Characterisation of metavolcanic megaclast structures within the Moyston Fault hangingwall mélange (Moornambool Metamorphic Complex), western Victoria: Insights from potential field modelling and machine learning

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SUMMARY

The 'Stawell Corridor', western Victoria, is a major goldfield where resurgent exploration is targeting metavolcanic bodies closely associated with major gold deposits. The Magdala Antiform hosts the Stawell Gold Mine and is the type-deposit for the style of mineralisation sought. Additional structurally related metavolcanic domes have been identified throughout the corridor, however few have seen substantial exploration due to obfuscation by sedimentary cover. A significant contrast in density and magnetic susceptibility exists between the metabasalt domes and the turbidite metasediments that host them, and this contrast makes potential field methods an ideal method for discriminating and characterising Magdala-style domes during exploration.

A ground gravity survey was conducted over the Magdala Antiform and two associated dome structures - Wildwood and Lubeck - to ascertain their signatures in gravity. The survey comprised profiles that transect the domes. Station spacing was varied, using 25 meters across dome surfaces and wider (50-100 meter) spacing beyond dome extents to establish background trends.

The acquired gravity profiles were forward modelled together with public magnetic data using drillhole, petrophysical and reflection seismic constraints as available. The Magdala profile is well-constrained by drillhole data gathered at Stawell Gold Mine and provides an opportunity to study the dome expression in gravity with detail. Profiles for Wildwood and Lubeck are relatively lacking constraints, with only a few drill sites nearby. Survey results suggest there may be significantly more metabasalt bodies throughout the Moyston Fault hangingwall than previously identified.

A second stage of the project aims to train a machine learning algorithm to identify potential Magdala-style dome structures from gridded potential field data, to assess the usefulness and reliability of machine learning methods in a mélange setting. Automating the early stages of interpretation in mapping has the potential to significantly ease the manual load of mapping at regional scales, especially in a structurally complex area like the Stawell Corridor.

Key words: Potential fields, Magdala Antiform, Moyston Fault

INTRODUCTION

The western Victorian goldfields are a world-class gold endowment. Gold resources throughout western Victoria are undergoing new development as deeper and previously overlooked prospects become viable targets for exploration, following improvements in geophysical data quality and model confidence, and driven by an expanding regional geological understanding. The Stawell Corridor, a fault-bounded wedge on the western edge of the Stawell Zone stratigraphically comprised of the Moornambool Metamorphic Complex (Cayley & Taylor, 2001), is a multi-million-ounce goldfield that constitutes much of the Stawell Zone's total endowment (Olshina & Lisitsin, 2011). As of 2011 the Stawell Zone had extracted a historical total of 3.9 million ounces of gold (Olshina & Lisitsin, 2011), and current estimates project up to a further 38 million ounces of gold resources undiscovered beneath sedimentary basin cover (Lisitsin *et al.*, 2009).

Stawell Gold Mine (SGM) is a major active gold mine in the Stawell Corridor, and the second largest hardrock gold mine in Victoria. Operators North Stawell Minerals (NSM) report 62 tonnes of gold produced since reopening SGM in 2016, and historical records total an additional 127 tonnes produced since 1853 (Fredericksen *et al.*, 2008). Gold is mineralised along a contact with a kilometre-scale megaclastic metabasalt body known as the Magdala Antiform, or

Magdala Dome, which sits within the Moornambool Metamorphic Complex mélange. The competence contrast at the interface between the metabasalt and surrounding St Arnaud Group turbidites allowed for sustained fluid flow over the course of an extended period of orogenic stress, leading to repeated generations of gold mineralisation (Robinson *et al.*, 2006; Wilson *et al.*, 2020).

Additional Magdala-style metabasalt dome structures are known to lie along-strike with the Moyston Fault for the extent of the Stawell Corridor. Many of the other domes are similarly prospective for gold mineralisation, proven by preliminary drilling. However, the exploration targets are buried tens to hundreds of meters beneath Murray Basin sedimentary cover (Noble & Dugdale, 2008), and have not historically been seen as favourable for mine expansion due to a lack of data and the stability afforded by the large endowment at Magdala.

The contrast between the relatively dense and magnetic metabasalts and the lower density, largely non-magnetic St Arnaud Group make potential fields methods effective for identifying buried dome structures. However, repeated episodes of structural deformation have made the domes difficult to interpret, and until an aerial gravity gradiometry (AGG) survey acquired by North Stawell Minerals (NSM) over the Magdala tenement in 2020, data were too sparse to adequately characterise the dome geometries and extents. Additionally, during mineralisation, fluid flow was channelled primarily along lobate "waterloo" structures on the dome surfaces (Schaubs et al., 2006). These waterloo structures are a high priority target for exploratory drilling to determine gold potential. Waterloo structures vary from tens to hundreds of meters in scale. Given the density contrast with the background turbidite, the larger waterloo structures are expected to be resolvable in gravity given sufficient survey resolution.

The NSM tenements extends for 60km along the corridor, including the Magdala, Wildwood and Lubeck domes. With intent to extend mining operations to the other domes, improved data and model confidence over the prospective domes has become valuable. Potentially hundreds of related metabasaltic dome structures lie along the extent of the Moyston Fault.

For this project, we designed and acquired a high-resolution ground gravity survey to supplement the NSM AGG survey and characterise the Magdala, Wildwood and Lubeck dome extents and geometries.

Additionally, the second stage of the project aims to train a machine learning (ML) algorithm to recognise potential Magdala-style dome structures from gridded AGG and aeromagnetic data. Given the tectonic scale of the Moyston Fault and the Magdala-style dome formation ubiquitous along its strike extent - each with potentially similar prospectivity to Magdala - an ML tool to automate the initial stages of regional interpretation would help accelerate undercover exploration programs. ML geological interpretation and mapping is a developing field (Karpatne *et al.*, 2019), and interpretations produced need to be scrutinised and evaluated for reliability.

GROUND GRAVITY SURVEY

Survey Design

The ground gravity survey was planned using the Geoscience Australia 2019 National Compiled Gravity Grid and the Geological Survey of Victoria (GSV) Compiled Zone 54 Total Magnetic Intensity (TMI) Grid, obtained from the Geophysical Archive Data Delivery System; an aerial gravity gradiometry survey acquired by North Stawell Minerals in 2020; and previous potential field interpretations of the dome locations (Noble & Dugdale, 2008).

The Magdala Dome traverse was 2 kilometres in total. Stations were spaced at 25-meter intervals directly over top of the dome crest to target changes in the lobe structures for an extent of 1100 meters and spaced at 50 meters over and beyond the dome flanks to ascertain the background trend. The Magdala traverse consisted of 84 stations in total.

The Wildwood Dome traverse extended 6 kilometres, with similar 25 meter station spacing over the dome crest. Stations were at 50 meters on the flanks peripheral to the dome crest and within its influence in gravity, and 100 meters beyond the dome flanks, regarded as background. The Wildwood traverse totalled 138 stations.

Interpretations of the Lubeck Dome area suggested a set of domes in parallel to the main Lubeck dome. Drillholes in the area did not reach sufficient depths to intersect the basalts, so the subsurface interpretation was relatively unconstrained. To better understand the relationships between the domes, an 8 kilometre traverse was collected at a consistent 50 metre spacing across the southern end of the dome complex. The Lubeck traverse totalled 175 stations.

The survey was conducted with a Scintrex CG5 Autograv relative gravity meter, and a Trimble R6 Real-Time Kinematic differential GPS for locations and elevations. Gravity measurements were tied to the Australian Absolute Gravity Datum 2007 (Tracey *et al.*, 2007), using the Australian Fundamental Gravity Network node at the Cato Park Pavillion (Station 1995901338) in Stawell. Locations were tied to permanent cadastral marks with level-adjusted Australian Height Datum elevations.

Gravity data were processed to correct for drift, tidal variation, the theoretical gravity correction (the 1980 International Gravity Formula; Telford *et al.*, 1990), free-air correction, and Bouguer and terrain corrections (Blakely, 1996) using a crustal average background density of 2.67 g/cm^3. The resulting terrain corrected gravity data were used for forward modelling.

POTENTIAL FIELD PROFILE MODELLING

Modelling Approach

Terrain corrected gravity data were modelled using the GM-SYS® profile modelling extension for Oasis Montaj® version 2022.1 (Geosoft, 2022). Rock properties were constrained by measurements taken during field work and a petrophysics datasheet supplied by NSM. The Magdala model was based on a 3D mine model used by NSM and constrained with nearby drillhole data (summarised in Table 1). The Wildwood model was informed by the 06GA-V1 seismic line interpreted by Cayley *et al.* (2011) and drillhole data. The seismic line and nearby drillhole data were also used to constrain the Lubeck model. Gravity was simultaneously modelled against its 1st vertical derivative and profiles from the TMI grid.

Lithology	***Avg. density* [g/cm^3]**	***Standard deviation***	***Minimum***	***Maximum***	***Avg. magnetic susceptibility* [SI * 10^{-5}]**
Basalt	2.82	0.10	2.76	3.18	671.04
Stawell Facies	3.06	0.37	2.43	3.89	2018.34
Albion Formation	2.77	0.06	2.71	2.85	321.84
Leviathan Formation & St Arnaud Beds	2.76	0.04	2.73	2.82	28.50

Table 1. Summarised rock properties and statistical distributions for density measurements. Data were collated from petrophysical studies commissioned by SGM (supplied by NSM) as well as field measurements of magnetic susceptibility in drill core from Magdala.

Results

A recreation of the Stawell Gold Mine 3D model along the profile was reproduced in GM-SYS® to compare with the observed gravity (Figure 1). The existing model only needed the scope to explain the immediate structures of the mine and its ore lodes. As a result, the model only accounts for the major structures that fit moderately well to the medium (kilometre-scale) wavelengths observed. However, a set of short (hundreds of meters) wavelength anomalies are not accounted for by the current model surfaces alone. The short wavelengths and high amplitudes of the anomalies suggest high-density bodies near to the surface. The anomalies align closely with known fault planes, suggestive of further fragmentation of the metabasalt and at a smaller scale than accounted for in the model.

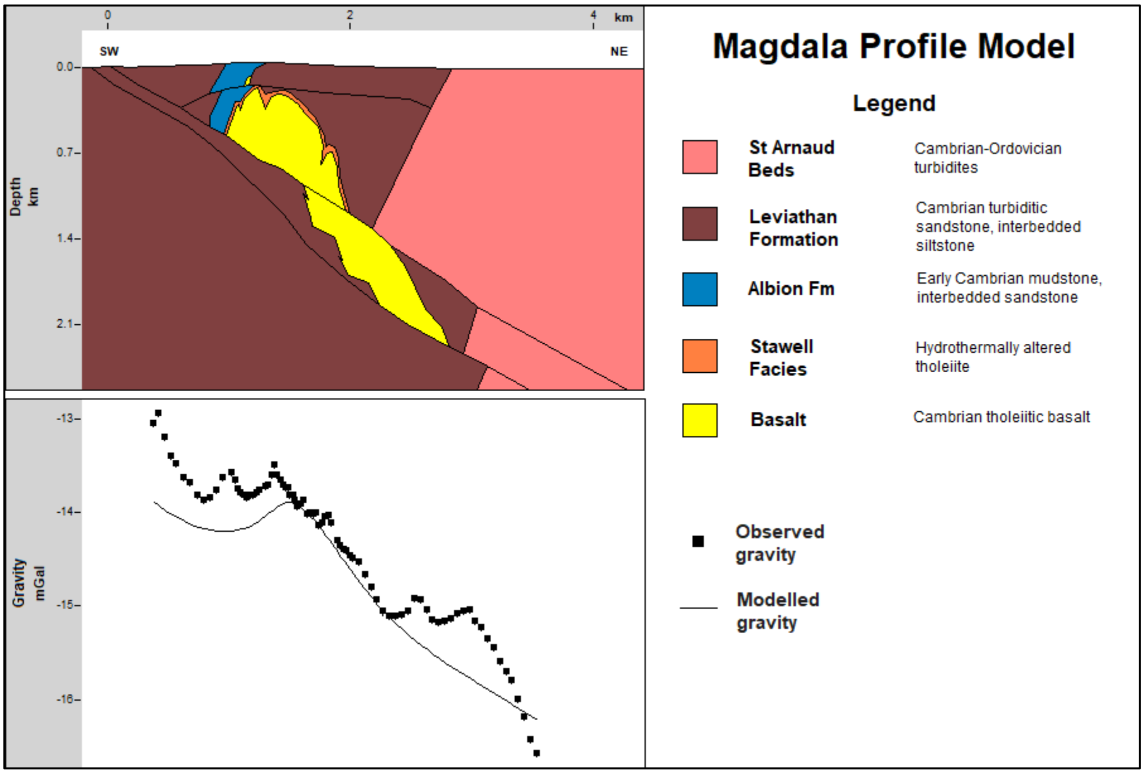

Figure 1. Stawell Gold Mine 3D model reproduced in a GM-SYS® 2D profile (above) with modelled gravity compared to observed gravity (below).

The model in Figure 2 incorporates drillhole constraints and mine cross-sections to explain the short-wavelength anomalies. Additional bodies of metabasalt have been added to the model at locations where metabasalt has been reportedin drill core. Attributing these additional occurrences with the same density value attributed to the Magdala basalt (2.81 g/cm^3) produces a close match with the observed gravity. This model assumes the anomalies to be coherent blocks of metabasalt, except for the brecciated zone along the Coongee Fault to the northeast, where metabasalt breccia has been interpreted to straddle the interpreted Coongee Fault position. The modelled section suggests the possibility of additional, previously unrecognised, local footwall splays to the Coongee Fault in this vicinity.

An unusually high-wavelength anomaly was observed at the southwest end of the section. To fit the gravity, the body required a minimum density of 2.9 g/cm^3, within a standard deviation of the average value, but unusually high for the Magdala area. The body may be another volcanic intrusion, or a portion of a different basalt body, or a dome of ultramafic composition (meta-igneous domes of ultramafic composition are recorded in other parts of the MMC).

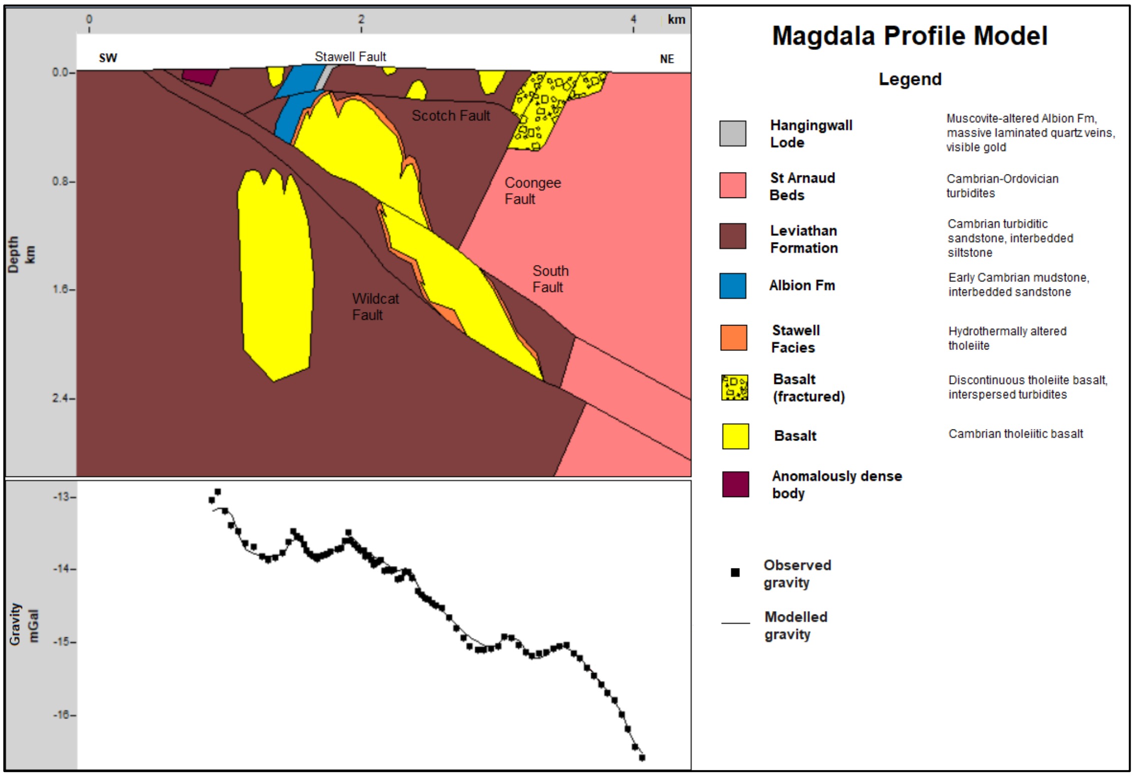

Figure 2. 2D GM-SYS® profile model of the Magdala dome, modelled to fit the observed gravity with incorporated drillhole constraints.

The upper Magdala dome is 800 meters across and extends to 700 meters depth, with waterloo 'lobes' developed on the upper surface, likely 'mullion' structures developed in response to protracted shearing across the metabasalt-metasediment interface. The Magdala body is draped by the Stawell Facies metasediments. Lower Magdala represents multiple offset segments of the lower part of the Magdala dome sheared between the South Fault and Wildcat Fault, extending 1.5 kilometres deep and dipping northeast. Lower Magdala is offset from upper Magdala across the South Fault by approximately 800 meters. A western Magdala-type body located below the Wildcat Fault, 400 meters across and 1.2 kilometres deep, has been interpreted in order to better fit the long wavelength pattern seen in the gravity profile.

The brecciated basalt body along the Coongee Fault extends for approximately 500 meters either side of the fault zone, and to about 600 meters depth. Four smaller half-cylinder basalt bodies from 40 to 160 meters across are distributed through the Scotch Fault hangingwall near-surface. A section of Albion Formation 200 meters across intersects the surface, with a 40 metre offset across Scotch Fault. The eastern side of the Stawell Fault hosts the Hangingwall Lode, coincident with a near-surface gravity high.

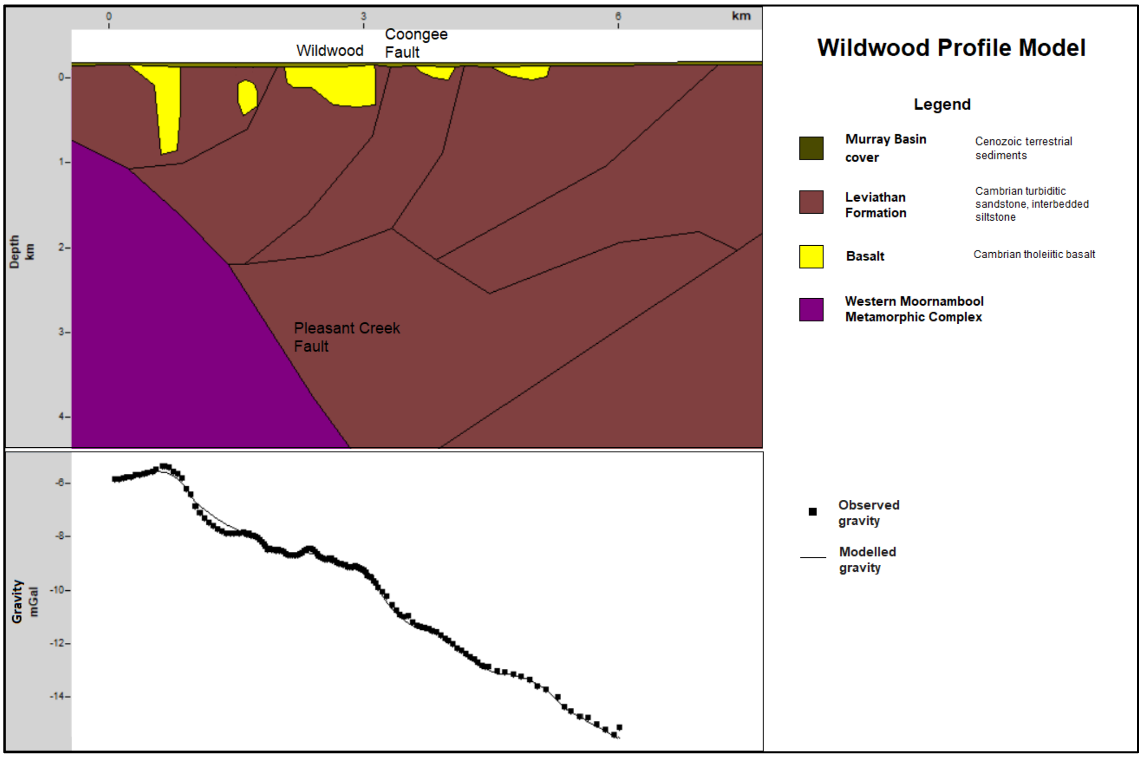

Figure 3. 2D GM-SYS® profile model of the Wildwood dome (above) with modelled gravity compared to observed gravity (below).

A preliminary Wildwood model (Figure 3) consists of five fault-associated basalt bodies suspended within Leviathan Formation metasediments, buried beneath 50 meters of Murray Basin sediments, located in the hangingwall of the Pleasant Creek Fault. The Wildwood basalts that intersect the paleosurface beneath the Murray Basin vary from 400 meters to 1.2 kilometres across, and from 120 to 900 meters deep. The gravity indicates the presence of an additional buried body 350 meters across and 500 meters deep. The shapes of these domes will be refined using the gravity 1st vertical derivative to model possible surfaces for the basalt bodies. The Pleasant Creek Fault passes beneath the section dipping northeast, from 600 metres depth on the western side to 4 kilometres on the eastern side of the traverse. Faults were extrapolated from the GA06-V1 seismic line. Drillhole data are sparse at the targeted section of Wildwood, and the holes along the section do not report intersections with metabasalt – these near-surface anomalies may therefore be products of, or interact with, other forms of volcanic intrusions.

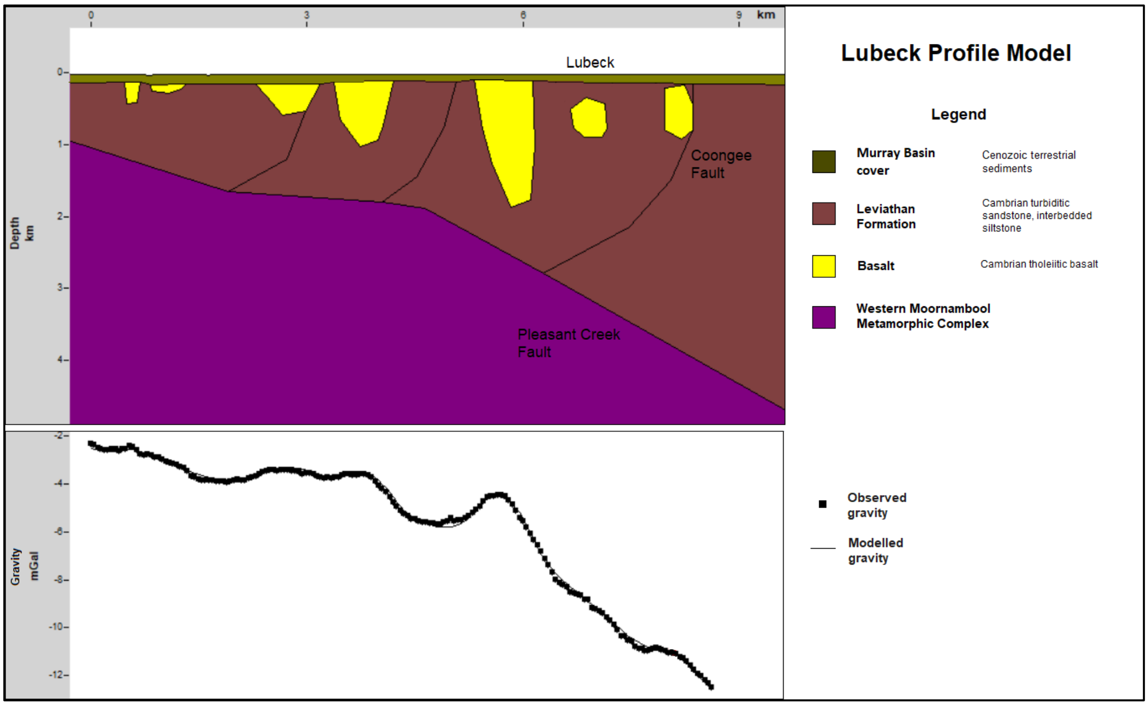

Figure 4. 2D GM-SYS® profile model of the Lubeck dome (above) with modelled gravity compared to observed gravity (below).

A preliminary Lubeck model (Figure 4) consists of seven discrete basalt bodies suspended in the Leviathan Formation beneath 150 meters of Murray Basin sediments, located in the hangingwall of the Pleasant Creek Fault. The bodies range from 200 to 800 meters across, and extend up to 1.7 kilometres depth. The Pleasant Creek Fault passes from 1 kilometre depth in the west to 4.6 kilometres east of the traverse. Similarly to Wildwood, drilling constraints that report intersections with metabasalt are sparse. Developing the models against the gravity 1st vertical derivative will refine the dome surfaces.

The forward models suggest that metabasalt domes / megaclasts are more widely dispersed throughout the Moornambool Metamorphic Complex and in less of a linear trend than has previously been interpreted locally. The additional bodies modelled are significantly smaller than the major Magdala, Wildwood and Lubeck domes, and are likely to have been missed by the broadly spaced regional surveys. This interpretation of the Stawell Corridor points to a more complex, multi-scale understanding of the basalt emplacement, and supports the kinematic evidence that the western Stawell Zone represents an accretionary wedge (as in Wilson *et al.*, 2020).

DISCUSSION

In the Stavely Arc Delamerian subduction model the Magdala-style domes were emplaced as the gouge material scraped from an oceanic basalt floor into a type-1 backstop (Taylor & Cayley, 2000), developed in front of the Stavely Arc during Cambrian continent-dipping subduction / accretion (Cayley et al. 2011). The basalts were suspended in the metasediment-dominated accretionary material, faulted and sheared along the extent of the Moyston Fault. The non-linear pattern of basalt emplacement modelled here and their association with major faults each support the interpretation of the Moornambool Metamorphic Complex as an accretionary mélange (Cayley & Taylor, 2001).
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The Magdala Dome gravity profile indicates the possibility of additional local structural complexity along the trace of the Coongee Fault – if basaltic domes and breccia are intersected by multiple Coongee Fault splays as suggested by the gravity data, this region could have previously unrecognised potential to localise mineralisation.

The models presented are cases that assume all anomalies to be discrete metabasalt bodies. Mafic and felsic dykes are also common along the Stawell corridor, and a set of models that produce a similarly close fit with the observed gravity could be produced that explain many of the features with dykes. A closer pass of the models against the gravity 1st vertical derivative hopes to better reduce the possible-fit models. By nature of the mélange, the basalt bodies are largely non-stratigraphic, and so are difficult to constrain by geological means other than association with faults. Nonetheless, drillhole data across the extent of the survey suggests the widespread emplacement of seemingly random isolated basalt clasts throughout the Leviathan Formation.

An approach that treats the basalt distribution less linearly, with bodies at scales down to the tens of meters, may help to better understand the complex structural relationships of the western Stawell Zone. With potential for such widespread basalt emplacement, an ML tool to identify Magdala-style domes with their geological context (primarily, fault-associated) could significantly ease the effort of targeting potential domes at depth.

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