High Resolution Seismic for Minerals

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HiSeis Pty Ltd

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MINERALS vs OIL AND GAS

Used ubiquitously in oil and gas industry

WHY?

• Can investigate to large depths
• Provides continuous maps of layer boundaries and structures
• High Resolution
• Maintains resolution with depth

Used rarely in minerals industry

WHY NOT?

• Expensive? ...Is it really???
• Complex geology, fast velocities...Much progress has been made
WHY SEISMIC?

Typical Solution (Drilling)

- Detect point locations of contacts and structures
- Each hole tests a small area and provides limited context for further exploration
- \( \approx \$300K \) per km
- 3 holes in 3 months
- Resolution of conventional minerals geophysics degrades rapidly with depth

Problem

Deep brownfield exploration

- Map contacts and structures in 3D
- Each 3D seismic surveys screens multiple km\(^2\) and provides framework for subsequent exploration
- \( \approx \$300K/km^2 \).
- \( >3km^2 \) acquired and processed data in 3 months
- Resolution is maintained at depth

Seismic Solution (Seismic + Drilling)
OVERVIEW

How does it work?

How to establish it will work?

Case Studies
HOW DOES IT WORK?

- Reflections occur at changes in acoustic impedance (Density*Velocity).
  Eg abrupt changes in:
  - lithology and alteration
  at
  - bedding planes, faults, shears, intrusions etc

<table>
<thead>
<tr>
<th>Rock type log</th>
<th>Density g/cc</th>
<th>Velocity m/s</th>
<th>Reflection Coefficient (at base of unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slate 1</td>
<td>3.5</td>
<td>5600</td>
<td>0.09</td>
</tr>
<tr>
<td>Mafic 1</td>
<td>2.8</td>
<td>5750</td>
<td>0.08</td>
</tr>
<tr>
<td>Felsic 1</td>
<td>2.7</td>
<td>5000</td>
<td>-0.17</td>
</tr>
<tr>
<td>Altered ore</td>
<td>3.0</td>
<td>6350</td>
<td>0.07</td>
</tr>
<tr>
<td>Andesite</td>
<td>2.7</td>
<td>6150</td>
<td>-0.07</td>
</tr>
<tr>
<td>BIF</td>
<td>3.2</td>
<td>6000</td>
<td>0.04</td>
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<tr>
<td>Dolerite</td>
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<td>6350</td>
<td>0.04</td>
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<tr>
<td>Porphyry</td>
<td>2.7</td>
<td>6100</td>
<td></td>
</tr>
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</table>

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SEISMIC TRACES SIMPLIFIED

Acoustic Impedance = Velocity * density

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WHAT CAN SEISMIC SEE?

Resolution maintained with depth

Minimum resolvable bed thickness
• ~ 25m (top and bottom resolvable)

Minimum detectable bed thickness
• ~ 5m or less

Minimum fault throw
• ~ 10m

Horizontal Resolution
• ~ 25m across
SEISMIC DETECTABILITY

**P-wave Velocity vs. Density**

- Felsic volcanics
- Massive sulphides

**Visible to Seismic**

- Structures thick host mineralisation
- Grey Zone
  - Detectability depends on S/N, wavelet, etc.

**Not Visible to Seismic**

- Very Thin < 3m
- Acoustic Impedance Contrast
  - < 0.01 Very Small
  - < 0.1 Large

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SEISMIC IN PRACTICE

How do we de-risk a seismic survey?

Seismic Survey

Site Visit / Noise Test

Vertical Seismic Profiling / FWS

Rock Property Measurements

Synthetic Modeling

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ROCK PROPERTY MEASUREMENTS

- Measure transit time through core, half core or hand specimen
- Need flat ends
- Multiple samples per rock unit
SYNTHETIC MODELLING

- Wide scattering
- Forward modelling of possible geological scenarios is crucial for survey planning
- 3D effects
  - Implications for targeting
SONIC AND DENSITY LOGS

Strong reflectors in VSP data

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pedance contrasts
Greg, 16-Apr-13
VSP’s provide the macro-scale linkage between geological/petrophysical variations and the bulk in-situ response measured using surface seismic reflection techniques.
Strong reflectors in VSP data

Reflectors

Reflectors

Reflectors

Reflectors

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SITE VISIT

Evaluate:

• Access restrictions
• Logistical constraints
• Vibrational noise
• Electrical noise
• Any HSEC risks
CASE STUDY – KAMBARDA

Objectives

• Map subsurface stratigraphy and structure to 1km depth
• Map the basalt/ultramafic contact
• Map structures that offset this surface
KAMBALDA ROCK PROPERTIES

Accoustic impedance

2.5 2.7 2.9 3.1 3.3 3.5 3.7 3.9 4.1 4.3 4.5

P-wave velocity

density

massive disseminated intermediate mafic

matrix u/m

sediments

Lines of constant impedance

4000 4500 5000 5500 6000
KAMBALDA SURVEY DESIGN

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Concept of seismic fold
Number of source-receiver combinations with the same midpoint
Data from these source-receiver combinations are stacked into 1 seismic trace in standard common midpoint processing. Typically aim for a fold of 100 or more in hard rock surveys.
Actual coverage on reflector controlled by dip
# Kambalda Survey Design

<table>
<thead>
<tr>
<th>Acquisition parameter</th>
<th>Setting</th>
<th>Acquisition Parameter</th>
<th>Setting</th>
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</thead>
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<td>Nominal fold</td>
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<tr>
<td>Receiver Spacing</td>
<td>10m</td>
<td>Record length</td>
<td>3000ms</td>
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<tr>
<td>Shot spacing</td>
<td>20m</td>
<td>R/S Interval X-line</td>
<td>90m/50m</td>
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<tr>
<td>Channels/Patch</td>
<td>500</td>
<td>Receiver Density</td>
<td>550 per km²</td>
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<tr>
<td>Source type</td>
<td>Explosives</td>
<td>Shot Density</td>
<td>630 per km²</td>
</tr>
</tbody>
</table>
KAMBALDA FAULTING

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KAMBALDA BASAL CONTACT

channel structure on basalt surface

Looking to NW

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KAMBALDA INTRUSIVES

High amplitude reflections well tracked using opacity filter
KAMBALDA ATTRIBUTES

Direct indications of NiS

1. Standard attributes were calculated throughout the cube
   • Did not assist detection

2. Targeted approach
   • Expectations for NiS close to basalt ultramafic contact
   • Investigated amplitude variations close to contact
Kambalda Direct Targeting

Possible new target

Ni confirmed by drillhole

Ni confirmed by drillhole

Map showing amplitude extracted in a window close to the interpreted basal contact
Case Study – Bullabulling

Background

• 3.5 Moz resource
• No deep drilling
• Conventional geophysical methods did not map the mineralised shear

Objectives

• Assist targeting of a deep hole

<table>
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<th>Acquisition Parameter</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiver Spacing</td>
<td>10m</td>
<td>Sample rate</td>
<td>1 ms</td>
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<tr>
<td>Max Fold</td>
<td>200</td>
<td>Record length</td>
<td>3000ms</td>
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<tr>
<td>Shot spacing</td>
<td>10m</td>
<td>Total line km</td>
<td>3*6km</td>
</tr>
<tr>
<td>Source type</td>
<td>Weight drop</td>
<td>Offset</td>
<td>2km</td>
</tr>
</tbody>
</table>

Courtesy Bullabulling Gold
CASE STUDY – BULLABULLING
CASE STUDY – BULLABULLING

Cross-section on Seismic Line Showing Planned Drill Holes

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CASE STUDY – BULLABULLING

Figure 1: Section showing lithology and mineralization on traces of BBDE001 and BBDE002 with preliminary interpretation

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MAPPING VIA TEXTURE

Strong semi-continuous reflections
Shear
Multiple discontinuous reflections

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DATA INTEGRATION IS KEY

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HYDROGEOLOGY

Courtesy Fortescue Metals Group

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SHALLOW TARGETS

Bottom of Lake sediments

Stacking velocity 2300m/s
CONCLUSIONS

Reflection seismic:
• Can map the:
  • Lithological boundaries
  • Faults
  • Alteration zones
  • Intrusions
    which control mineralisation and potentially hazardous
    conditions for mining

• Is the only technique which can provide continuous high
  resolution 3D maps of these at depth (particularly >500m)
  • 10-15m cubes to 2km+

• Is cost competitive especially for deep investigations

• Has low environmental impact
"A high-resolution 3D seismic survey has now been completed over a 21 square kilometer area surrounding the Neves-Corvo mine. Preliminary results have clearly imaged the major Semblana deposit, verifying the effectiveness of this new tool in the search for blind massive sulphide deposits"


"Based on 3D models created using recently acquired seismic data, 2 new diamond drill holes were planned, each planned to drill to a minimum depth of 600m. A new prospective ultramafic-amphibolite sequence identified below the current deposit and further significant intersections from existing deposit were discovered"

Announcement from Bullabulling Gold Limited to the ASX, September 6, 2012 and October 30, 2012.
ACKNOWLEDGEMENTS

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