Introduction

- Sediment hosted copper
- Lumwana copper deposit
- Caribou Dome copper deposit

- Acknowledgements to Barrick Gold and Polar X
- Thank you to Terra Resources geophysicists (my co-author Lynelle and Anthony)
Sediment-hosted, Stratiform Base Metal Deposits

Major deposits formed within reduced pyritic, organic-rich, calcareous shales an metamorphic equivalent. Remaining third occurring within sandstones.

Host rocks occur as anoxic coastal marine sediments overlying oxidised continental clastic sediments. Forming through precipitation

Abundant deposits within Upper Proterzoic and Upper Paleozoic rocks deposited in arid and semi-arid area in continental rift environments

Two subclasses

1. Sediment-Hosted Copper
2. Sediment Hosted Pb-Zn Deposits (SedEx- Sedimentary Exhalative)

SedEx (Sedimentary Exhalative Deposits) are defined as the formation of precipitated ore deposits due to the interaction of metal bearing hydrothermal fluids and seawater.

Economically a major source of Lead and Zinc. Also Cu, Au, Ag and W amongst other minerals.

Occur as clusters or stacked lenses

Figure 1. Generalised genetic model for deposit scale sediment hosted stratiform Cu deposits (Brown 1992) Pore within footwall redbeds occupied by aqueous brine containing dissolved copper. Interaction with in situ sulphides during migration into basal greybeds results in cupriferous sulphide precipitates.
Overview of the Central African Copperbelt outlining the international boundaries of the basement-proximal Zambian Copperbelt and basement-distal DRC Copperbelt.
Simplified representation of the stratigraphic column and graphs outlining the transgressive-regressive sedimentary cycles in ore formation within the Copperbelt (Eden, 1974). Ore bodies are restricted to the Lower Roan Group of the Katanga Supergroup.
Kamoa Cu Deposit (DRC) - Ivanhoe
Lumwana Copper Mine

Project Status
- Operating
- Development
- Historical

Cu Endowment
- 0 - 1 Mt
- 1 - 5 Mt
- 5 - 10 Mt
- 10 - 20 Mt

Cu Grade %
- 0 - 0.5
- 0.5 - 1
- 1 - 3
- > 3

Labels
- Project Name
- 2010 Cu production

Lumwana Copper Mine

Kamoto 56Kt
Kansanshi 230Kt
Kamoto 120Kt
Nchanga 217Kt
Konkola 80Kt
Nkana (Mopani)
Mufulira (Mopani)
Tenke Fungurume
Central African Copperbelt Stratigraphy

Deposit Types
- Zn
- Cu

(modified from Cailteux et al., 1994)
Bi-lobate open dome of old Proterozoic Basement similar but more metamorphosed than the Copperbelt Basement

Internal geology comprise a number stacked thrusts sheets composed predominantly of Basement with some Katangan

Separated from the younger Katangan by a major layer parallel shear zone

Cu deposits hosted within sheared & altered Basement
MALUNDWE SHEET

- Basement Gneiss
- Malundwe Ore Schist
- Mottled Schist
- Epidote Schist
- Mottled Schist
- Quartzite Lower Roan
- Muscovite-Quartz Schist
- Lower Roan?
- Carbonates, amphibolites, gabbros & pelites

CHIMIWUNGDO SHEET

- Basement Gneiss
- Upper Ore Schist
- Middle Gneiss
- Main Ore Schist
- Lower Gneiss
- Lower Ore Schist
- Basement Gneiss & Mottled Schist
- Lower Roan?
- Locally Quartzite Lower Roan

Legend:
- Pink: Hanging Wall
- Blue: Ore Package
- Yellow: Footwall
- Light Blue: Nguba / Kundelungo

Top of Early Shear Zone
Vertical Scale: 50m
Thrust
Chimiwungo Sequence

Mwashya Group
- Carbonate Schist

Loan Roan Group
- Kwabv: Basalt Hill Volcanics
- Rimming Quartzite

Chimiwungo Sheet
- Chimiwungo Deposit Outcrop
- Chimiwungo Sheet Gneiss & Schists

Malundwe Thrust Sheet
- Hanging Wall Gneiss to Schist
- Foot Wall White Schist (L.Roan)
- Kyanite Bearing Schist

Kamaranda Sheet
- Kamaranda Sheet

Decollement MBD
Early MBD Thrust
Katangan Detachment
Late Lufilian Extension

CHIMIWUNGO PIT
$3.50/lb Cu

Section

1km
Chimiyungo - Geology

**S (Looking West)**

$1.20/lb Cu Pit Shell

$2.50/lb Cu Pit Shell

$3.50/lb Cu Pit Shell

- **Fault**

**Hangingwall Gneiss**
- pink to grey qtz-fsp-biotite gneiss to schist

**Upper Ore Schist**
- grey mus-phl-qtz-ky-cpy± py-po schist

**Middle Gneiss**
- grey qtz-fsp-biotite gneiss to schist

**Middle Ore Schist**
- mus-phl-qtz-ky-cpy± bn

Legend:
- Leached overburden
- Hangingwall gneiss
- Oxide ore
- Ore schists
- Middle gneiss
- Footwall schist

500m
Chimiwungo - Mineralisation

- Cpy – py – po with earlier cpy – bn in lower ore schist
Chimiwungo – Petrophysics

- Strong correlation of copper mineralisation and increased chargeability
- Chargeability greater than 16msec - ore
- Chargeability from 12-16msec - ore dominant
- Magnetic maps the edges of the Basement and internal structures
- Radiometrics defines the Katangan Lower Roan
- EM maps stratigraphy and structures
Chimiwungo IP – Survey Details

<table>
<thead>
<tr>
<th>Array Type</th>
<th>Double Offset Pole-Dipole IP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter</td>
<td>Search WB30 30KVa</td>
</tr>
<tr>
<td>Receiver</td>
<td>Search SSIP 96 channel, full waveform</td>
</tr>
<tr>
<td>Current Electrode</td>
<td>2 foil pits per station</td>
</tr>
<tr>
<td>Potential Electrode</td>
<td>CuSO4 pot</td>
</tr>
<tr>
<td>Input Current:</td>
<td>0.5-5.1A</td>
</tr>
<tr>
<td>Frequency</td>
<td>0.125Hz</td>
</tr>
<tr>
<td>Tx Infinite</td>
<td>&gt;2.5km</td>
</tr>
<tr>
<td>Tx Line Spacing</td>
<td>400m</td>
</tr>
<tr>
<td>Tx Pole Spacing</td>
<td>100m</td>
</tr>
<tr>
<td>Rx Line Spacing</td>
<td>400m (200m from Tx line)</td>
</tr>
<tr>
<td>Rx Dipole (A) Spacing</td>
<td>100m (200m, 400m derived)</td>
</tr>
<tr>
<td>Line Orientation</td>
<td>Chimi Nth, Mutoma – E-W; Chimi SW – WNW-ESE</td>
</tr>
</tbody>
</table>

Diagram showing the survey layout with labeled distances and orientations.
Chimiwungo IP – Survey Details
Chimiwungo IP – Processing and Modelling

Processing
Scientific Computing Application TQI Pdb software
1) correcting for transmitter and receiver station locations;
2) checking input currents and voltage potentials;
3) reviewing measured resistivity and chargeability values. Poor data (based on repeatability and decay) were removed before being averaged into Newmont Standard time windows (450-1100ms) to perform 3D modelling. The large amount of data redundancy allowed for the removal of poor data without any effect of the quality of the modelling results.

Modelling
UBC’s DCIP3D modelling software.
Numerous 2D and 3D models were undertaken order to choose the most optimal parameterisation in terms of the following:
1) Resistivity % error and error floor;
2) IP % error and error floor;
3) Cell/mesh definitions;
4) Length/Alpha scale:
5) Regularisation mode and Chi-factor and;
6) Number of iterations.
Chimwungo IP/resistivity - Results

Resistivity Model - Section 8639500N

Depth of investigation +500m
Chimiwungo IP – Results

Barren Sulphides in FW

Sulphide rich (Py) granitic? unit

Ore Schist >500m

Chargeability

Resistivity

Sub-Horizontal Geometries

Sub-Vertical Geometries
Chimiwungo IP – Results

- Resistivity maps Chimi South Fault and Katangan stratigraphy

![Resistivity maps showing Chimi South Fault and Katangan stratigraphy](image_url)
Sediment Hosted – Replacement Style

- Australian examples are atypical sediment hosted copper deposits (Mt Isa)
- Variations from SEDEX to epigenetic Cu
- Good grade (Average 1.77% Cu)
- Associated base metals as pathfinders or ore
- OC and UG potential
- Moderate to large footprint
Caribou Dome – Mineralisation

Sample COV0002

Drill core from CD15-14 (Lense 7/8 Target) – containing >16% Cu

CD15-03
51.1m @ 5.3% Cu
Incl. 2.3m @ 17.1% Cu
14.1m @ 10.6% Cu
3.3m @ 9.0% Cu
3.2m @ 9.6% Cu

CD15-01
12.2m @ 3.2% Cu
Incl. 5.7m @ 5.1% Cu

Drillhole Section:
69940mN +/- 10m

Possible Initial Open Pit

Lense 4:
Extends predominantly to the Northeast
18.1m @ 9.3% Cu

12.2m @ 5.0% Cu

Existing Adit

Existing Decline

13.0m @ 4.9% Cu

12.8m @ 5.8% Cu

15.4m @ 7.0% Cu

1.2m @ 9.8% Cu

15.2m @ 3.2% Cu
## Caribou Dome – Petrophysics

<table>
<thead>
<tr>
<th>Sample Information</th>
<th>SCIP</th>
<th>Inductive Conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sample</strong></td>
<td><strong>Comments</strong></td>
<td><strong>Resistivity (Ω·m)</strong></td>
</tr>
<tr>
<td>ID</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COV0001B</td>
<td>Block- coil parallel to fabric</td>
<td>57.89</td>
</tr>
<tr>
<td>COV0001A</td>
<td>Block – coil perpendicular to fabric</td>
<td>24.16</td>
</tr>
<tr>
<td>COV0002</td>
<td>Quarter Core</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Sample COV0001A
Sample COV0001B
Sample COV0002

Drill core from CD15-14 (Lense 7/8 Target) – containing >16% Cu
Caribou Dome – Airborne Magnetics

- Aeromagnetic data valuable in prioritising IP anomalies.
- Highest-priority IP anomalies are located at or near the contact between the magnetic volcanic sequence of rocks and the non-magnetic sedimentary sequence of rocks.
- Aeromagnetic data define this preferred stratigraphic level well.

High priority IP targets on image of airborne magnetics data.
Caribou Dome IP – Survey Details

Survey Specifications:

- Array type: Double-Offset Pole-Dipole 3DIP Array in swaths
- Time Domain: 50% duty cycle
- Frequency: 0.125Hz
- Dipole spacing: 100m
- Rx line spacing: 200m
- Tx line spacing: 100m
- Current locations: Offset from potential electrode locations by 50m (along line) on both the same and adjacent lines. The adjacent lines were offset from the receiver lines by 100m in both directions

Survey Equipment:

- IP receivers:
  - 2 x Elrec Pro receivers
  - 2 x Elrec 6 receivers
- IP transmitters:
  - 2 x GDD 3600w TX-II transmitters
- 13km – 18 gauge wire
- 30 x 6 conductor 100m IP cables
- 10 x 10 conductor 100m IP cables
- 2 x Honda 5kW generator
- 1 x Laptop PC with Prosys II & Geosoft Oasis Montaj

Illustration showing Double-Offset Pole-Dipole survey lines and transmitter and receiver station configurations.
Caribou Dome IP – Survey Details

- Broad coverage with enough detail to resolve geological problem
- Achieve greater depth penetration (off-end Tx injection)
- Good lateral and across-line resolution
- High data redundancy so noisy data points can be ignored

Map of survey area showing location of IP lines and station locations on elevation image. Final modelling area depicted in black polygon.
Caribou Dome IP – Terrain

The 2016 exploration camp at the Caribou Dome Project located directly down-slop of Lenses 4, 5 and 6.
Results of 3D PDIP modelling showing resistivity volume in local coordinates.

- 96 x lines (32 blocks) total to n=6
- Corrected for Tx/Rx station locations
- QA/QC input currents (I) and voltage potentials (Vp's), remove noisy and/or poorly recorded data, within TQI Pdb
- Averaged in Newmont Standard time windows (450-1100ms) and output to perform modelling within UBC3D
- Optimal inversion parameters chosen from numerous preliminary 2D and 3D modelling

Results of 3D PDIP modelling showing chargeability volume in local coordinates.
Map of survey area showing location of high priority (black outlines) and lower priority (blue outline) IP targets with respect to chargeability at -100m below surface. Red areas show known zones of mineralisation.
Caribou Dome IP – Results

Map of survey area showing location of high priority (black outlines) and lower priority (blue outline) IP targets with respect to resistivity at -100m below surface. Red areas show known zones of mineralisation.
Caribou Dome IP – Results

Map of survey area showing location of high priority (black outlines) and lower priority (blue outline) IP targets with respect to surface sampling for copper concentrations. Red areas show known zones of mineralisation.
Caribou Dome – Induced Polarisation

Lense 7/8 IP Target
- First hole ever drilled to test this target, in 2015, intersected 14.1m @ 9.9% Cu

Select IP cross sections relative to mineralisation at the Caribou Dome Project

Lense 5 IP Anomaly
Lense 7/8 IP Target
Lense 9 IP Target
Guardian IP Target
Menel IP Target

Section 70265N
Lense 7/8 Target
Inverted 3DIP Data Through Discovery Hole CD15-14
The two examples show the sediment hosted copper deposits are not inductively conductive and the dominant EM response is pyritic siltstones/shales.

The petrophysics have been important in determining which geophysical techniques to apply and how to best target mineralisation.

Both Cu deposits are chargeable and were able to be targeted directly with 3DIP.
Geophysics for Sediment Hosted Copper and Gold Mineralisation, The Role of 3DIP

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