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Mine Scale Constrained Geophysical Inversion; A Case Study at the Darlot-Centenary Gold Mine

Sarah Monoury
SRK Consulting
Melbourne
smonoury@srk.com.au

Ben Jupp
SRK Consulting
Melbourne
bjupp@srk.com.au

Andrew Foley
Gold Fields
West Perth
andrew.foley@goldfields.com.au

SUMMARY

SRK Consulting (SRK) conducted a geological and geophysical modelling study of the Darlot-Centenary Gold Mine, Western Australia. This study defined geological boundaries in areas where drilling was limited, allowing for targeting of potential extensions to the gold mineralisation. 3D geological modelling of the structural setting and geometry of gold mineralisation within the deposit has shown a strong relationship between gold grade and a magnetic sub-domain within the Mount Pickering Dolerite. The magnetic dolerite domain is considered as a more prospective unit and a target for exploration drilling.

To define the boundaries of the dolerite multiple unconstrained magnetic inversion, models were conducted. This was followed by geologically constrained inversions. The resulting models were consistent and both methods are capable of resolving the prospective magnetic dolerite domain. However, the constrained inversion model ultimately provided a better representation of the geometry of the folded dolerite units. Using the inversion modelling, SRK was able to provide greater certainty in the subsurface geometry of the prospective Mount Pickering Dolerite, providing greater accuracy for the potential near mine exploration targets.

Key words: 3D geological modelling, constrained magnetic inversion, exploration targeting and gold mineralisation.

INTRODUCTION

Understanding the subsurface geometry and the controls on mineralisation are the most pertinent questions facing exploration and mine geologists. During the course of a modern mineral exploration program commonly large datasets are collected which include detailed geophysical data. Magnetic and gravity data are routinely modelled in 3D using unconstrained inversion techniques, which rely on the geophysical properties without taking into account geology either from interpretation or drilling information. The lack of geological control can make these models difficult to interpret and as a result they poorly represent the observed geology. However, with advances in inversion and 3D modelling packages it has become easier to integrate geophysics and geology into consistent and more reliable models.

SRK recently undertook a magnetic inversion study using the VPmg v7.1 (Fullagar Geophysics) at the Darlot-Centenary Gold Mine (Darlot) which is located within the Yandal Greenstone Belt in Western Australia. Geophysical inversion modelling integrated high-resolution magnetic datasets with down-hole petrophysical data collected during drilling. This study followed on an initial phase of 3D structural modelling based on drilling data, providing the broad geometry of mineralisation within the deposit. The aim of this study was to refine the structural and lithological boundaries of the model, focusing on areas where drilling was limited in the near mine area.

The study was undertaken using a local mine grid, which is rotated. With the exception of the geology section, the maps presented are in the local mine grid.

GEOLOGY AND MINERALISATION

Darlot is located approximately 120 km north of Leonora, Western Australia. It lies in the Yandal Greenstone Belt of the Archean Yilgarn Craton (Beardsmore and Gardner, 2003). The deformed volcano-sedimentary succession at Darlot consists of felsic - mafic volcanic and sedimentary rocks, which are intruded by the differentiated Mount Pickering Dolerite (MD). The lithological sequences have been folded by the Darlot Syncline, an open northwest-plunging fold cross-cut by the northwest striking El Dorado shear zone. Sinistral movement along the El Dorado shear zone offsets the south-western limb of the fold by 1500 m (Beardsmore and Gardner, 2003). Lamprophyre and granite intrusions are recognised within the mine and occur as irregular bodies, dykes and breccias.

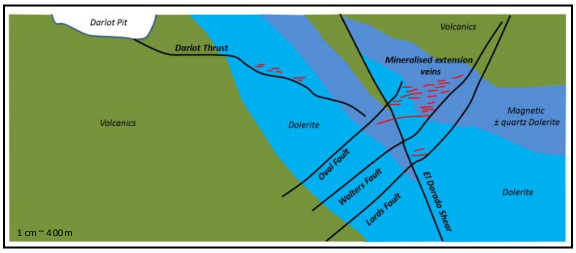

Figure 1. Schematic E-W cross section of the Darlot Mine (veiw towards north)

Gold mineralisation at the deposit is controlled by thrust faults, dolerites, lithology and host rock chemistry (Krcmarov et al., 2000; Beardsmore and Gardner, 2003; Kenworthy and Hagemann, 2007). Two distinct ore bodies (Darlot and Centenary) are recognised in the upper portion of the western limb of the Darlot Syncline.Gold mineralisation is hosted within, but not limited to, the relatively competent magnetic Mount Pickering Dolerite sub-domain (MMD), within sub-horizontal to moderately dipping extensional vein arrays and in the surrounding wall rock (Figure 1: Beardsmore and Gardner, 2003). Vein arrays are developed along east and

west dipping mine scale reverse faults, which include the Darlot, Oval, Lords and Walter faults (Figure 1).
The MMD domain has a strong magnetic contrast compared to the other geological units, making it suitable for performing geological constrained inversion modelling.

GEOLOGICAL MODELLING

3D modelling of Darlot was conducted using the Leapfrog™ implicit 3D modelling system and covers a total area of 5.78 km^2 (Figure 2). The model incorporates lithological horizons and major structures and has been constrained by over 11,000 drill holes predominately within the mine area. A total of six units were modelled within the project and are summarised within Table 1.

Unit
Lamprophyre + Granitoids
Mafic Volcanics
Felsic & Intermediate Volcanics
Porphyritic Dolerite (Mount Pickering Dolerite)
Magnetic Dolerite (Mount Pickering Dolerite)
Dolerite (Mount Pickering Dolerite)

Table 1. 3D modelled stratigraphy at the Darlot Mine

The structural framework of the mine incorporates the eastern limb of the Darlot Syncline and 25 individual faults have been modelled. Little displacement is observed along the late stage steep reverse faults, more offset is evident along the mineralised faults with the largest offset recognised across the strike slip Eldorado Shear (~1500 m).

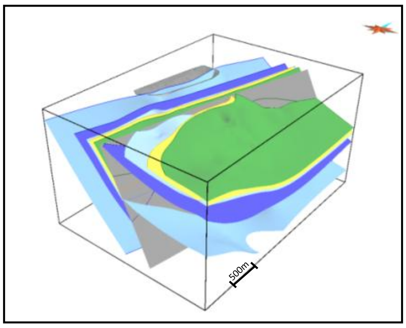

Figure 2. 3D Modelled Lithology Surfaces of Darlot Model (local grid)

DATA PREPARATION

Pre-processing of high resolution magnetic data (25 m line spacing) was conducted in order to account for the regional magnetic response and adjusted for mine grid co-ordinate transformations. To remove effects of the small short-wavelength (surficial) features, those too small to be resolved by modelling, were filtered using an upward continuation of 50 m. To account for uncertainties, an error was assigned to 10% of the standard deviation of the data.
The inversion modelling was done using an adaptative 3D mesh. The cells have an expanding vertical size (Z) and fixed lateral values (X-Y) of 50 m. Furthermore, where aeromagnetic data had high sample density along the flight lines, the data was resampled. The mesh size and amount of data were chosen to speed the computation time that allowed for testing of different assumptions.

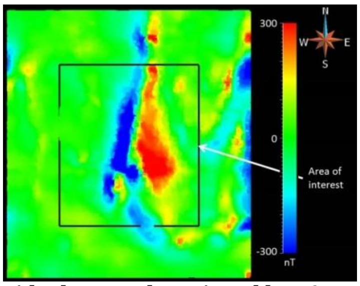

Figure 3. Residual upward continued by 50 m

UNCONSTRAINED MODELLING

Unconstrained inversion modelling aims to minimise the misfit between the computed and observed data. This process applies no geological constraint, but uses physical properties (i.e. magnetic susceptibility) to fit the observed response. The resulting model defines the geophysical property distribution that best minimises the misfit.
Using the magnetic dataset covering the Darlot study area (Figure 3), a good match was achieved between the computed and observed data. The dominant magnetic anomaly modelled was an east dipping body of high magnetic susceptibility. The source correlates well with the known MMD unit and confirms the extension of the MMD interpreted from structural analysis.

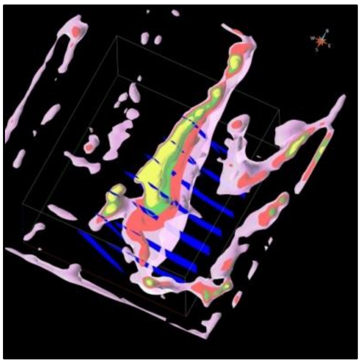

Figure 4. Unconstrained inversion iso-surfaces from 0.01 SI to 0.04 SI by 0.01 SI step with MMD unit (Blue)

ROCK PROPERTIES

Prior to constrained inversion modelling the 3D geological model (starting model) was discretised into a 3D raster (block) model at 50 m x 5 0m x 50 m and 10 m x 10 m x 10 m resolutions using the GOCAD™ 3D modelling software (Figure 5). Discrete geological properties were applied to each unit in order to preserve the geological character of each unit.

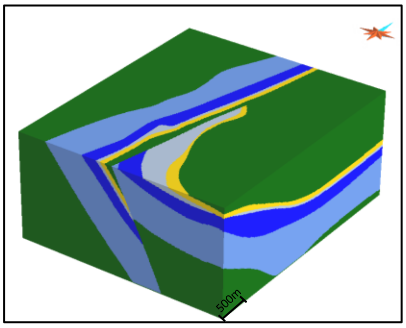

Figure 5. 3D rasterised Darlot model (scale)

Rock properties for each unit were evaluated using downhole magnetic susceptibility readings. Rock properties were applied to each geological unit and the properties of the dominant magnetic unit were found to correlate with the MMD with a mean magnetic susceptibility of 0.043 SI. The susceptibility data for the MMD unit was observed to be heterogeneous in nature, but some zones of demagnetisation were evident, possibly related to alteration or remanent magnetization.

FORWARD MODELLING

Forward modelling computes the magnetic field produced from a geological model and compares the computed response to the observed response. The process is iteratively repeated until a good match is obtained. During forward modelling, the model parameters are manually adjusted providing better control on the parameters influencing the modification during the inversion. This iterative process is automated during the constrained inversion workflow. Forward modelling was initially run to assess the parameters for the starting model and then to determine the approach of the inverse modelling.

During forward modelling, SRK assumed that the remanent magnetization and self-demagnetization within the MMD unit had minimal influence on the total magnetic field (TMF). With all the units being selected for the inversion, initially the mean and then the median magnetic susceptibility values were used. The mean susceptibility proved to return a better fit than the median value, however, the computed magnetic field was poorly reproduced (Figures 6 and 7). The following process of constrained inversion aimed to improve the fit.

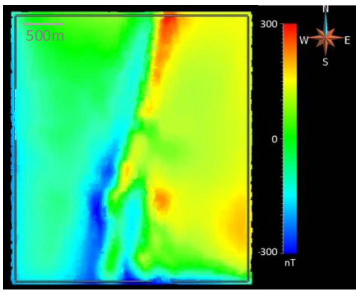

Figure 6. Forward model computed data

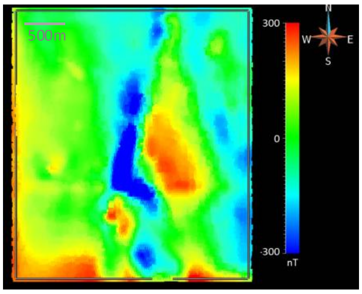

Figure 7. Forward model misfit

CONSTRAINED MODELLING

Three parameter types are available in VPmg: geological contacts, rock properties and basement. VPmg offers four inversion styles based on the freedom of the different parameters (Fullagar, 2013).

Maintaining the susceptibilities in the range of the measured values and the initial geometry was found to generate a corridor of extremely low magnetic susceptibilities within the MMD (Figure 8).

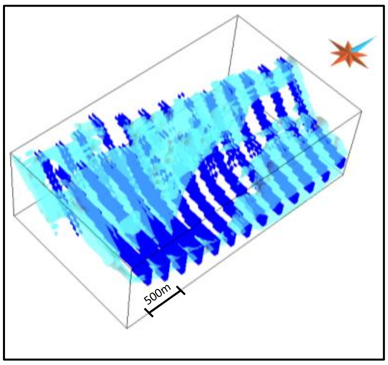

Figure 8: 0.01 SI iso-surfaces over MMD slices (blue)

As the basic geometry was well understood, the contact and basement parameters are initially fixed during the inversion while the magnetic susceptibilities were adjusted. Magnetic properties can be modified by two inversion types: homogeneous and heterogeneous. Homogeneous modelling only allows the variation of homogeneous rock while heterogeneous modelling allows the properties to change only in heterogeneous rock.

Several scenarios of constrained inversion models were run until the magnetic susceptibilities were better defined throughout the geological units. Iteratively each scenario becomes the starting model of the next one. In the final model the MMD, granitoids and felsic units were considered as heterogeneous whereas the other units were considered as homogeneous. Once the magnetic susceptibility of the homogeneous rocks was set, the magnetic susceptibility was adjusted for the heterogeneous rocks.

The magnetic response from the preliminary constrained models suggested a component of remanent magnetization, although the strength and orientation remained unknown. Several manual tests were performed to improve the computed response using the mean magnetic susceptibility. The computed magnetic field was comparatively reproduced for a remanent magnetization vector with an assumed vertical azimuth and an inclination of -30 degrees. The ratio of remanent magnetization to induced magnetization, the Koenisberger ratio was set to 0.3. Despite these processes a misfit remained with both high (red) and low (blue) misfit areas evident (Figure 9 and 10).

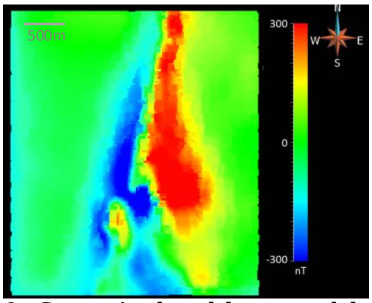

Figure 9. Constrained model computed data with remanent magnetization adjusted

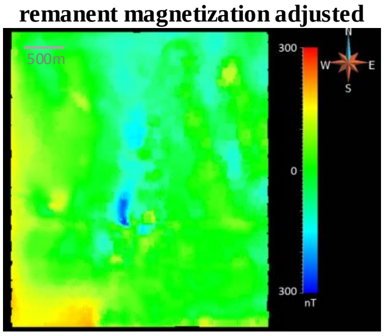

Figure 10. Constrained model misfit with remanent magnetization adjusted

The magnetic susceptibilities were fixed and the geological contacts were constrained at drill holes and resulted in changes in the MMD unit and granitoids. The resulting model (Figure 11) has removed MMD material (red blocks) in the fold centre and added MMD material (green blocks) beneath the mafic volcanics in the north-west of the project area. It provides a better understanding of the distribution of this unit outside of current drilling.

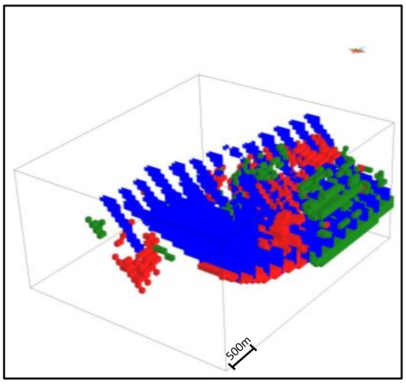

Figure 11. MMD modifications – Blue initial model (EW model slices), Red substracted and Green added

CONCLUSIONS

Both constrained and unconstrained inversion modelling validated the northern extension and subsurface geometry of the MMD unit, indicating areas prospective for gold mineralisation to the north of the currently mining. Geometric inversion modelling indicates the MMD is located within the northern hinge zone of the syncline, where it may be deeper and thicker than the starting geological modelling suggested. The inversion modelling indicates a weakly magnetic zone within the MMD, extending from the syncline along the western limb. The constrained inversion modelling provides a better representation of the fold geometry, honouring the geological model and the geophysical response. Using a combined approach has ultimately resulted in a better 3D geological model of the MMD unit which provides greater confidence for exploration drill targeting.

ACKNOWLEDGMENTS

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