Integrated multidisciplinary high resolution 3D geophysics in brownfields and in-mine exploration: New successful approaches in gold, nickel and uranium districts

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**Theme 1: Using holes better** (getting more relevant information quicker)...example NiS mines in W Australia

- Drill holes
- Access Drives
- Access Declines

**Theme 2: Exploring the “Life of Mine Volume”**

- Quicker
- More effectively
What’s been happening?

Last few years:

• Strong demand for expansion of mining activities:
  • Emphasis on re-examining old mines or sites of mineralisation

Necessity to delineate extension of known mineralizations at greater depths

Need to define new more robust exploration targets, often beyond the reach of potential field methods

Exploration by drilling – too expensive, too slow

>>>>> Application of Tunnel and DHTEM

>>>>> Application of 2D/3D surface and borehole SEISMIC becomes an obvious choice
Theme 1: Better use of Holes: in holeTEM for NiS
TEM: Torch V 1.1
Torch v1.1

Nickel shoot in June 2003 ore reserve

EM Torch Profile

Percussion holes logged with blast hole probe
125m/shift @ $15/m (diamond drilling 10m/shift @ A$150/m)
In Mine FL3D TEM

Multiple underground Transmit Loops
Traverses PLUS DHTEM surveys
All 3 component Magnetic field
Multiple underground Transmit Loops

Traverses PLUS DHTEM surveys

Hole 52
Decline TX Loop

Hole 52
Stope TX Loop
ULTEM: Illuminating the Life of Mine Volume

Ultra Large (UL) Underground Transmit Loops (TEM)
Sub parallel to Ore plane or prospective ore plane
Advantages of seismic reflection method

- **RESOLUTION:** Preserves resolving power with depth
- **3D IMAGING:** Can provide detailed images of lithology AND structure of subsurface
- **DEPTH OF PENETRATION:** Works well to depths of several km’s
- **EDGE DETECTION:** Good at detecting edges of structures
The issues in Mine site Seismic exploration

- Remote, inaccessible sites
- OHS compliance getting more difficult
- Environmental restrictions
  - Seismic line misaligned with dip of dominant structure
- Complex structure
  - Different types and elastic properties of shears, faults, dykes
- High velocity – often small change in elastic properties, lower resolution achieved than in soft rocks
- Massive and heterogeneous regolith
  - Scattering of energy, loss of high frequencies and excessive time delays
- Lack of sonic and density logs
  - Difficult to calibrate seismic images
Three Springs Talc Mine

Laying the geophone array out
Golden Grove VMS 3D, WA – Seismic Source Weight Drop
Seismic in the Pits – Not an easy place to work?

Vibrator Trucks
Dip-move out correction / seismic imaging

DMO always useful, even when degrades the image!
- Provides an improved velocity model
- Indicates out-of-plane events
- Typically DMO+MAS provides the most reliable result (3D but also 2D)
Acquiring 3d Seismic Data—
the CHDG learnings

- Lightweight system with low environmental impact
  - Recording system with 1200 channels with accessories is <2000 kg
  - Wt Drop or Explosive source is quick and cost effective
  - 3 Land Cruisers plus truck for Wt Drop/Skidsteer

- Small seismic crew for 3D - 6 people
  - Fit within existing mine camps
  - Less people for OHS/Inductions/Mngt

- Cost of survey is about $50k-140k/sq km of coverage for several sq km (including the data processing)
1. Map the host channel?
2. Map intrusive rocks (porphyries, felsics and intermediates) into Ultramafics; do they have seismic signature?
3. Map major shears, faults
4. Map interface between Basalt and Kambalda Komatiite (Ultramafics)
5. Map the Ore?
1. Map the Host Channel

Tracking lava channel - depth slices
Extracting geology from 3D seismic:
what is the best way?
Conventional “horizon” approach - not too useful
Attributes: instantaneous, coherency, spectral decomposition, opacity....?
2. Map intrusive rocks (porphyries, felsics and intermediates) into Ultramafics; do they have seismic signature?

Opacity x histogram

Tabular bodies - porphyries, felsics?

Shears?
3. Map major shears, faults

Small 3D (3 Km2) – shot south of McLeay (2007) (interpreted structural elements)

Courtesy of CSM, designed, processed and interpreted by CHDG,
4. Map interface between Basalt and Kambalda Komatiite (Ultramafics)
Forward Modeling of the FWB/Komatiite Interface – Its Possible!

Synthetic seismic Section (FD)

Geology Model

(Australian polarity convention)

Courtesy of CSM, designed, processed and interpreted by CHDG,
5. Map the NiS Ore?

Interference “tuning” can enhance seismic response of Ni nickel bodies (black arrow) or make it less visible (orange arrows)
Targeting NiS directly via Reflection seismic

Ni confirmed by drill hole possible new targets

Map showing RMS amplitude extracted in a window above (10m) and below (4m) of the basalt contact.

Sesimic Attribute: RMS amplitudes
Seismic for Gold Exploration

- Reflection seismic produces higher resolution images than any other geophysical technique
- Can image shallow and deep structures
- Can resolve complex structures which are of great importance for mineral exploration

Mineralization
- Different settings for mineralisation
- Alteration Halos
- Shallow targets < 500m
- Zones from 1 to 10’s of meters

Fluid Conduits
- What are the roots of the shallow (<500m) plumbing system?
- Mineralised zones, meters to 100’s of meters
- Variable complexity – ramps, flexures, second and third order plumbing – what’s it worth to get a handle on this early?
St Ives Gold Camp—Explored using shallow focussed techniques
Surface Geochemistry, Magnetics…but
Gold Exploration – the St Ives Anticline
Gold Exploration - Borehole Sonic Log

- **Au (ppm)**
- **Density**
- **P-wave**
- **S-wave**
- **0-1000 m offset synthetic**

High Gold Content

Intermediate / Volcaniclastic mix

Condensor Dolerite
Seismic Attributes - Lambda-Mu-Rho

LMR – Softer Rocks (Orange) Harder Rocks (Blue)

>800 ppb Gold Content

>2000 ppb Gold Content
URANIUM: Exploration for Unconformity related uranium deposits with 3D seismic

Complex deposits
Intensely faulted zones provide paths for hydrothermals (chlorite)
“Rich ore pockets of limited size”
Uses of Seismic

- **Brownfields Exploration** where maximum resolution and depth are important
  - A 1,000m drill hole cost $250,000 to not reach a poorly defined target in 2 months.
  - For $250,000 you could image a 1 km2 area to a depth of 2000m in 2 months
    - From Seismic data 1 x $250,000 hole could be better designed to evaluate a well defined target, perhaps designed to avoid bad rock/drilling conditions in 1 month?

- In **Feasibility studies**, where knowledge of the geometry of 3d structures is important in understanding risk in mine development.

- In **Feasibility studies**, where the potential of the mineral system may better be appreciated/defined to fast track payback.

- In **advanced exploration** to more effectively evaluate the depth potential of shallow smoke to be the top of the big one.
Conclusions

- Important to consider all holes in a mine as potential platforms for geophysical surveys
- Important to construct an understanding of the petrophysical stratigraphy in the mine environment
- Deployment of geophysics within the constraints of the Mining operation is difficult but critical.
- Seismic reflection provides a new perspective on where/how to explore, especially in brownfields terrains
- Method is tricky to make effective in weathered terrains and Hard Rock environment – but it is possible
- 3D is the best for many hardrock environments, but most costly to get wrong!
- Interpretation requires geophysicist and geologist to exchange information – two way process
- Requires very close integration with Mine Activities and schedules

3D seismic is not just a tool for rich oil and gas explorers
Acknowledgement to CHDG Sponsors

- Rio Tinto Exploration
- Rio Tinto Argyle
- ERA
- Aviva
- Newmont
- Jubilee Mines
- Sydney Gas
- Barrick Gold
- Independence Group
- Anglo-Gold
- CRCLEME
- State Govt of WA
- MINCOR

- Consolidated Minerals
- BHPB Minerals
- Goldfields
- Heathgate Resources
- Resolute Mining
- Ballarat Gold
- Oxiana
- CSIRO/GNS
- ACARP
- CO2CRC
- WaterCorp
- Dept of Water WA