Using 3D modelling and numerical deformation - fluid flow simulations to target gold mineralisation around basalt domes in the Stawell Zone, Central Victoria

Peter Schaub1, Tim Rawling2, Jon Dugdale3, Chris Wilson2

1 pmd*CRC, CSIRO Exploration and Mining, PB Box 1130, Bentley, WA 6102
2 pmd*CRC, School of Earth Sciences, University of Melbourne, VIC 3010
3 MPIMines, Stawell, Victoria

Expensive ‘drill-centric’ exploration programs typically have unpredictable outcomes. In the Victorian goldfields, over the last few decades, they have been spectacularly unsuccessful at finding any significant new gold deposits. At Stawell, in western Victoria, new cost effective exploration tools are being developed and tested. These techniques use 3D modelling and numerical deformation-fluid flow simulations to discriminate the potential fertility of prospect regions based on limited (but reliable) field data. The strategy adopted to facilitate this predictive modelling is to develop strong understanding of a ‘type model’ through research. This provides the deformation, alteration and metamorphic history, and the geometry of critical units, plus the petrophysical properties of those units are defined. Numerical simulations are carried out on this well defined model and results of the simulations can be compared with known deposit geometries and grades. Data sets are acquired to constrain the geometries of similar geological features in identified target areas (by field mapping, potential field data, geochemical drilling, inversion modelling). Realistic 2D and 3D models can be constructed which may include various alternative interpretations. Numerical simulations are applied to the ‘target models’ using the (now tested) ‘type model’ parameters. Predicted targets are tested with strongly spatially constrained drilling programs.

At Stawell, type models have been developed at both ore shoot scale (Dukes Nose locality) and at the dome scale (Magdala Dome). Using extensive drillcore, underground mapping and sampling databases, initial 3D models were constructed in gOCAD. These geometries were used in deformation - fluid flow numerical simulations. Critical variables, such as the orientation of stress fields during deformation, were well established from previous research. Initial results show a strong correlation between the location and geometry of zones of predicted high fluid flow and actual ore shoot geometries in the Magdala system, both at shoot and dome scale. This indicates that at the dome-shoot scale the geometry of the dome and its geometrical relationship to the syn-mineralisation stress fields is absolutely critical to the localisation of mineralisation within the deposit. The same modelling techniques and philosophies were applied to identified exploration targets within the same structural belt (Kewell and Wildwood Domes). 3D models were constructed using a combination of aircore drill data, potential field data and geophysical inversion modelling.

Geological background to numerical models

During the model definition process three critical elements were identified. These were: 1) the geometry of the model elements, 2) the rock types involved, and 3) the orientation of the stress field during gold mineralisation.
The geometry for the Dukes Nose model was defined by a combination of drilling, underground mapping and, to a lesser extent, geophysical interpretation. The Kewell and Wildwood model geometries were defined by air core drilling, minor diamond drilling and detailed magnetics and gravity inversion modelling. The three dimensional model at Dukes Nose was originally built in MineSight by the mine geologists at MPI and was then imported into gOCAD where it was pre-processed for FLAC modelling. The Kewell and Wildwood models were both built in gOCAD.

Three major rock types were considered to be critical to the modelling. These were the basalt (domes), volcanogenics (altered and deformed? volcanogenic sediments) and the mine schist. The petrophysical data used for each rock type in the modelling was taken from geotechnical data supplied by MPI but better data is currently being acquired and the models will be reassessed in light of these data once they become available.

The deformation history at the Magdala mine has been well documented by Miller and Wilson (2002). Three early ductile deformation events predated the gold mineralisation and produced a variably developed layer parallel schistosity, upright folds with a strong axial planar fabric, and a differentiated crenulation cleavage and refolding, respectively. Gold mineralisation was coeval with two subsequent brittle deformation events. The first (D4) resulted in the development of NE striking reverse faults due to dominantly ENE-WSW directed compression. The second event (D5) marked a switch to a sinistral shearing environment characterised by tension gashes near the basalt that formed during NW-SE oriented shortening. The deposit was subsequently dismembered by several later brittle faulting events, the effects of which were removed for the purposes of this modelling exercise.

**Numerical modelling results**

In all models, areas of high fluid flow rate occur within the volcanogenics because of the high permeability assigned to them, but within this unit high fluid flow is controlled by the proximity of areas of contraction and dilation. Areas of contraction on the flanks of the basalt dome occur where the dip is steep and at a high angle to the shortening direction. Towards the top of the domes the volcanogenics become areas of dilation. This causes fluid flow rates to be highest close to the top of the dome where both volume strain and pore pressure gradients are highest.

**Dukes Nose, Magdala Dome - Ore-shoot scale**

Models of the Dukes Nose show that, on the ore/-/shoot scale, areas of high fluid flow and dilation are in part controlled by variations in thickness of the volcanogenics unit along strike. Rotating the far-field stress field causes areas of high fluid flow to be shifted down plunge.

*Figure 1. Dukes Nose numerical simulation results. (a) Minesight model of Dukes Nose and Extended Basalt with Darcy Flow vectors (red – highest flow rate, blue – low flow rate) and shear strain contour, (b) basalt surfaces with flow vectors and grade envelopes (aqua – Dukes Grade 4g/t, green – Central Lode Grade 4g/t).*
In both ore-shoot and dome scale models, areas of high fluid flow are concentrated at the top of basalt lobes on the flanks of the dome. This occurs because the volcanogenics separating the basalt bodies are contracting and are areas of higher fluid pressure. Fluid is forced up this thin unit towards the area of dilation, which occurs near the top of basalt lobe. Areas of maximum dilation still occur near the top of the main basalt dome but the fact that the intervening volcanogenics are contracting and have high permeability causes high fluid flow rates to be localised above the minor lobe.

**Magdala Dome**

Areas of maximum fluid flow in models of the entire Magdala Dome shortened from the NE-SW are located near the top of the dome on both flanks. When the stress field is rotated to E-W, it causes the maximum fluid flow rate to be shifted towards regions near the Dukes Nose on the SW flank – an area of known mineralisation. High values of fluid flow on the flanks of the dome appear to be coincident with disseminated mineralisation, while areas of dilation are closer to the crest of the dome and are coincident with areas of vein hosted mineralisation. Areas of maximum dilation occur where the plunge is relatively shallow and changes in the plunge are gradual.

**Kewell Dome**

In the Kewell Dome models, the presence of thin basalt lobes on the flanks of the domes cause the region above the basalt lobes, within the intervening volcanogenics, to become the region with the highest fluid flow rates. This occurs because this unit separating the basalt bodies is contracting and is an area of high fluid pressure. Fluid is forced up this thin unit towards the area of dilation which occurs above the top of basalt lobe. Areas of maximum dilation still occur near the top of the main basalt dome but the fact that the intervening volcanogenics are contracting and have high permeability cause high fluid flow rates to be localised above the minor lobe.

*Figure 2. Fluid flow vectors from models of the Magdala dome. a) NE-SW shortening b) E-W shortening after NE-SW shortening.*

*Figure 3. Kewell Dome numerical simulation results. Yellow surface – basalt, red surface – shear strain contour, mauve surface – ground level, fluid flow vectors. Existing diamond holes KD1 and KD2 are marked (blue circles) as are the proposed diamond hole locations (green circles). Dome is 3.5km in length and view is to the north.*
Wildwood Dome

In the Wildwood model, areas of maximum dilation occur on the NNW end of the dome where the plunge is relatively shallow and changes in the plunge are gradual. At the SSE end of the dome where the plunge is more variable, dilation is lower. This is consistent with the Kewell model where areas of maximum dilation coincide with the gentle plunge of the dome on the SSE side.

Summary

Numerical modelling has placed constraints on some of the factors which may be important for the location of gold mineralisation on the flanks of these basalt domes. In all models, areas of high fluid flow rate correlate well with areas of known mineralisation. Areas of high fluid flow rates are controlled by the shape of the basalt domes and the far-field stress direction. Areas of dilation do not necessarily coincide with these same areas. The presence of the volcanogenics (which are given weaker mechanical properties than the matrix or the basalt) causes the absolute values of dilation and fluid flow to increase; however, the relative position of areas of dilation and high fluid fluxes with respect to the position of the domes does not vary greatly.

The volcanogenics are areas of contraction on the flanks of the basalt dome where the dip is steep and at a high angle to the compression direction. Towards the top of the domes the volcanogenics become areas of dilation. This causes fluid flow rates to be highest close to the top of the dome where areas of contraction and maximum dilation are in close proximity.

The presence of thin basalt lobes on the flanks of the domes cause the region above the basalt lobes, within the intervening volcanogenics, to become the region with the highest fluid flow rates. This occurs because the volcanogenics separating the basalt bodies is contracting and is an area of high fluid pressure. Fluid is forced up this thin unit towards the area of dilation which occurs within the volcanogenics near the top of basalt lobe. Areas of maximum dilation still occur near the top of the main basalt dome but the fact that the intervening volcanogenics are contracting and have high permeability cause high fluid flow rates to be localised above the minor lobe.

In the Magdala Dome models, the rotation of the compression direction from NE-SW directed to E-W directed causes the locus of maximum dilation to be located within the upper portions of the volcanogenics high above the Dukes Nose. The region of highest fluid flow also changes position; down plunge along the top of the Dukes Nose. This is caused by the higher fluid pressure gradient within the Dukes Nose towards the NNW end of the model.

The numerical simulations run on these models predicted zones of high fluid flow (high mineralisation potential) that matched very closely the existing drilling and assay data. More importantly, the analysis of these results immediately changed the targeting criteria that will be used to assess basalt domes in the region, as well as providing an excellent template for developing explorative drilling programs within these prospect regions. Drilling on the south end of the Kewell Dome where the models predicted areas of high fluid flow and significant dilation, has yielded encouraging results.

Reference