3D interpretation of geological, 3D seismic and conventional geophysical data from the Darlot Gold Mine

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SUMMARY

The Darlot gold mine is an Archean orogenic deposit located in the world-class gold and nickel terrain of the Yandal granite-greenstone belt, part of the Yilgarn Craton in Western Australia. A 3D seismic survey centred on the Darlot-Centenary mineralised system was acquired in 2016-2017 with the objective of improving lithological and structural interpretation, and to generally extend understanding of the Darlot 3D mineralised system to support targeting. The capability of modern 3D seismic surveys to image formational contacts and structures in hardrock environments can have a game-changing impact on the effectiveness of brownfields exploration programs because the geometry of mineralised systems can be directly imaged over large volumes of ground. Furthermore, because the formational and structural geometry revealed by 3D seismic also provides the primary control on the physical property variations that magnetic, gravity, and electrical or EM methods respond to, seismic interpretation provides ideal constraints and guidance on the interpretation of other geophysical data. This is particularly valuable when an objective of geophysical interpretation is imaging of second-order controls on physical property variation, such as the effects of alteration.

We present the preliminary results of an integrated geological, petrophysical, seismic and non-seismic geophysical program to effectively support brownfields targeting in hardrock environments.

Key words: 3D Seismic, Magnetics, Gravity, hardrock, gold, integrated interpretation

INTRODUCTION

The Darlot gold mine is an Archean orogenic deposit located in the world-class gold and nickel terrain of the Yandal granite-greenstone belt, part of the Yilgarn Craton in Western Australia (Figure 1). Total production from Darlot and the associated Centenary deposit since 1988 has been 17.8 Mt at 4.8 g/t Au with a recently increased ore reserve of 1.92 Mt at 3.5 g/t. Mining face grades of 26 g/t to 35 g/t from the recently discovered (February 2018) ‘Oval West’ area and additional ounces from nearby exploration successes indicate the potential to expand the Darlot reserve base.

Gold mineralisation of the Darlot and Centenary deposits is typically associated with narrow, flat extension veins controlled by brittle-ductile D2 and D3 faults and strain partitioning at areas of contrasting competence. Host rocks are the magnetic Mount Pickering dolerite, which overlies felsic volcanoclastic sediments and felsic intrusive rocks, all of which are geochemically and rheologically favourable to gold precipitation. Mineralisation is associated with disseminated pyrite found in the albite, silica and carbonate alteration selvages of structures and veins. Lamprophyre intrusions occur throughout the deposit with a variety of orientations (occurring pre-, syn- and post-mineralisation); despite being barren, they have a spatial association to mineralisation.

Figure 1. Geology of the Darlot Gold Mine area. The red polygon shows the extent of the 3D seismic survey, and the dashed line shows the El Dorado Shear. Mafic igneous units are shown in various shades of green.

METHOD AND RESULTS

A 3D seismic survey centred on the Darlot-Centenary mineralised system was acquired in 2016-2017 (Figure 2) with the objective of improving lithological and structural interpretation, and to generally extend understanding of the Darlot 3D mineralised system to support targeting. The effectiveness of reflection seismic depends on the presence of contrasts in acoustic impedance (density × velocity) and use of appropriate survey geometries in order to capture reflections. A de-risking program conducted prior to acquisition included sonic velocity and density measurements on core, and limited numerical modelling. This work indicated that some of the mineralised structures and alteration zones, as well as faults, felsics, lamprophyres and dolerites would all exhibit strong...
acoustic impedance contrasts with adjacent units and would be good reflectors.

Figure 2. 3D view of the Darlot seismic cube. Strong reflectors in the eastern part of the cube are associated with folded dolerite sills.

3D seismic data was acquired and processed with prestack time migration and converted to depth using a derived velocity model. The depth conversion model was constrained by drilling data and by imaging underground developments and tying reflection depths to those workings. The final, processed seismic volume covers an area of 25 km$^2$, with interpretable resolution extending from 300 m to 3000 m depth with a cell size of $15 \times 7.5 \times 4$ m. The processed seismic volume exhibited numerous interpretable contacts and structures. Seismic interpretation tools in GOCAD were used to create an initial wireframe formational and structural model from the seismic volume. Interpretation challenges at Darlot included imaging of weak acoustic impedance contrasts and vertical to sub-vertical structural features.

We then used the 3D model interpreted from existing drilling as geometrical constraints on the interpretation of other geophysical data, which provided a means to validate and refine seismic interpretation of geometry, interpret parts of the volume that were too shallow to be effectively resolved from the seismic survey, and image physical property variations within formations that may have a bearing on targeting decisions.

**GEOPHYSICAL DATA**

Apart from the seismic data, there is a large amount of conventional geophysical data, including:

- Aeromagnetics (20 m flight height, 25 m spaced lines)
- Ground gravity (200 m station spacing).
- Induced polarisation (e.g., Pittard and Bourne, 2007).
- Surface geological mapping.

A large number of physical property measurements are also available, including magnetic susceptibility, natural gamma, IP and full-waveform sonic logs, as well as density and ultrasonic velocity measurements on core conducted as part of a de-risking survey undertaken prior to the 3D seismic survey.

There are approximately 3300 drillholes within the seismic cube. Deeper parts of the main syncline in the magnetic dolerite unit (MMD) are not well tested by drilling.

The gravity and magnetic data are shown in Figures 3 and 4.

Figure 3. First vertical derivation of the Bouguer gravity, upward continued 200 m. The blue rectangle shows the extent of the 3D seismic survey.

Figure 4. First vertical derivative of the reduced-to-pole magnetic data. The blue rectangle shows the extent of the 3D seismic survey.

**INTERPRETATION**

This paper focuses on interpretation of the potential fields data from Darlot. Detailed interpretation of the seismic data is in progress and will be described in a companion paper. All interpretations presented here were performed in GOCAD Mining Suite, which allows integration of 3D seismic, potential fields and drilling data. Potential fields interpretation was conducted using VPmg, interfaced to GOCAD Mining Suite.

The initial stage in interpretation was to establish relationships between the geology and the various geophysical data. At present, the seismic data has been interpreted qualitatively via
horizon picking tied to drilling. Qualitative observations about
the relationship of the potential fields data with the known
geology have been verified through 3D forward modelling
using VPmg.

Magnetic Interpretation

The main unit evident in the magnetic data is a magnetic unit
(MMD) within the Mt Pickering dolerite. Other magnetic
dolerite units are evident from both the magnetic data and
from geological mapping. Magnetic data also shows weak
dendritic magnetic anomalies, presumably associated with
maghaemite present in both modern and palaeo-drainages.

The magnetic data also provides a wealth of information on
structure. Many structures identified from the magnetics are
also evident in the seismic data, and the magnetic
interpretation is being used to guide ongoing interpretation of
the seismic data (Figure 5).

Figure 5. Structure interpreted from the magnetic data,
superimposed on the seismic data. The light blue surface is the
Darlot pit.

Figure 6 shows the response of the initial MMD model created
prior to this integrated interpretation, which included the
major syncline evident in the magnetic data, and a subvertical
MMD unit just west of the El Dorado Shear. The interpretation
was refined to include an obvious smaller, folded MMD unit within the main fold, and the response of
the refined model is also shown in Figure 6. The revised
interpretation more completely explains the observed
magnetic response. Additional magnetic highs suggest the
possible presence of more MMD within the syncline and also
in the southwest of the area modelled. The smaller fold occurs
within the top 200 m of the earth, at depths too shallow to be
imaged by the seismic data. This is one illustration of the
complementary information which may be obtained from the
3D seismic and potential fields datasets.

Gravity Interpretation

Initial inspection of the gravity data suggested that it was
likely to be dominated by the response of the regolith, which
is up to ~100 m thick in the area. Figure 7 shows the top of
fresh rock determined by tomographic inversion of the
refraction statics from the seismic survey, for comparison with
the gravity and magnetic data (Figure 3 and Figure 4). There is
reasonable correlation between the main highs and lows in the
gravity data and bedrock ridges and palaeochannels identified
from the seismic data.

### Table 1. Densities and susceptibilities of the various units modelled. MMD is the magnetic dolerite unit.

<table>
<thead>
<tr>
<th>Geology</th>
<th>Density (g/cc)</th>
<th>Susceptibility (SI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regolith</td>
<td>1.97 - 2.17</td>
<td>0</td>
</tr>
<tr>
<td>MMD</td>
<td>2.65 - 3.15</td>
<td>0.05</td>
</tr>
<tr>
<td>MD1</td>
<td>2.67 - 2.8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>MD2</td>
<td>2.67 - 2.8</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

The gravity response of the regolith was calculated based on
the seismic top-of-fresh-rock model. No petrophysical data
was available for the regolith density, and so a range of
densities from 0.5 – 0.7 g/cc less dense than fresh rock were
trialed until a preferred interpretation was obtained. Contrary
to initial expectations, the response of the regolith was quite
subdued and did not explain the main elements of the gravity
response. This implies that the gravity data is mainly
responding to density variations within the bedrock.

Initial interpretation of the gravity data had suggested there
was no response from the MMD unit. However, when the
regolith response was subtracted there was a residual gravity
anomaly associated with the contact between the eastern limb
of the syncline and the faulted western limb. This gravity
response is likely to occur because there is a sufficiently large
accumulation of anomalously-dense MMD at this contact. The
observation that thick MMD units may produce coincident
gravity and magnetic anomalies provides an immediate
targeting criterion for further such occurrences in the area around Darlot.

Figure 7. Top of fresh rock derived from tomographic inversion of the refraction statics data.

The next phase of the interpretation was to remove known geological responses, in particular that of the MMD unit, from the gravity response in order to identify any features of interest in the residual data. When this was done, the residual image showed a northwest-trending gravity low, offset slightly to the northeast of the axis of the main syncline (Figure 8). Gravity modelling was conducted to try to explain this gravity trough while at the same time remaining consistent with the seismic data. A convincing fit to the residual gravity can be obtained by a synclinal model with a deeper keel than the initial interpretation (Figure 9), and with lower-density material between the more dense upper and lower dolerite sills. The updated model is shown in Figure 11 and shows improved agreement with the seismic and gravity data (Figures 10 and 12). This modelling provides proof of concept for updating the shape and thickness of the Mt Pickering Dolerite. The next stage is to incorporate these findings into a revised seismic interpretation explicitly incorporating drillhole data.

CONCLUSIONS

This paper provides a progress report on an ongoing integrated interpretation of the 3D seismic, potential fields and IP data at Darlot with the ultimate objective of improved exploration targeting. The next stages of the interpretation will be to include detailed structural interpretation of the seismic as a constraint on the potential fields interpretation and to incorporate the IP data. It is envisaged that the integrated interpretation will result in improved potential fields interpretation in surrounding areas not covered by the seismic.

The interpretations presented here show the value of a methodical approach to interpretation of the potential fields data, with the response of known features being removed to identify residual anomalies associated with bedrock density variations.

Figure 8. Gravity data with the response of the regolith and the dense magnetic dolerite unit (MMD) removed. The image shows first vertical derivative, upward-continued 200 m.

Figure 9. Cross-section through the seismic cube showing the pre-seismic interpretations of the bases of the upper and lower dolerite sills (purple surfaces). The lower surface cross-cuts the seismic reflectors in the east.

Figure 10. Cross-section through the seismic cube showing the revised interpretations of the of the upper sill and the top (A-A) and base of the lower sill. The revised interpretation shows improved agreement with the seismic data.

Figure 11. Top of the low sill (A-A in Figure 10), interpreted from gravity, seismic and drilling data.
ACKNOWLEDGEMENT

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REFERENCES


Figure 12. Comparison of observed (top) and modelled gravity (bottom) for the model shown in Figure 11.