to inform 3D geometry, kinematics, and overprinting relationships. When combined with geological context the data can constrain tectonic settings and evolutions, and importantly provide context for mineral system analysis. We use examples from the IOCG belts of Proterozoic Australia. We present data from the Mount Woods Inlier in the northern Gawler Craton, to this part of the craton is highly extended, resulting the development of a metamorphic core complex. We then illustrate the tectonic setting for IOCG mineralisation in the Curnamona Province, illustrating how structural analysis of the data provides key constraints on tectonic transport direction.

Key words: aeromagnetic, gravity, tectonic analysis, structural geophysics

INTRODUCTION

For many decades, regional aeromagnetic and gravity data have been used in a variety of ways to assist in elucidating subsurface geology. Initially the data was used to identify "anomalies" that could be used for targeting mineral deposits and regions of alteration. The discovery of the giant Olympic Dam deposit in 1975 representing the effectiveness of this approach (Esdale et al., 1987). The next stage in the evolution of "potential field" interpretation was using the data to create geological maps, facilitated by advances in representing the data as "grids" rather than contours. The data created opportunities to understand buried geology and provide a context for vast tracks of the Australian continent buried beneath younger cover successions (e.g. Isles and Rankin, 2013 and references therein). Further advancements in interpretation was recognition that aeromagnetic and gravity data could be interpreted in a manner similar to approaches of structural geology, in which the data could inform 3D geometry (Jessell et al., 1993), overprinting relationships, and kinematics (Betts et al., 2007), leading to a new discipline termed "Structural Geophysics" (Jessell and Valenta, 1996). Structural Geophysical approaches have become more complex as computing advances enable large datasets to be processed rapidly, and new methods and workflows for data manipulation and inverse modelling of the data (e.g. Armit et al., 2014). The other significant advance in how the geoscientific community use regional aeromagnetic and gravity data was the availability of the Australia continent gravity and magnetic grids in the mid 1990's. These grids provided unprecedented image of the Australian crust, which have been subsequently been used to understand the architecture of the Australian continent at a variety of scales (Aitken, 2010; Korsch and Doublier, 2016; Betts et al., 2016).

In this abstract, we use several case studies to show how tectonic analysis using potential field data, utilising advancements in potential field analysis, to determine tectonic regime and processes, regional kinematics (e.g. transport direction) and the key geological features. We demonstrate this using examples from the Iron Oxide Cu-Au (IOCG) belts in Proterozoic Australia (Figure 1).

TECTONIC ANALYSIS OF REGIONAL POTENTIAL FIELD DATA: ADVANTAGES AND PITFALLS

Aeromagnetic and gravity data is amenable to tectonic analysis because:

(1) The data provides information about crustal structure at multiple scales varying from mine-scale to continental-scale.
(2) There is excellent spatial resolution of the data, which allows great coverage at comparable resolution, and often allows correlation of the data with geological observation and data.
(3) The data is can be treated so that different crustal levels can be interrogated (e.g. Motta *et al.,* 2019) and different scales identified and interpreted.
(4) Applying Structural geophysical approaches to the data provides information about the evolution and architecture of a region.
(5) There is very good understanding of the petrophysical characteristics that cause the signal in the data, and these that is relatable to geological processes and features (e.g. alteration related to redox, stratigraphy, igneous rocks, and structures).

There are some pitfalls associated with undertaking tectonic analysis of potential field data:

(1) There remains a scaling issue associate with petrophysical data (e.g. Clark and Emerson, 1992) and interpreted elements of a tectonic analysis. The spatial resolution of petrophysical data is sparse and biased. Data is collected in regions of outcrop, where weathering has modified the petrophysical property (e.g. oxidation, which lowers the magnetic susceptibility) or where there is access to drilling, which is often most dense where there is an exploration target, and therefore by definition, is anomalous and not truly representative of the bulk petrophysics.
(2) Errors in the determining subsurface geometry can subsequently lead to erroneous interpretation of the tectonic meaning of a structure and the regime in which it formed.

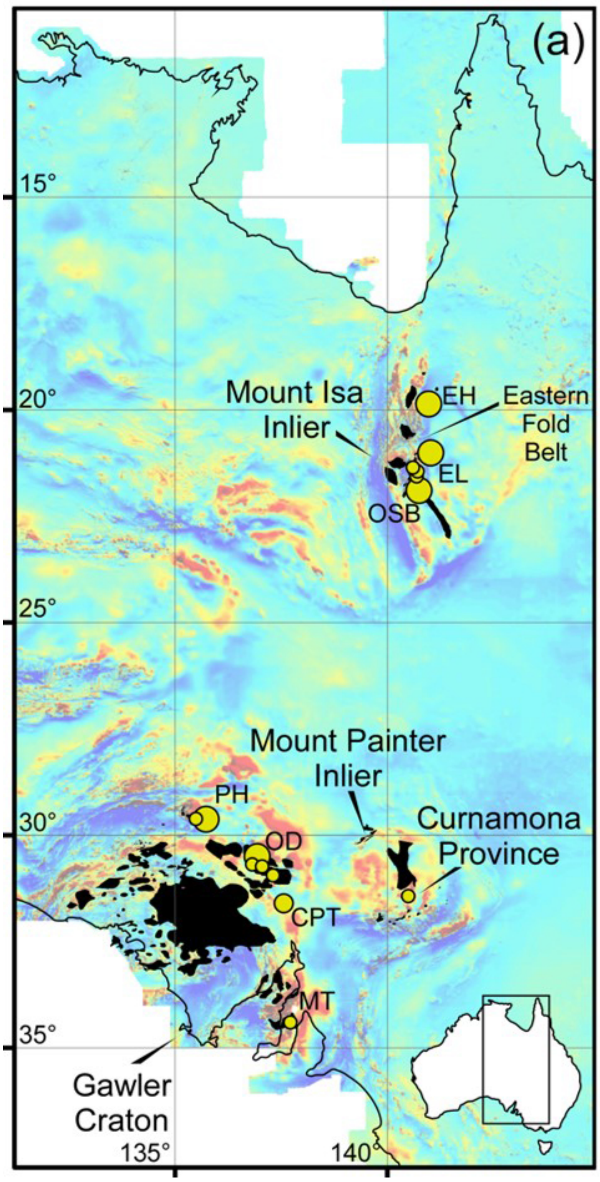

Figure 1. Aeromagnetic image showing major IOCG ore deposits. EH: Ernest Henry; EL: Eloise; OSB: Osbourne; OD: Olympic Dam; CPT: Carrapateena; PH: Prominent Hill. Black polygons are the surface expression of Mesoproterozoic Magmatic provinces.

CASE STUDIES

Mount Woods Inlier

The Mount Wood Inlier (Betts et al., 2003; Chalmers, 2007) is host to the ca. 1582 Ma (Belperio et al., 2007) Prominent Hill IOCG deposit on its southern domain margin. The inlier has limited exposed rocks; however, has excellent potential field coverage that images buried geology in high resolution (Figure 2). Rocks within the inlier comprise weakly magnetic, deformed basement gneiss intruded by mafic and granitic plutons of the ca 1600-1580 Ma Hiltaba Suite. The southern inlier has extensive iron oxide alteration. The inlier records an evolution that spans the ca 1740-1690 Ma Kimban Orogeny, post-Kimban basins, ca 1600-1580 Ma Hiltaba Suite magmatism and volcanism, and associated with deformation and contact metamorphism (Forbes et al., 2011, 2012), which is overprinted by deformation associated with the ca 1560-1540 Ma Kararan Orogeny.

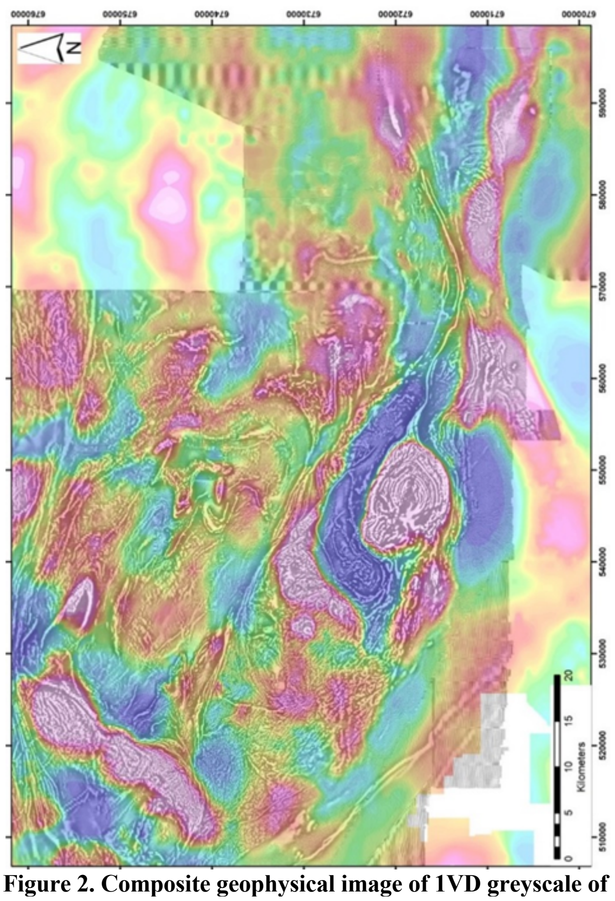

Figure 2. Composite geophysical image of 1VD greyscale of RTP aeromagnetic data superimposed on colour drape map of the Bouguer gravity data from the Mount Woods Inlier.

Geophysical interpretation of high-resolution gravity and aeromagnetic datasets (12.5 m cell size) reveals several discrete geological domains, each with a different geological evolutions, geophysical responses, and structural characteristics. When integrated with geological observation from outcrops, we interpret the architecture of the Mount Woods Inlier as the remnants of a metamorphic core complex that developed at ca. 1600-1590 Ma during regional ENE-WNW extension associated with the emplacement of the Hiltaba Granitoids. Critical to this tectonic analysis was the following evidence:

(1) The central domain comprising of para- and ortho-gneissic rocks is characterised by intense ductile poly-deformational folding and fault duplex development. These rocks form the basement and were deformed during the Kimban Orogeny. This domain is distinctly different from other regions in that it is characterised by a subdued aeromagnetic response with magnetic horizons that define the structural elements.
(2) The Skylark Fault Zone separates the central domains from highly magnetised rocks to the south. This fault is highly arcuate in map view, suggesting it bounds a regional dome. The Skylark Fault Zone dips shallowly south-dipping fault zone and preserves normal kinematics (in outcrop). The footwall is characterised by ductile basement rocks in the hanging wall comprises brittle-dominated deformation (Figure 3).
(3) Brittle NW-trending normal faults are developed in the hanging wall of the Skylark Fault Zone and appear to locally control stratal wedges in basinal successions. These faults are less prevalent in the footwall (Figure 3).
(4) The hanging wall of the Skylark Fault Zone has intensely magnetised regions that define post-Kimban Paleoproterozoic sedimentary basins and intrusion of voluminous mafic and granitic plutons of the Hiltaba Suite. Low metamorphic grade, syn-Hiltaba Suite basins occur in the hanging wall of the Skylark Shear Zone.

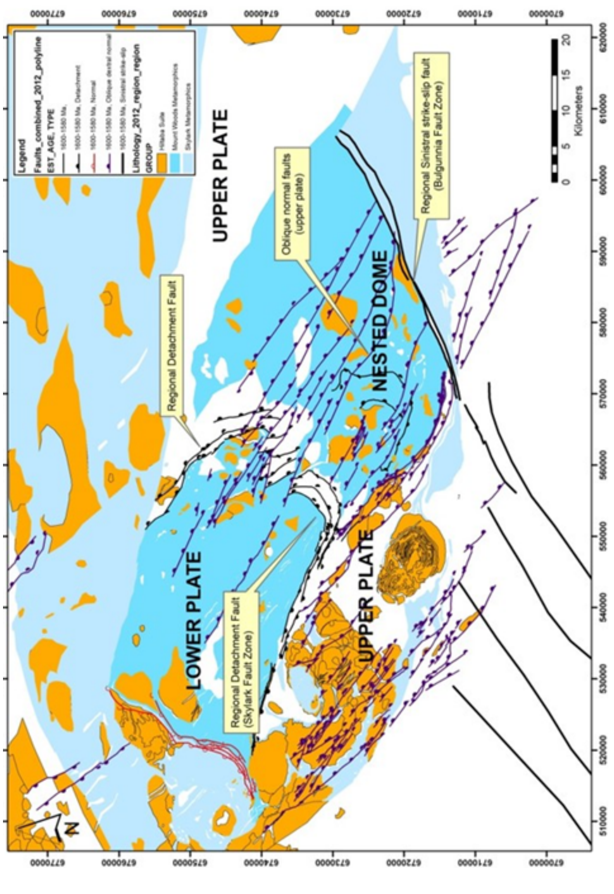

Figure 3. Tectonic map of the Mount Woods Inlier showing the location of the upper and lower plates of the Mount Woods Metamorphic core complex.

We interpret the footwall of the Skylark Fault Zone as the lower plate of a metamorphic core complex. The hanging wall represents the brittle upper plate. The timing of core complex development is poorly constrained but appears to be constrained between peak HT-metamorphism, dated between ca 1615-1590 Ma (Forbes et al., 2011; Chalmers, 2007) and the ca 1560-1540 Ma Kararan Orogeny. Normal faulting in the upper plate, overprints the mafic plutons, suggesting that plutons were emplaced into the upper crust early during the Hiltaba Event, during early stages of core complex development.

We have named this metamorphic core complex the "Mount Woods Metamorphic Core Complex". Several major faults associated with the Kararan Orogeny overprint the metamorphic core complex. The Cairn Shear Zone overprints the metamorphic core complex to the north, and to the Panorama Fault modifies the boundary to the west.

The tectonic analysis suggest that the Hiltaba Event represents a major extensional event that affected large tracts of the Gawler Craton. The presence of a metamorphic core complex in the Mount Woods Inlier suggest that the northern part of the craton may have been subjected to a different mode of extension associated unroofing of basement terranes.

Central Curnamona Province

In our second case study, we use high-resolution geophysical data from the central Curnamona Province, which hosts several IOCG related Cu-Au deposits within the Proterozoic rocks of the Benagerie Ridge Magnetic Complex. Neoproterozoic and Phanerozoic cover successions cover the Benagerie Ridge.

This region preserves the stratigraphy of the Willyama Supergroup that is overprinted by deformation associated with the Olarian Orogeny (Forbes et al., 2008) and magmatism of the Ninnerie Supersuite, which is equivalent to the Hiltaba Suite in the Gawler Craton (Wade et al., 2012).

Constrained by drill core and geophysical data (Figure 4), we undertake tectonic analysis of the region to understand the structural controls of Cu-Au mineralisation, which lie adjacent to a region redox boundary that separates magnetic units in the lower stratigraphy from non-magnetic units in the upper stratigraphy (Figure 4). The 3D geometry of the Benagerie Ridge is characterised by the following elements:

(1) An early, layer-parallel foliation, not imaged in the geophysical data. However, it is parallel to stratigraphic units imaged in the data. Magnetic marker horizons are parallel to the regional redox boundary. The sharp magnetic boundary is identified in aeromagnetic images and from petrophysical properties in drill holes (Figure 4).
(2) Recumbent folds occur on the western side and on the northeast of the major Benagerie Ridge Magnetic Complex (Figure 5). The folds are best imaged in the RTP tilt derivative aeromagnetic image because the processed data shows continuity and rock package boundaries Recumbent folds are tight to isoclinal with axial traces that trend to the northeast.
(3) Upright third generation folds with north-northeast oriented fold hinge zone is characterised by a smooth positive magnetic anomaly. The outermost parts of the F3 fold limbs have a relatively shallow magnetic gradient

compared to the innermost parts of the structure. Gradients in the magnetic show the hinge zone plunging to the northeast.

(4) Fold generations are overprinted by a series of north–south trending, dip-slip faults and large east–west striking fault with an apparent dextral sense offsets and defined by zones of magnetite depletion caused by oxidation (Armistead et al., 2018). The kinematics of the faults suggest a component of normal-oblique movement, with a north-block-down offset.

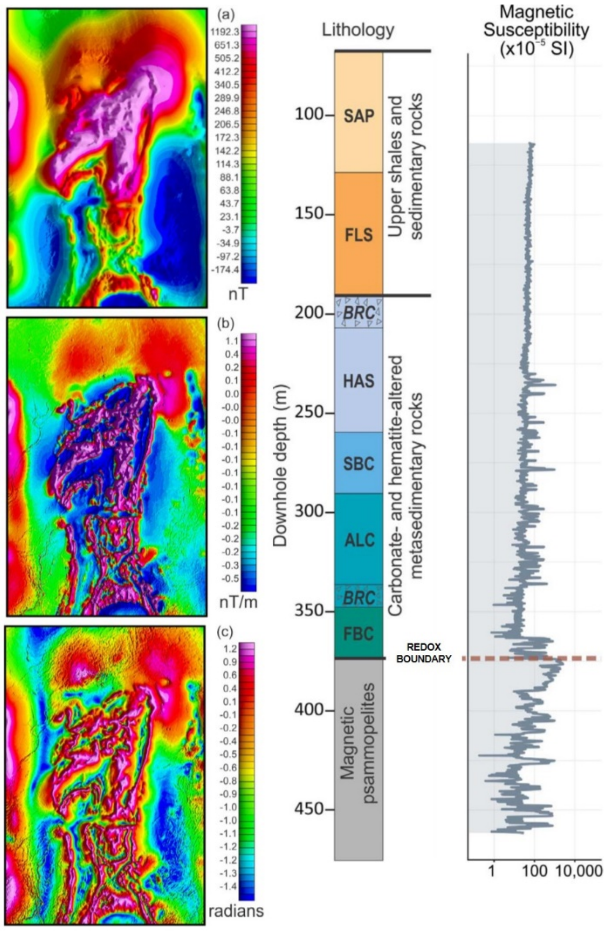

Figure. 4. Processed aeromagnetic images of the same geographic extent; all images sun-shaded with 100° declination and 55° inclination: a) Reduced to the pole (RTP) total magnetic intensity; b) RTP first vertical derivative; and c) RTP tilt derivative. Coordinate system GDA 1994.modified after Armistead et al. (2018). Drill log of typical North Portia drillhole (drill ID: BEN0592) with lithology, and magnetic susceptibility (log scale). The highest grades of Cu-Au-Mo mineralisation occur directly above the redox boundary (~375 m), where a sharp change in magnetic susceptibility also occurs.

To understand the 3D geometry, we construct a 3D model of the Benagerie Ridge using Noddy software (Armistead et al., 2018) (Figure 5), and is constrained from the aeromagnetic interpretation. Three folding generations (two subtly different recumbent generation and an upright generation) were required to replicate similar patterns to the observed aeromagnetic data. The resultant type 2 interference pattern requires tectonic transport from the north to south, different to previous interpretations form elsewhere in the province. The timing of recumbent folding coincides with extension occurring in the adjacent Gawler Craton, suggesting that either complex along strike tectonic processes were at play, or there is a requirement to rethink the significance of the recumbent folding in the context of regional extension, rather than shortening. In the latter scenario, the Benagerie Ridge may have occupied a deeper crustal level than the Gawler Craton.

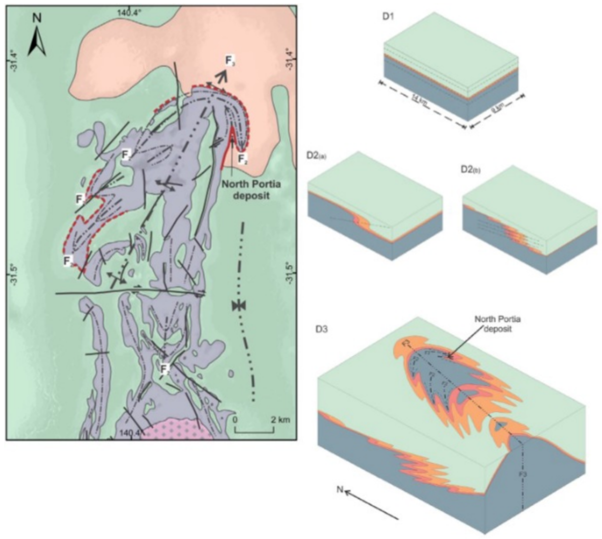

Figure. 5 Aeromagnetic interpretation of the Benagerie Ridge and the Noddy 3D deformation model showing the sequence of deformation events required to produce the type fold interference pattern identified in the Aeromagnetic data. Images modified after Armistead et al. (2018).

CONCLUSIONS

Tectonic analysis of regional gravity and magnetic data allow inferences about the evolution of geological provinces that cannot be determined from geological data alone. The approach utilises established methodology but considers the implications of the analysis in the context of the evolution of the province. In the two case studies presented, we have identified key tectonic/structural features that provide insights about the tectonic evolution that have not been previously determined. By undertaking a tectonic analysis, rather than a purely architectural analysis of the data allows greater inference and contextualisation of the controls of major ore systems and potentially provides a predictive tool for exploration.

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