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2½-D inversion constraints on the palinspastic retro-deformation of Siluro-Devonian structures in the Black Range region, western Victoria – the "Crab Nebula" untangled

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SUMMARY

The Stavely Arc developed during the Cambrian above a continent (west) dipping subduction zone within the Grampians-Stavely Zone in present-day western Victoria. Siluro-Devonian regional dextral trans-tensional strike-slip faults recently mapped by the Geological Survey of Victoria in Cambrian basement, previously only recognised in Grampians Group cover, have segmented what was a relatively simple Cambrian configuration of Stavely Arc volcanic fault slices into a complex array of segmented and variably rotated arc fragments, including the until now enigmatic "Crab Nebula" in the Black Range.

Inversion of magnetic data has provided an understanding of the 3D geometries of the three volcanic belts in the Black Range. Applying this understanding, together with over-printing criteria evident in filtered potential field data, within the context of a trans-tensional strike-slip stress regime, has enabled a retro-deformation of the Black Range belts into a single, west dipping belt of arc volcanics – an untangled, pre-Silurian "Crab Nebula". The proven prospectivity of the Black Range Belt (by the presence of the McRaes/Eclipse prospect) can now be extended to all three of the Black Range belts.

Key words: Stavely Arc, potential field inversion, trans-tensional strike-slip faults, retro-deformation, magnetics, Black Range

INTRODUCTION

Continent-dipping subduction along the eastern margin of Gondwanaland during the Cambrian is constrained by geochemistry and magmatic history (Foden et al., 2006; Kemp, 2003), geophysics and structural mapping (Cayley & Taylor, 1997; Greenfield et al., 2011, Cayley et al., in prep.) and geochronology (Miller et al., 2005; Lewis et al., 2015). The Stavely Arc developed above this subduction zone within the Grampians-Stavely Zone in present-day western Victoria. Initially Japan-style, the arc-complex transitioned to an Andean-like convergent scenario at the end of the Cambrian before being shortened and accreted to the margin. This correlation is important as the modern Andes host giant metals systems, and the geological setting suggests similar prospectivity may exist in the Stavely Arc in western Victoria. Today the upper parts of the arc, the Mount Stavely Volcanic Complex (MSVC), are thrust intercalated with Cambrian marine sedimentary successions.

Similarities in geochemistry and geological context suggest that separate fault slices of calc-alkaline volcanics at Mount Stavely, in the Black Range region west of the Grampians, east of the Grampians (Mount Dryden), in linking belts (e.g. Mount Elliot), and the Dimboola Igneous Complex extending into north western Victoria are all Stavely Arc fragments. Simple Cambrian convergent deformation does not seem to account for the faulted configurations and complex spatial distribution of identified arc segments.

Exposure of MSVC rocks in western Victoria is poor. Most arc-segments are buried beneath ?Ordovician-Silurian Grampians Group, Devonian Rocklands Volcanics, Cenozoic Murray Basin sediments, and Quaternary basalt lava flows (Figure 1). Geophysics and drilling has been crucial for understanding the arc system. 2-D cross-strike deep seismic reflection transects have added critical depth and geometry control (Cayley et al., 2011, in prep.), and characteristic magnetic and gravity signatures over exposed arc segments at Mount Stavely, Mount Dryden, and the Black Range/Rocklands (Figure 1a & b) have enabled interpretations of these belts to extend beneath cover, and allowed for the recognition of several additional arc fragments.

In the Black Range region the present day configuration of the Tyar, Black Range and Glenisla volcanic belts has been enigmatic since they were first identified in detailed magnetic data and drilling by CRAE in the 1980's and 1990's. Termed the "Crab Nebula" at the time, belts of magnetic metavolcanics appear to radiate out from a central hub, interpreted as a younger buried magnetic granite (Figure 1). Overprinting by the later intrusive at the convergence point of the three belts appeared to conceal the apparent complex geometric relationship between the belts.

Late Silurian to Early Devonian sub-vertical strike-slip faults mapped in the Grampians Group cover rocks (Cayley & Taylor, 1997) were not recognised in underlying Cambrian bedrock until 2012, when Geological Survey of Victoria (GSV) field mapping discovered large, sub-vertical dextral strike-slip faults cutting Cambrian metasediments east and west of Mount Stavely, and potential field interpretation identified dextral offsets of the Mount Stavely and Bunnugal volcanic belts south of the Grampians (Skladzien et al., 2015; Cayley et al., in prep). This additional structural control firmly links large strike-slip structures in the Grampians Group into the underlying Cambrian bedrock. These structures can be traced from Mount Stavely, beneath the Grampians Group, into the Black Range region, and provide a structural framework by which segmented arc belts can be retro-deformed in plan, using the regional magnetics, to reveal their pre-Silurian configuration. Recent high resolution company aeromagnetic data over Black Range has enhanced interpretation of existing regional government magnetic data and allowed the recognition of new Siluro–Devonian strike-slip structures within Cambrian basement. Overprinting criteria evident in filtered magnetic data, together with inversion modelling results indicate the development of a network of synthetic and antithetic strike-slip faults segmenting a single west-dipping fault slice of Stavely Arc volcanics into the complex array of separate fault slices observed in the geophysical data – a credible and palinspastically restorable explanation for the origin of the 'Crab Nebula'.

METHOD AND RESULTS

Geophysical data and enhancement

The limited amount of basement outcrop in the study area, and the often poor quality of exposure where it occurs has meant geological mapping in the area has been challenging, and the geological interpretation is heavily reliant on geophysical data and drilling. Geophysical data sets that were available for this study included high resolution (50 m line spacing and 50 m flight height) aeromagnetic data provided by Navarre Minerals Limited, regional Victorian government airborne magnetic data (200 m line spacing, 100m flight height), and regional gravity data (1.5 – 5.0 km station spacing). Other data that were utilised included open file drill hole logs and stratigraphic drill holes completed as part of the collaborative Geoscience Australia-GSV Stavely Project (Schofield et al., 2015), and SRTM data. Petrophysical properties were sourced from the GSV database and from direct measurements by the Australian Geophysical Observing System (AGOS) on stratigraphic drill core proximal to the study area (Skladzien et al., in prep.).

To gain the maximum information from the potential field data, various filters were applied, and visualisation enhancements made, allowing a detailed interpretation of Cambrian bedrock. Particularly useful were the Analytic Signal and Tilt filters for TMI (RTP) data (Figure 1a), and high pass filters for gravity data (Figure 1b).

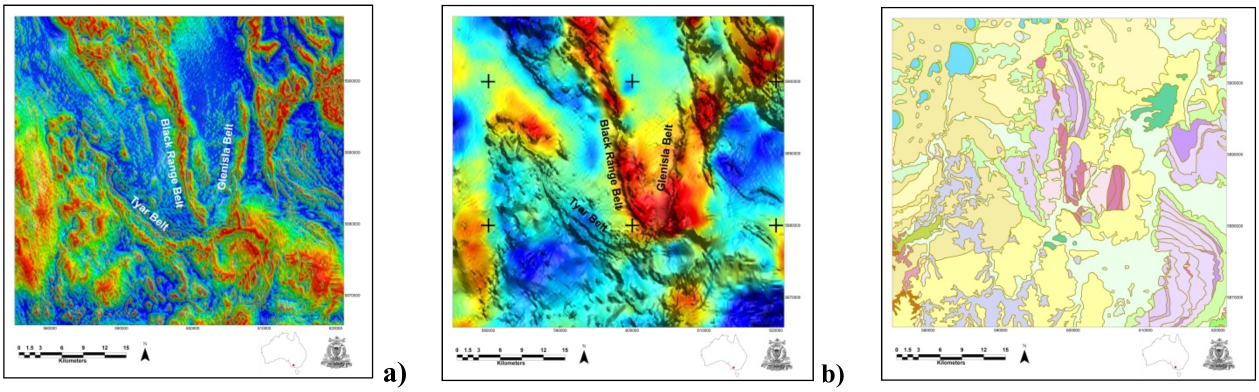

Figure 1. Images of filtered regional geophysical data and surface geology over the study area. a) Tilt filtered TMI (RTP); b) pseudocolour of 30km high pass filtered Bouguer gravity (red – high; blue - low), overlain on TMI intensity with NE sun-shading; c) 1:250k surface geology showing exposed slivers of Cambrian volcanics (dark pink).

2½ D inversions

Fault slices of mafic to ultra-mafic units comprising the volcanic belts in the Black Range region are bounded by Cambrian metasediments of the Nargoon Group. This juxtaposition of rocks with markedly contrasting petrophysical properties has produced relatively simple regional magnetic anomalies associated with the volcanics in profiles extracted from magnetic data. The main purpose of the inversion exercise was to determine the overall dips of the belts. As such, regional surfaces were calculated using a 2nd order polynomial in order to approximate the regional component within the observed data, thus allowing for the modelling of only the shorter wavelength anomalies derived from the relatively shallow volcanics. In the case of the Tyar Belt an additional off-section body directly west of the belt was required to compensate for the high magnetic response associated with magnetic intrusives not compensated for by the regional surface (Figures 2b and 3). Numerous profiles were extracted along the length of all three belts and anomalies inverted using the Quick Inversion tool in ModelVision Pro (Figure 2). This tool is optimised for inversion of magnetic anomalies using a tabular source body. This body type was found to effectively represent the planar magnetic volcanic units, producing a calculated response closely matching the observed data (Figure 2). An attempt was made to correlate bodies between sections along the belts (same coloured bodies) where it was possible to trace continuous anomalies in plan view.

Modelling of the 1VD of TMI was carried out concurrently with modelling of TMI to optimise the inversion. Bodies for which a good fit between the observed and calculated response was achieved for both TMI and 1VD are considered more reliable than those for which the 1VD response does not fit as well. Inverting on 1VD was valuable in separating overlapping anomalies and constraining the dip of bodies where modelling only the TMI response was ambiguous. Profiles were extracted from gridded data to ensure modelled sections were orthogonal to the local strike of magnetic units in an effort to minimise off-section effects. This was important as the 1VD in-line filter is one-dimensional and is computed on the assumption that there is no variation perpendicular to the profile. The three belts were each modelled separately, the Black Range and Glenisla Belts modelled using high resolution data provided by Navarre Minerals Limited, while the western-most Tyar Belt (not covered by the high resolution data) was modelled using regional Victorian government data.

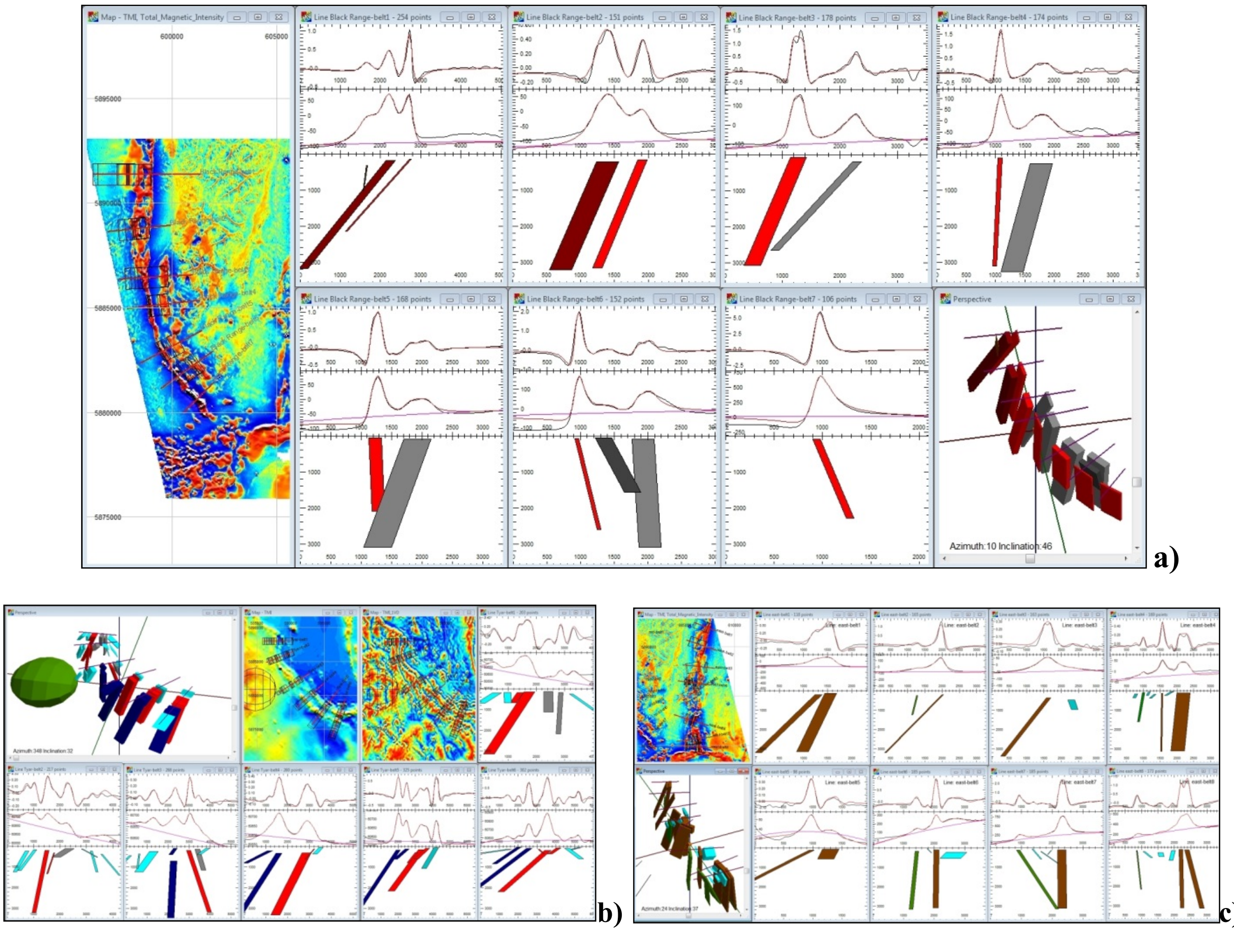

Figure 2. Panels showing inversion sections for a) Black Range Belt, b) Tyar Belt and c) Glenisla Belt. For each panel: sections are from north (top left) to south (bottom right); All sections are west (left) to east (right); top profiles show 1VD, bottom profiles show TMI. Plan images show gridded TMI (1VD) with section locations (Tyar panel also shows TMI - left image). 3D perspectives are also shown. Observed profiles in black; calculated response in red; regional in pink. Black Range and Glenisla belts modelled using high resolution data; Tyar Belt modelled using regional data.

Geological interpretation

Numerous elongate magnetic anomalies, orientated N-S to NW-SE, outline the mafic to ultra-mafic Cambrian volcanic units within each of the Tyar, Black Range and Glenisla belts (Figure 1a). Internal terminations, offsets and convergence of anomaly trends along strike within the belts support the interpretation of complex, internally faulted and deformed slices of arc volcanics. Cross-strike 2½-D inversions indicate predominantly west dipping magnetic units along the linear sections of the belts (Figures 2 and 3). Exceptions to this, particularly in the Glenisla Belt, appear related to smaller scale structures which have locally deformed the magnetic units, complicating the observed response.

Abrupt terminations of the northern end of the Tyar Belt and southern end of the Black Range Belt evident in magnetic data suggest the belts are truncated by later Siluro-Devonian structures - the Henty Fault and the Cherrypool Fault, respectively (Figure 4a). These belts show an overall change in the dip of modelled volcanic bodies along strike (Figure 2 and 3). The arcuate terminations of the belts in plan are spatially coincident with steepening dips of bodies when correlated across numerous sections – even slightly overturned in case of Black Range Belt (Figures 2 and 3). These results are consistent with deformation associated with strike-slip fault drag-folding, indicating fault propagation from depth, consistent with rock dynamics.

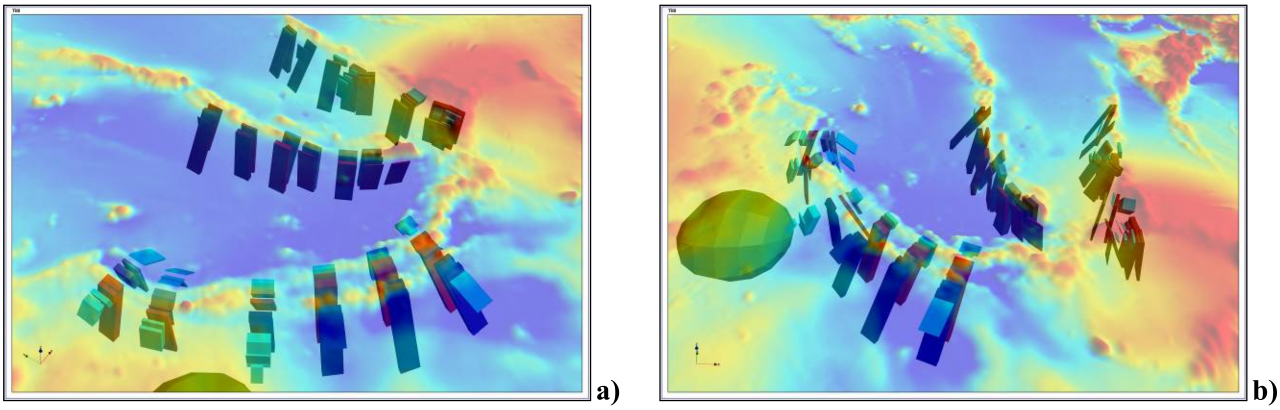

Figure 3. 3D perspective views of modelled tabular bodies representing the three segmented Stavely Arc fault slices in the Black Range region, with transparent TMI (RTP) overlay. a) view towards northeast; b) view towards north. Green ellipsoid body to the west represents a buried intrusive – see text.

A network of synthetic and antithetic strike-slip faults is interpreted to have been active in the region, formed in a regional dextral trans-tensional stress regime, during the Late Silurian to Early Devonian. Sinistral movement along the NNE trending Cherrypool Fault (and it's interpreted continuation – the Latani Fault) has off-set the southern end of the Black Range Belt from the northern end of the Glenisla Belt, resulting in the drag-folding related arcuate geometry and associated steepened to overturned volcanic units at the southern end of the Black Range Belt. The Cherrypool Fault has in-turn been over-printed by the dextral NW trending Henty Fault which has off-set the western end of the Tyar Belt from the southern end of the Glenisla Belt, again steepening the dip of and drag-folding the Tyar Belt in the west (Figures 3 and 4a). Using this evidence, deformation along post-Cambrian strike-slip structures can be regionally retro-deformed allowing the belt segments to be aligned in their approximate Cambrian configuration - a single, roughly N-S trending, west dipping fault slice of Stavely Arc volcanics (Figure 4b).

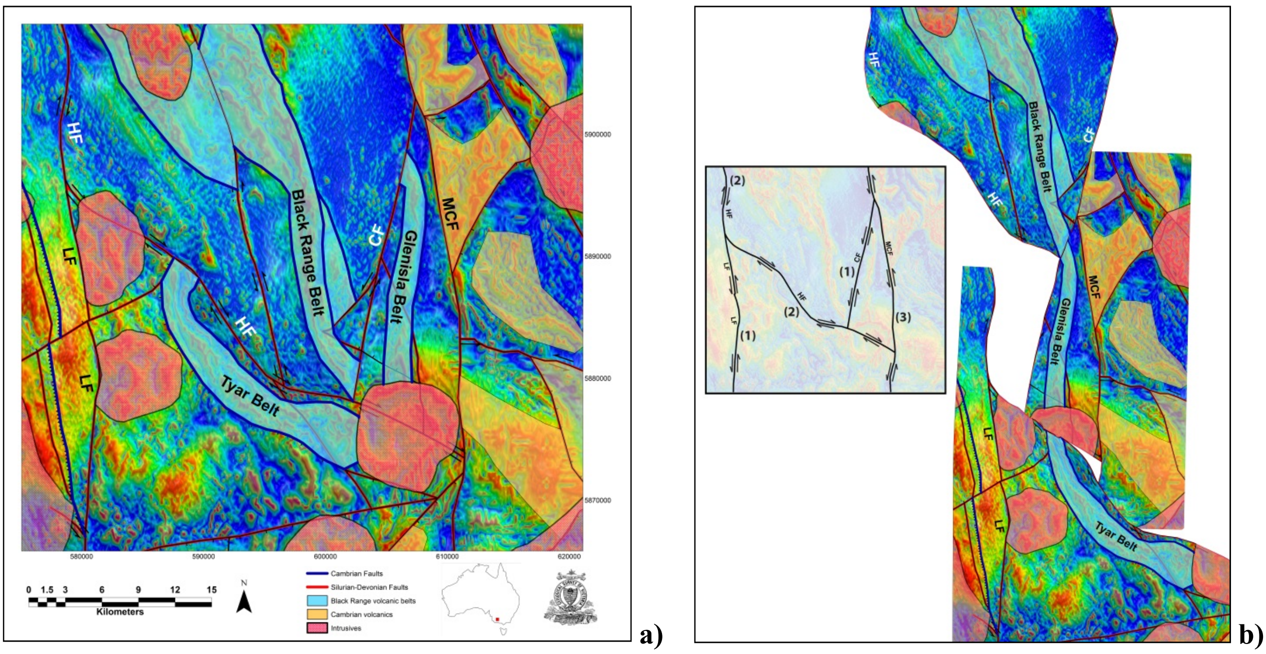

Figure 4. a) Magnetics image (tilt filter of TMI (RTP)) of the study area showing the locations of Black Range volcanic belts and the distribution of Cambrian volcanics, intrusives and fault locations. HF – Henty Fault; CF – Cherrypool Fault; LF – Latani Fault; MCF – Mosquito Creek Fault. b) Palinspastic retro-deformation of tilt filtered TMI honouring over-printing criteria and supported by inversion results. The three Black Range belt segments have been restored into a single belt pre-Silurian configuration. Insert shows faulting sequence: 1 – sinistral Cherrypool/Latani Faults; 2 - dextral Henty Fault and 3 – Mosquito Creek Fault (truncates Henty Fault, not retro-deformed in reconstruction).

Gravity data (Figure 1b) shows highs located over the denser volcanic belts, and lows coincident with intrusives and metasedimentary rocks. The exception is the Tyar Belt which appears to have no associated gravity high, unlike the other two belts. CRAE drilling in the 1990's intersected andesite in the southern half of the belt, much like that of the Black Range Belt, and the similarity in magnetic character compared with the other volcanic belts suggests a related composition and structural history. The subdued gravity response over the Tyar Belt may be explained by the effects of increased cover thickness, or relatively large volumes of buried intrusives directly west of the belt (Figure 3), and potentially intruded directly below the belt, or a combination of the two.

However this subdued gravity response may also be related to a relatively lower density of gravity stations in the vicinity of the Tyar Belt, therefore not fully capturing the gravitational signature of the volcanics.

CONCLUSIONS

Magnetic inversion modelling has provided an insight into the geometries of the Cambrian volcanic fault slices constituting the three segmented volcanic belts of the “Crab Nebula” in the Black Range region, validating a palinspastic retro-deformation of the belts along Siluro-Devonian strike-slip structures into a single fault slice of Stavely Arc volcanics. The Siluro-Devonian regional trans-tensional stress regime applied to the current study area, inferred from field observations in Grampians Group cover sequences and Cambrian metasediments, as well as potential field data, holds wider implications for the understanding of the entire Stavely Arc system in western Victoria, and its Cambrian configuration.

Given the proven prospectivity of the Black Range Belt by the existence of VHMS and/or porphyry-style Cu-Au mineralisation at the McRaes/Eclipse prospect, the realisation that all three belts form part of a now segmented, single fault slice of Stavely Arc rocks means that all three belts now share that prospectivity. However, explorers need to consider the implications of deformation and truncation of the volcanic belts by regional, post mineralisation strike-slip structures when designing exploration programs.

ACKNOWLEDGMENTS

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