Second Biennial Great Basin and Western Cordillera Mining Geophysics Symposium
The Nugget, Reno | May 16, 2015
Hosted as Short Course at 2015 GSN Symposium

Sponsors

Condor Consulting, Inc.

Magee Geophysics

EGG
### Session A | Case Histories: Nevada and the Great Basin

**Chairperson:** Brock Bolin, Newmont Mining

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<tr>
<td>7:30</td>
<td>Registration and Coffee</td>
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<tr>
<td>8:30</td>
<td>Symposium Introduction</td>
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<tr>
<td>8:40</td>
<td>Processing and Interpretation of Skarn Related Remnant Magnetization Railroad Property, Nevada — <em>James Wright, J. L. Wright Geophysics</em></td>
</tr>
<tr>
<td>9:10</td>
<td>3D Resistivity and 3D IP mapping of an epithermal gold/silver mineralization setting, Comstock Trend, Nevada — <em>Bill Ravenhurst, Crone Geophysics and Exploration Ltd.</em></td>
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<tr>
<td>9:40</td>
<td>Project scale exploration using GRACE satellite gravity data — <em>Clark Jorgensen, Big Sky Geophysics</em></td>
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<td>10:10</td>
<td>Overview-scale 3D resistivity imaging for the indirect location of deep feeder structures in hot-sprig epithermal gold settings — <em>Greg Shore, Premier Geophysics Inc.</em></td>
</tr>
<tr>
<td>10:40</td>
<td>Coffee Break</td>
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### Session B | Technological Advancements

**Chairperson:** Bill Doerner, Emblem Exploration Services

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<td>11:10</td>
<td>Geophysical Exploration at the Altan Nar Project, Mongolia — <em>Chester Lide, Zonge International</em></td>
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<tr>
<td>11:40</td>
<td>3D IP: Depth and Definition Successes — <em>Pierre Bérubé, Abitibi Geophysics</em></td>
</tr>
<tr>
<td>12:10</td>
<td>3D inversion of the long period EarthScope MT data over Great Basin Area — <em>Alex Gribenko, TechnolImaging</em></td>
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<tr>
<td>12:40</td>
<td>Lunch</td>
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### Session C | Canada and the Yukon

Chairperson: Bob Lo, Consulting Geophysicist

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<th>Event</th>
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<tr>
<td>1:40</td>
<td>Regional airborne EM-Magnetics in Selwyn Basin — An Explorer’s Perspective—<em>Jean Legault</em>, Geotech Ltd.</td>
</tr>
<tr>
<td>2:10</td>
<td>SAM (Sub-Audio Magnetics): High Resolution and Deep Exploration Case Studies—<em>Dennis Woods</em>, Discovery Geophysics</td>
</tr>
<tr>
<td>2:40</td>
<td>Geophysical signatures of Carlin systems formed along the northern margin of ancient North America—<em>Ken Witherly</em>, Condor Consulting</td>
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<tr>
<td>3:10</td>
<td>Coffee Break</td>
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### Session D | Geologist’s Views

Chairperson: Lee Sampson, Barrick Gold Exploration Inc.

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<th>Time</th>
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<tbody>
<tr>
<td>3:40</td>
<td>Case Studies of Exploration Geophysics at McCoy-Cove—<em>Chad Peters</em>, Premier Gold Mines USA</td>
</tr>
<tr>
<td>4:10</td>
<td>Enhancing Exploration Drill Success by Integrating Geophysical Data—<em>Joseph Becker</em> and <em>Jeff Nicholes</em>, Newmont Mining</td>
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<tr>
<td>4:50</td>
<td>Closing Statements</td>
</tr>
<tr>
<td>5:00-6:30</td>
<td>Happy Hour at the Great Basin Brewery</td>
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Processing and interpretation of skarn related remanent magnetization, Railroad property, Nevada

James Wright, J. L. Wright Geophysics

Skarn deposits have a well-deserved reputation as being irregular in shape and difficult to mine, but often endowed with high grades. Nevertheless, examples do exist where skarn mineralization is a significant contributor to the mineralized inventory in large deposits. For example, 80% of the 2013 gold / copper reserves at the Ok Tedi deposit in Papua New Guinea are hosted in skarn. Notable Nevada examples include the McCoy and Fortitude gold deposits.

Irregular distribution of skarn is a result of several factors including pre and post mineral structural disruption, multiple intrusive events, retrograde alteration and irregular distribution of the hosting rocks. Both magnetite and pyrrhotite are common mineralogical constituents of skarns. The irregular geometric distribution of skarn is reflected in the associated magnetic responses, with further complexity related to zonation within the skarn. Often the magnetic anomalies are dipolar in character and exhibit strong remanent magnetization. Robust topography in the vicinity of the causative intrusion adds yet another complexity to interpretation of skarn magnetic responses.

Examples of complex skarn related magnetic anomalies related to the Bullion intrusion in the Railroad property, Nevada are analyzed. Dipolar anomalies with strong remanent magnetization, beneath rugged terrain are processed to yield three dimensional models. A newly discovered magnetic anomaly with over 1.3 kilometer strike length is analyzed, yielding significant exploration potential in a portion of the property considered previously to be of low priority. In fact, the magnetic anomaly correlates directly with a 0.5 mgal gravity high. Special emphasis is placed on the practical aspects of interpretation and the tradeoffs/approximations required when working with real world data.
GREAT BASIN AND WESTERN CORDILLERA MINING GEOPHYSICAL SYMPOSIUM
PROCESSING AND INTERPRETATION OF SKARN RELATED REMANENT MAGNETIZATION, RAILROAD PROPERTY, NEVADA

James Wright / J. L. Wright Geophysics

RAILROAD PROPERTY LOCATION
NORTHEAST NEVADA
REVERSE MAGNETIZED VOLCANICS

BULLION PLUTON & STOCK

USGS REDUCED TO POLE AIRBORNE MAGNETICS
BULLION STOCK AND DIKES
GREAT BASIN AND WESTERN CORDILLERA MINING GEOPHYSICAL SYMPOSIUM
PROCESSING AND INTERPRETATION OF SKARN RELATED REMANENT
MAGNETIZATION, RAILROAD PROPERTY, NEVADA

WOODRUFF FORMATION
MUDSTONE / SANDSTONE

100 SPACED LINES / ~3 M STATIONS

GROUND MAGNETIC SURVEY STATION POSTING - OCT. 2014
NORTH PINION RANGE GEOLOGY
GROUND MAGNETIC SURVEY – TOTAL FIELD
100 M EAST – WEST LINES
GREAT BASIN AND WESTERN CORDILLERA MINING GEOPHYSICAL SYMPOSIUM
PROCESSING AND INTERPRETATION OF SKARN RELATED REMANENT
MAGNETIZATION, RAILROAD PROPERTY, NEVADA

REMANENT DIPOLAR RESPONSES

MAGNETIC SKARN RESPONSE
RAILROAD PROPERTY – BUNKER HILL

DELMAS SKARN
GREAT BASIN AND WESTERN CORDILLERA MINING GEOPHYSICAL SYMPOSIUM
PROCESSING AND INTERPRETATION OF SKARN RELATED REMANENT MAGNETIZATION, RAILROAD PROPERTY, NEVADA

DELMAS SKARN

BULLION STOCK DETAIL
ENDO & EXO SKARNS
GREAT BASIN AND WESTERN CORDILLERA MINING GEOPHYSICAL SYMPOSIUM
PROCESSING AND INTERPRETATION OF SKARN RELATED REMANENT
MAGNETIZATION, RAILROAD PROPERTY, NEVADA

DIPOLE MAGNETIC FIELD
NORTH POLE SUBTRACTS / SOUTH POLE ADDS
BACKGROUND FIELD 53000 nT
WHY DIPOLAR RESPONSES

- COMPLEX THERMAL HISTORY – MULTIPLE INTRUSIVE EVENTS
- NATURAL ZONING WITHIN SKARNS
- COMPLEX STRUCTURAL HISTORY – DEFORMATION DURING AND AFTER INTRUSION
- COMPLEX HOST GEOMETRY – IRREGULAR DISTRIBUTION OF CARBONATE ROCKS
- RETROGRADE EFFECTS ON SKARN MINEROLOGY – GREY EAGLE : PYRRHOTITE & DELMAS : MAGNETITE

GREAT BASIN AND WESTERN CORDILLERA MINING GEOPHYSICAL SYMPOSIUM
PROCESSING AND INTERPRETATION OF SKARN RELATED REMANENT MAGNETIZATION, RAILROAD PROPERTY, NEVADA

Mesozoic

<table>
<thead>
<tr>
<th>Jurassic</th>
<th>Cretaceous</th>
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<tr>
<td>Middle</td>
<td>Lower</td>
</tr>
<tr>
<td>Upper</td>
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Cenozoic

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<tr>
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<td>Eocene</td>
</tr>
<tr>
<td>Oligocene</td>
<td>Miocene</td>
</tr>
<tr>
<td>Pliocene</td>
<td></td>
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</tbody>
</table>

Earth Magnetic Field Reversals
Sea Floor Spreading Magnetic Stripes - Ferromagnetism

Bullion Stock
WEAK NORTH SIDE LOW ALONG DECLINATION LINE

Total Field
COMPACT BODY RESPONSE
DEPTH 200M
EARTH FIELD
53000nT / Decl. 16°E / Incl. 65°

RTP Total Field
GREAT BASIN AND WESTERN CORDILLERA MINING GEOPHYSICAL SYMPOSIUM
PROCESSING AND INTERPRETAITION OF SKARN RELATED REMANENT MAGNETIZATION, RAILROAD PROPERTY, NEVADA

EARTH FIELD: 53000 nT, Decl. 16°E, Incl. 65°

CHART OF REMANENT DIPOLAR ANOMALIES
INTERPRETIVE CHALLENGES

- Undersampled anomalies
- Dipolar responses
- Remanent magnetization
- Rugged terrain

OBJECTIVE: Device a procedure to yield an approximate model for the under sampled, remanently magnetized, dipole anomalies leading to drillable targets

PHILOSOPHY: Accept less model detail for better estimates of general anomaly attributes – total magnetization vector declination / inclination
DIPOLE MODELS OVER TOTAL FIELD MAGNETICS
Gravity Response: ~0.5 mgals / 350 m Width
Gravity coverage 150 m square grid
TOPOGRAPHIC DISTORTION

SOURCE DIPOLE: Depth 230 m / Elev. 1940 m / Decl. 105° / Incl. -20°

EARTH FIELD: Decl. 16° / Incl. 65° / 51230 nT
EXCEL SOLVER SPREADSHEET DIPOLE MODEL
GREAT BASIN AND WESTERN CORDILLERA MINING GEOPHYSICAL SYMPOSIUM
PROCESSING AND INTERPRETATION OF SKARN RELATED REMANENT
MAGNETIZATION, RAILROAD PROPERTY, NEVADA

DIPOLE MODEL FIT SUMMARY
GMAG – UL / DIPOLE MODEL - UR / % ERROR – LL
% ERROR = ((GMAG-MODEL)/1100)*100%
522 DATA POINTS IN MODEL

DIPOLE RESPONSE PROCESSING SUMMARY
TOPO – UL / TOTAL FIELD – UR / TF LEVELED – LL / RTP - LR
LEVEL ELEV: 2250 m / MAGNETIZATION VECTOR : D = 104° & I = -20°
2.5 MODEL
RTP LEVELED TOTAL FIELD MODEL PROFILE
MODEL – OBSERVED DATA COMPARISON
MODEL SECTION AND PLAN
~ 280m SQUARE
~30 – 80 m THICK
DIPPING ~20° TO NW
GREAT BASIN AND WESTERN CORDILLERA MINING GEOPHYSICAL SYMPOSIUM
PROCESSING AND INTERPRETATION OF SKARN RELATED REMANENT
MAGNETIZATION, RAILROAD PROPERTY, NEVADA

MODEL SECTION AND PLAN
ANALYTIC SIGNAL
SIGNAL TENDS TO OUTLINE
CAUSATIVE BODY
GROUND MAGNETIC TOTAL FIELD COPPER SOIL GEOCHEMISTRY
SUMMARY

- IDENTIFICATION LARGE SKARN RELATED MAGNETIC RESPONSE
- CUSTOM PROCESSING – DIPOLE MODEL, LEVELING, RTP & 2.5 D MODEL
- EMPHASIS ON PRATICAL ATTAINABLE GOALS
- RECOGNITION OF ATTRACTIVE EXPLORATION TARGET
- POSSIBLE ENOSKARN ALONG SHALLOW INTRUSIVE CONTACT
- TARGET DEFINED SUFFICIENTLY FOR DRILL TESTING

ACKNOWLEDGEMENTS

Gold Standard Ventures Corp.
Magee Geophysical Services, LLC
3D resistivity and 3D IP mapping of an epithermal gold/silver mineralization setting, Comstock Trend, Nevada

Greg Shore,* Geophysical Consultant, Aurora, ON, Canada
Larry Martin, Comstock Mining Inc., Virginia City, NV, USA
Bill Ravenhurst, Crone Geophysics & Exploration Ltd., Mississauga, ON, Canada
Josh Lymburner, Crone Geophysics & Exploration Ltd., Mississauga, ON, Canada

The Comstock Lode district is best known for producing over 8 million ounces of gold and 192 million ounces of silver, primarily in the late 1800’s. Today, the district sees renewed exploration and resumption of profitable mining, using modern methods.

In January, 2015, a true 3D IP and resistivity survey (3D E-SCAN ) was conducted over a portion of the Comstock Trend, south of Silver City. The close-spacing survey was a blind test, done without geologic or drill-related guidance or expectations. The survey was designed with default parameters with the intention of delivering an objective 3D mapping of the entire resistivity spectrum from very conductive through to very resistive, with Induced Polarization (IP) results included, with equal sensitivity to all directions and shapes of geo-electric features. A 3D resolution depth of >200 m was anticipated.

The 600 m by 700 m property area included a known (drilled-off) gold-silver ore zone, but the location and nature of this deposit remained unknown to survey operators until after the processed 3D survey results were tabled. The deposit is the South Dayton, an extension to the Dayton ore zone that lies north of the 3D survey area. The property and the deposits are owned by Comstock Mining Inc., Virginia City, NV.

A range of anomalous resistivity and IP anomalies occur within the area’s Alta and Santiago Canyon volcanic units, against an identifiable background of basement metavolcanics that slope steeply to the east.

Locally intense high resistivity signatures characterize some of the areas of shallow historic vein workings, a signature that is common for volcanic-hosted silica-filled vein features.

Of six anomalous IP zones mapped within the first 100 metres below surface, two were revealed to survey operators as having been fully investigated, while four remain to be studied. The two enclose the known and drilled-off centers of silver-gold mineralization that constitute the South Dayton orebody. The orebody’s host rock is identified as a quartz porphyry intrusive, part of the Santiago Canyon Formation. In the Comstock Trend, “The presence of quartz porphyry enhances mineralization in the intruded units and hosts

The unambiguous direct location by 3D IP of the economically-mineralized quartz porphyry intrusives that host the South Dayton ore zone is the first confirmed result of the ongoing examination of the three types of 3D earth models delivered from this blind survey test. The models are 3D IP, 3D resistivity, and 3D MF (a ratio of IP/resistivity, a.k.a. “metal factor”).

The 3D results recognize many of the fault and structure orientations known to exist within the district, some known to be associated with mineralization events.

Work continues to evaluate the potential for exploration significance of the rest of the patterns and distributions that have been revealed by the 3D survey models.

* Corresponding author’s email:  gashore@premiergeophysics.com
2015 GSN Symposium: SC-4 “New concepts and discoveries”

3D IP and resistivity mapping of an epithermal gold/silver mineralization setting on the Comstock Trend, Nevada.

Greg Shore, Geophysical Consultant
Larry Martin, Comstock Mining, Inc.
Bill Ravenhurst, Crone Geophysics and Exploration Ltd.
Josh Lymburner, Crone Geophysics and Exploration Ltd.
Since 1860, the Comstock Lode (district) has produced more than 8 million ounces of gold and 192 million ounces of silver from over 33 bonanza-grade epithermal vein deposits.

Most of this production came from underground mining, using primitive techniques.
The modern era

The present viability of the district as a renewed producer of gold (and local economic benefits) could not have been achieved without the prior consolidation (blue areas) of a great many individual properties.

That process began in 2003.

Strategically located packages continue to be acquired to this day.
The renaissance of the district has featured modern open pit mining and heap leach technologies. The resumption of underground mining is indicated for the near future.
The 2015 3D E-SCAN survey area included mineralization known as South Dayton.

As elsewhere along the southern Silver City fault trend, major NW fault structures have prepared conditions for mineralization associated with later NE-trending faulting.

Tuffs (Santiago Canyon, Alta) are the principal ore host, with gold grades enhanced in areas where a quartz porphyry intrudes. The underlying metavolcanics have hosted high grade mineralization elsewhere; the potential at South Dayton remains untested.
The survey area.

Very tight lateral constraints will challenge the ability to acquire deep data.

The location and nature of the known mineralization is withheld from the survey team.
The 182-station 3D E-SCAN survey setup is completed in 3 days, by a crew of 4.

The entire SE quadrant is wired up via a 100 foot long culvert under the highway, maintaining the uniformity of the survey station spacing (and of the subsequently acquired 3D data).
Once the basic grid station spacing is selected (50 m), there are no more decisions. No line orientation decisions, no line spacing or offset current parameters.
The diagram reminds us of the principal strike orientations of known structure in this area.

No single orientation of conventional survey line data can objectively map this complexity, let alone discriminate and reveal any other local structural orientations which may prove to be important, once they are known.

True 3D mapping objectivity appears to be essential here.
Sample depth is Ze of Edwards, 1976 - the effective depth of penetration in a uniform earth, in meters.
ten shots:

B POLE-POLE E-SCAN ARRAY
a=200m to n=7
930 data, uniformly all-directional

A POLE-POLE ARRAY
a=200m to n=14
140 data, uni-directional

C POLE-DIPOLE ARRAY
a=200m to n=14
140 data, uni-directional

D POLE-DIPOLE OFF-LINE ARRAY
a=200m to n=14
420 data, essentially uni-directional

E TITAN 24 (POLE-DIPOLE) array
a=100m to n=28
1624 data, essentially uni-directional

F DIPOLE-DIPOLE ARRAY
a=200m to n=14
140 data, uni-directional

PLAN VIEW
PLAN VIEW

1600 m wide area

B POLE-POLE E-SCAN ARRAY
$a=200m$ to $n=7$
7,520 data, uniformly all-directional

8 lines or 1600 meters coverage width

E TITAN 24 (POLE-DIPOLE)
$a=100m$ to $n=28$
6,496 data, essentially uni-directional

4 2X spaced lines or 1600 meters coverage width
This is the uniformly-distributed, high density, all-directional 3D data set* that is required to back up our intention to interpret and use even the most subtle any-direction patterns in the 3D earth model at South Dayton.

*Full Spectrum 3D (fs3D)

6,000 precisely selected all-directional data to >300m depth (Ze)
3D INVERSION MODEL

RESISTIVITY

44-50 m below surface

OHM-METERS
3D INVERSION MODEL

RESISTIVITY

44-50 m below surface

OHM-METERS
3D INVERSION MODEL

IP (%)  

50-56 m below surface

INDUCED POLARIZATION %
3D INVERSION MODEL

IP (%)

50-56 m below surface

INDUCED POLARIZATION %
3D INVERSION
MODEL

IP (%)

VERTICAL SECTION

Au oz/ton

- >= 0.100
- >= 0.067
- >= 0.036
- >= 0.015
- >= 0.007
3D INVERSION MODEL

IP (%)  

50-56 m below surface

INDUCED POLARIZATION %
3D INVERSION MODEL

IP (%)

25-31 m below surface

INDUCED POLARIZATION %
3D INVERSION MODEL

IP

25-31 m below surface

OVERLAY SHOWS PRELIMINARY MANUALLY-PICKED EDGE/CENTERLINE LINEAR FROM ALL 3D RESISTIVITY ELEVATIONS.

INDUCED POLARIZATION %

WORK IN PROGRESS

NW-NE intersection

NW-NE intersection
With the 3D E-SCAN field survey program wrapping up just over 3 months ago, this very substantial amount of 3D IP and 3D resistivity model imaging and mapping product is today only at the earliest stages of analysis, of correlation with known site geology, and interpretation of new drill targets and exploration insights.

The establishment of an IP anomaly spatially associated with known South Dayton ore mineralization, and the mapping of hidden, often subtle NE-trending features throughout the area, are early examples that indicate the potential for local and wider-area exploration benefits from fs3D IP/resistivity mapping.
2015 GSN Symposium: SC-4
“New concepts and discoveries”

3D IP and resistivity mapping of an epithermal gold/silver mineralization setting on the Comstock Trend, Nevada.

Greg Shore, Geophysical Consultant
Larry Martin, Comstock Mining, Inc.
Bill Ravenhurst, Crone Geophysics and Exploration Ltd.
Josh Lyburner, Crone Geophysics and Exploration Ltd.

Thanks are due to Larry Martin and Comstock Mining Inc. for permission to show these results, and for their excellent support before, during and after the field survey.
Project scale exploration using GRACE satellite gravity data

Clark Jorgensen, Big Sky Geophysics

The GRACE (Gravity Recovery and Climate Experiment) satellite data allow for project scale exploration for mineral deposits. The data provide good regional coverage in areas where no ground gravity data exist and can also be used to augment national databases.

The GRACE program consists of two satellites orbiting in tandem 220 km apart and was launched in 2002. Tracking of the satellites is obtained using GPS and a radio link between the two satellites. The radio link allows a more accurate measurement of orbit perturbations caused by the earth’s gravitational field. In 2008 the National Geospatial-Intelligence Agency (NGA) publicly released a 2.5 arc minute model (roughly 4.2 km) of the earth’s geoid (Pavlis, et al., 2008). The International Gravimetric Bureau (BGI) calculated the complete Bouguer anomaly for these data using the ETOPO1 one arc minute grid to 167 km with a reduction density of 2.67 g/cm³ (Fullea, et al., 2008). These data are free for download from the internet (BGI, 2010).

The NGA augmented the satellite data using ground data and have applied a topographic filter assuming the mountains to be of higher density than the plains. The NGA obtained permission to include ground data for countries (for example the former Soviet Union and Mongolia) which are not currently publicly available which makes these data sets very valuable. In the case of the Great Basin, the topographic filter is not particularly helpful because the density contrast between the mountains and the pediment is not great. The augmented satellite data overemphasize the density of the mountains for this region.

Two examples are presented. The first example is for potash exploration in eastern Eritrea. Here the satellite data are greatly aided by the additional Soviet ground gravity stations to provide a good image of the basin. The second example is from northern Nevada. The GRACE satellite data indicated a gravity high in the basin that was not indicated in the US National Geodetic Survey database. Detailed ground gravity surveying confirmed the GRACE gravity high was real and changed the geologic model for the project and is directing current exploration efforts. GRACE gravity data have been processed as complete Bouguer anomaly data by the BGI and are available for download for free.
Project Scale Exploration using GRACE Satellite Gravity Data: Two Case Studies

Clark Jorgensen

Big Sky Geophysics
### Dedicated Satellite Gravity Missions

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<th>Satellite</th>
<th>Launch</th>
<th>Agency</th>
<th>Instrument</th>
<th>Altitude</th>
<th>SHD</th>
<th>Ground Resolution</th>
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<td>CHAMP</td>
<td>2000</td>
<td>GFZ</td>
<td>accelerometer</td>
<td>450 km</td>
<td>65</td>
<td>400 km</td>
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<tr>
<td>GRACE</td>
<td>2002</td>
<td>DLR/NASA</td>
<td>accelerometer (2)</td>
<td>500 km</td>
<td>160</td>
<td>260 km</td>
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<tr>
<td>GOCE</td>
<td>2009</td>
<td>ESA</td>
<td>accelerometer (6)</td>
<td>270 km</td>
<td>200</td>
<td>100 km</td>
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<tr>
<td>EGM08</td>
<td>2008</td>
<td>NGA</td>
<td>GRACE/ground</td>
<td>N/A</td>
<td>2159</td>
<td>6 km</td>
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GRACE (Gravity Recovery and Climate Experiment) Satellite
EGM2008 “Terrestrial” Data Sources

- DOT determined by satellites
- Trackline marine gravity data
- Airborne gravity surveys
- Public ground gravity databases
- NGA gravity databases
- Proprietary ground gravity databases
EGM2008 “Terrestrial” Data Sources

Pavlis, et al., 2008, GA of EGU
EGM2008 “Terrestrial” Data Sources

Pavlis, et al., 2008, GA of EGU
EGM2008 Processing
(Pavlis, et al., 2012, JGR)

- Assume block diagonal covariant error matrix
- Translate spherical coordinates to ellipsoidal coordinates
- Downward continue to reference ellipsoid
- Merge ground databases
- Crosscheck merged databases with other data
- Least squares inversion of GRACE and ground data
- Produce Free Air anomaly for entire globe at 5’ intervals
EGM2008 Terrestrial Data Error Estimates

Pavlis, et al., 2008, GA of EGU
Bureau Gravimétrique International (BGI) Complete Bouguer Anomaly Processing

- Program FA2BOUG (*Fullea, et al., 2008, Computers and Geosciences*)
- Discretize 5’ Free Air anomalies to 2.5’
- Terrain corrections using ETOPO1 1’ elevations
- Post data to website
Eritrea (Bada Basin) Potash Exploration

- Sanu Resources wants to explore for high grade deposits of potash in the Bada Basin.
- Only general geology is known of the basin area and no depth information.
- Design a fast geophysical program to assess basin geometry.
- Decide on limited gravity and magnetic surveys for study.
Bada Basin Gravity Profiles (Simple Bouguer Anomaly)

Line 1

Line 2

Line 3
Gravity Profiles and EGM08 Data
Joint Gravity and Magnetic Modeling of Profile Line 2
Joint Gravity and Magnetic Modeling of Lines 1-3
Bada Basin Results

- 21 magnetic and 4 gravity profiles were used to quickly define the basin
- EGM08 was used to establish the regional gravity gradient
- UBC MAG3D (Li and Oldenburg, 1996, Geophysics) was used to create a reliable RTP image to identify geologic units
- Joint modeling of the gravity and magnetic data were used to outline the shape and depths in the basin
- Several wide spread shallow holes were drilled
- No potash was encountered and the property was dropped
- The property was evaluated quickly and cheaply
Great Basin, USA Gold Exploration

- A company wants to explore for gold near the Snowstorm Mine, north of Battle Mountain, NV
- Good geochemical anomalies occur along the front of the Sheepcreek Range
- Gravity and Magnetic surveying are undertaken to better define the subsurface geology
NGS and EGM2008 Gravity Data
Complete Bouguer Anomaly for Area of Interest
CBA and Measured Vertical Gradient Magnetics for Area of Interest

(Capps, et al., 2010, GSN Symposium)
CBA and Mapped Geology for Area of Interest
(Capps, et al., 2010, GSN Symposium)
Snowstorm Mine Results

- New gravity anomaly was identified that we believe is the North Central Nevada Rift.
- Mag highs in relative gravity lows over the broad gravity high agree with mapped faults and contain skarns.
- We believe the faults acted as conduits bringing mineralization up from the rift, updating the geologic model.
- The large gravity high could have been identified from the EGM2008 data.
- The BGI terrain corrections are sufficient for preserving the anomaly in an area of steep terrain.
Baikal Rift

- In 1994 Russia released the gravity data for the Soviet Union at a 1° interval.
- The Baikal Rift is a strong gravity low centered on Lake Baikal.
- The NGA provided data are gridded at a 15’ interval.
Baikal Rift Region Complete Bouguer Anomaly
Russia
EGM2008
Baikal Rift Complete Bouguer Anomaly with Geology

Russia

EGM2008

Geology from USGS OFR 97-470E (based on Geologic Map of USSR, Nalivkin, 1966)
Conclusions

- EGM2008 appears very accurate in these selected cases, but since terrestrial data are derived from varies sources quality may be expected to vary.
- EGM2008 contains data that are generally unavailable.
- Terrain corrections appear to be acceptable.
- Data are free for download from the BGI.
- Data can be used as an exploration tool, even in mature areas such as the Great Basin.
Acknowledgements

- NGA release of EGM2008 model to the public
- BGI and Fullea, et al. for calculating complete Bouguer anomalies
- MWH Geo-Surveys and Sanu Resources collected the data for the Bada Basin
- Sanu Resources and Criss Capps for permission to present the data
Overview-scale 3D resistivity imaging for the indirect location of deep feeder structures in hot-spring epithermal gold settings.

Greg Shore, * Geophysical Consultant, Aurora, ON, Canada

The targeting of deep feeder systems beneath surficial sinter deposits is a difficult geophysical challenge. While the sinter deposit itself may be readily mapped with DC resistivity methods as a (usually) shallow resistive zone, the prospect of directly detecting the system’s much narrower feeder structures at depth is often limited by the absence of a geophysical signature that is sufficiently strong and/or voluminous as to allow detection from the distant surface.

In a layered volcanic terrane in New Zealand, shallow (~100 m) resistivity survey data show two separate resistive anomalies that correspond with siliceous erosional remnants, sinters, located more than 2 Km apart. Simplest logic suggests two independent hydrothermal systems, one below each manifestation. Over the same area, 3D resistivity imagery that extends beyond 1000 m depth (overview-scale) reveals a common connection at depth: a “bull-horns” shaped alteration imprint. This resistivity anomaly’s “horns” extend upward to connect with each of the silicic-outcrop areas. The cause of the pattern is attributed as a precipitate-sealed cap, formed as a column of upwellng hydrothermal fluids cools, de-pressurizes and precipitates its mineral load, effectively blocking its own continued upward flow. The upward fluid flow, now deflected laterally by its own precipitate cap, eventually regains upward permeability at the edges of the cap, continuing to surface as the “horns” of today’s now-cooled system imprint.

In examining this set of very deep full-spectrum 3D (“fs3D”) images, the location of the (still geophysically undetectable) deep fluid source structures can be inferred to lie below a central precipitate cap, and not beneath the individual surface manifestations. The precise location, the type, orientation, dimensions and number of fluid-delivery structures involved, and the possibility of bonanza-grade gold mineralization, are questions that can now be tested with a limited, well-focused deep drilling program.

A similar “bull-horns” resistive anomaly pattern marks the >1 million ounce Clementine – Gwenivere gold vein system at the Hollister property in north-central Nevada. The historic sequence of drilling illustrates the challenge of detecting underlying plumbing, eventually resulting in the intersection of numerous basement-hosted feeder structures that are not located beneath either of the surficial sinter deposits, but are centered between them, under the single resistive “cap” anomaly. Within the fs3D resistivity mapping area that extends from west of Clementine – Gwenivere to east of the Hatter stock, there are similar complex resistive patterns that support an interpretation of a single central location for deep feeder structures.
These examples illustrate the enhanced perspective that can be derived from large-scale full-spectrum 3D imaging at district or system scale: mapping entire in situ hydrothermal systems and geologic features of similarly large dimensions, and mapping the (sometimes subtle) alteration patterns imprinted by the geologic process upon the host lithology, can lead to the recognition of basic processes of alteration and mineralization, and focus new exploration efforts on previously unrecognized system attributes, features and extensions.

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Using very large scale 3D resistivity imaging to predict the location of deep feeder structures underlying surficial epithermal hot-spring manifestations.

Greg Shore, Geophysical Consultant
What is very large scale 3D resistivity?

Very large scale 3D resistivity provides the opportunity to map peripheral and underlying aspects of a mineral resource’s emplacement process. These geophysical signatures may be an order of magnitude larger or deeper than those of the initial resource target.
What is very large scale 3D resistivity?

Few geophysical systems are capable of meeting the required criteria.

Very large scale 3D resistivity mapping has a surplus of active dimensions, both laterally and to depth, relative to those required for imaging the primary local target...

... all the while maintaining the high degree of hard-data-verifiable resolution and subtlety of pattern mapping required to illuminate and confirm these secondary, larger-scale earth attributes.
What is very large scale 3D resistivity?

In other words ...

... extend similar levels of the hard-data saturation resolution that are employed for the nearer-surface resource mapping...

... to the orders-of-magnitude greater volume of host rock that surrounds and underlies the shallower resource itself.

Criterion 1: very large, enclosing sampled volume, with little loss of 3D resolution

Criterion 2: hard-data supported, verifiably subtle 3D pattern imaging
What is very large scale 3D resistivity?

Scaling up...

Pseudosection: \( a = 10 \text{ m} \) \( n = 1 \text{ to } 7 \); depth (Ze) of about **60 metres**

![Image of 3D resistivity diagram]

Typical scale of district dipole-dipole array exploration (pseudosection, to \( n=7 \))

Scale of the pole-pole array raw data set for 3D inversion processing (pseudosection, to \( n=7 \)), showing data subset from one of the 4 orientations

Pseudosection: \( a = 100 \text{ m} \) \( n = 1 \text{ to } 7 \); depth (Ze) of about **600 metres**
What is very large scale 3D resistivity?

Scaling up... again

Pseudosection:  \( a = 100 \text{ m} \), \( n = 1 \text{ to } 7 \); depth (Ze) of about \( 600 \text{ meters} \)

True Section:  \( a = 400 \text{ m} \), \( n = 1 \text{ to } 12 \); data depth (Ze) of about \( 4,100 \text{ meters} \)
Very large scale 3D resistivity comes into play.

3D E-SCAN’s official target depth was 500 feet, that of the orebody itself. Purpose: test why there had been no measurable anomaly with dipole-dipole IP/resistivity, or EM ground surveys.

150-200 feet below surface ... through the orebody.

orebody outline

K2 OREBODY

MAPPED ALTERATION HALO

SANPOIL FORMATION

500 feet
Very large scale 3D resistivity comes into play. 3D E-SCAN’s available-on-demand very large scale sampling revealed a vertical conductive sheet lying deep below the epithermal silicic ore deposit.
Opportunities for very large (or “overview scale”) resistivity insights.

Before you can start:

1. Do you have the spatial data coverage within which to look for your very large scale patterns? Deep enough? Wide enough?

2. Do these data actually define and constrain pattern elements at the level that you would like to employ them for interpretation?

3. Do these data also define and constrain the non-anomalous “background” areas that define your selected pattern elements?

Or are you vulnerable to assigning exploration credibility to features that are the (predictable) artefacts, or the technically competent but ultimately misleading “good fit” computational result, of a too-sparse or non-uniformly distributed data set?

KNOW YOUR DATA... then you can get to work.

“Geological-looking” 3D imagery, without a verifiable hard data basis, isn’t enough.
Inadequate data, for all purposes.

3 anomalies but no available interpretation
Adequate data, for resolving this anomaly feature.

Just one more line resolves the ambiguity with hard data. No guess required.
Adequate data for resolving other details, nuances, subtle patterns.
Conventional resistivity traversing detects resistive zones that are associated with silicic erosional remnants... sinters.

100 metre penetration resistivity survey - example: dipole-dipole array  “a” = 100 m to “n” = 7

Section View Y14  6301475 to 6301550 m North. Viewer facing Grid North

Typically, both hot spring sites will be peppered with drill holes in search of the potentially-high-grade feeder systems beneath each one.
Very large scale 3D resistivity comes into play.

100 m Ze limitations give way to 1,500 m Ze imaging

Now we see the 3D resistivity imprint of the single hydrothermal upwelling system (epithermal system) that feeds both surface vents.
Where conventional exploration has drilling concentrated in the two proposed feeder areas beneath the surficial sinters....
... the real target for deep feeders lies deep below the single-source feeder system.
Very large scale 3D resistivity comes into play.

With Full Spectrum 3D resolution, subtle patterns that are usually buried in noise or as inversion interpolation pseudo-artefacts become *data-secured*, verifiable exploration detailing of the epithermal system’s alteration imprint.

**Topographic high = erosionally resistant, silicification**

Section View Y14 6301475 to 6301550 m North. Viewer facing Grid North.
Proposing better “3D” definitions for use in surface-measured DC resistivity

Not for downhole, hole-to-hole, mise a la masse or other below-surface (source or measurement) survey styles.

**Definition: True 3D**

“True 3D” is a term that is widely applied and seldom meaningfully defined. In this paper, “True 3D” means (for DC resistivity and IP):

A **True 3D field data set** is
1. uniformly all-directional, and
2. uniformly distributed both laterally and to depth*.

* The density (of uniformly laterally-distributed data) is permitted to fall off logarithmically with increasing Ze or “r”.

A **True 3D** inverted earth model is any model that has been data-constrained by a **True 3D** data set.

**True 3D** data occupy the central areas of any well-executed 3D distributed acquisition survey or 3D E-SCAN survey. Cross-line surveys are designed to produce **True 3D** data sets for conductive targets.

For Athabasca Basin purposes, low-density “True 3D” may be sufficient for targeting **large conductive zones**, for drill testing to confirm the presence of mineralization, alteration, or radioactivity levels of interest.

**Definition: Full Spectrum 3D fs3D**

“Full Spectrum 3D” or “fs3D” is a term that is proposed to distinguish those “True 3D” data which meet the extended criteria required for the equal and objective 3D resolution of features through the resistive end of the conductive-resistive spectrum.

An **fs3D field data set** meets the definition of
1. **True 3D**, and has a ...
2. higher density of sampling*.

* sufficient to resolve 3D resistive features with sensitivity equal to that which is (more easily) attained for more conductive features.

A full spectrum **fs3D** inverted earth model is any model that has been data-constrained by an **fs3D** data set.

**fs3D** data sets are found within the central areas of any 3D distributed acquisition (data-logger) survey or 3D E-SCAN survey, provided that the increased sampling density is uniformly distributed.

For Athabasca Basin purposes, low-density “True 3D” may be sufficient for targeting **large conductive zones**, for drill testing to confirm the presence of mineralization, alteration, or radioactivity levels of interest.
The Hollister’s Clementine and Gwenivere vein system: >1 million ounces Au
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E-SCAN 3D MAPPING
Regional pattern of 3D earth resistivity
500 - 550 feet below surface
Ivanhoe Project, North Carlin Trend, Nevada
Volcanic-hosted epithermal vein and vertical “blow” ore systems. Overview-scaled 3D resistivity maps the imprint (alteration envelope) of an undetectably-small 2-metre wide highgrade shear structure, the Phoenix Deposit.
Integrated Exploration at the Altan Nar Project, Mongolia

Michael A. Macdonald, Erdene Resource Development Corp.
Michael X. Gillis, Erdene Resource Development Corp.
Peter C. Akerley, Erdene Resource Development Corp.
Chester S. Lide, Zonge International Inc.

Altan Nar is a discovery-stage exploration project located in the Bayankhongor Aimag in southwestern Mongolia and is located approximately 980 km southwest of Ulaanbaatar. It is a discovery made in 2011 by ERD that resulted from a regional grassroots exploration program. Altan Nar is interpreted to be a carbonate-base metal gold system and is hosted in a series of Devonian to Carboniferous andesitic flows and breccias that are intruded by multiple stages of late porphyritic granitoid dykes. Epithermal Au and Ag mineralization is present in quartz breccia zones with characteristic multiple stages of brecciation, silicification and quartz veins within associated phyllic alteration zones (quartz-sericite-pyrite) and is commonly hosted within broad zones of polymetallic (Ag,Pb,Zn) mineralization.

Exploration work at Altan Nar since 2011 has consisted of detailed geologic mapping, rock and soil geochemical sampling, trenching, IP/resistivity and ground magnetic surveys, followed by scout and delineation drilling. To date, approximately 10,000 m of diamond drilling and 3,000 m of trenching has been completed. Approximately half of the drilling has been to define the initially-discovered mineralization in two areas known as the Discovery Zone and Union North.

Geophysical surveys include gradient-array induced polarization covering approximately 17 km² and ground magnetic surveys covering approximately 45 km². Follow-up dipole-dipole data were acquired in a smaller area surrounding the Discovery Zone and Union North Prospects. Gradient-array chargeability data show a series of linear highs that define an en-echelon pattern that may represent dilation zones related to a northwest trending dextral shear system. Drilling and trenching to date show a strong positive correlation between mineralization and IP highs. Mineralization appears to be structurally controlled and dilational jogs and fault intersections are often identified as geochemical anomalies and chargeability highs. Drill testing of these targets has demonstrated that dilational jogs produce both higher grade and larger intercepts. Mineralization is also associated with magnetic lows and quiet zones related to magnetite destructive alteration within the magnetic volcanic host rocks. Magnetic data provide an aid to mapping lithology, structure and alteration.
Currently mineralization has been indicated along a 5-6 km long by 1.5 km wide zone. To date, 27 widely-spaced scout holes have been drilled along the 5-6 km strike length, outside of the Discovery Zone and Union North Prospects, to test targets defined by combined geochemical, IP and magnetic anomalies. Over half of these holes returned intercepts of 0.5 g/t Au or higher, over intervals of 1 to 19 m (up to 4.4 g/t Au over 9m).
Integrated Exploration at the Altan Nar Project Mongolia

Michael MacDonald, Peter Akerley, Michael Gillis
Erdene Resource Development

Chester S. Lide,
Zonge International
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Altan Nar Project Location
 ALTAN NAR PROJECT

- Intermediate-Sulfidation System
- Discovered 2011
- Presently in discovery/exploration phase
- Currently two resource areas being defined.
  - Discovery Zone
  - Union North
  - Multiple additional targets
• Geologic Map

• A large granite intrusion lies beneath the eastern portion of the map area.

• Two distinct packages of volcanic rocks, Sequences A and B are observed to the southwest of this intrusion.

• Sequence A Volcanics.

Dominantly trachyandesite and minor rhyolite flows
Distinguished by strong arcuate NW-SE outcrop patterns and air photo lineaments.
Interpreted to have steep dips.
Intruded by granite porphyry and fine-grained granitic intrusions thought to be sills.

Sequence B Volcanics.

Dominantly andesite and tuffaceous rocks of intermediate composition.
Rocks are thought to be relatively flat-lying to shallow dipping due to lack of lineaments and topographic features.

Intrusive rocks less abundant and include a small granodiorite plug in south central map area.
Rocks are cut by three phases of late porphyritic granitoid dykes.
Some post-date and cross-cut mineralized zones.
Altan Nar Project
Total Magnetic Field
Upward-Continued 30m
Reduced to Pole
Ground magnetic survey.

Map showing Reduced to Pole image (RTP), upward-continued 30 m. Data set is compiled from survey conducted in 2010, 2011 and 2012. Line spacings vary from 100m in the southwestern and northeastern areas to 25 meters in the central map area.

Peralkaline granitic intrusion in northeast map area exhibits low-magnetic values and low magnetic relief. This corresponds to the granitic (alkalic) intrusive.

Sequence A volcanic rocks are defined by the area of high magnetic relief. Strong NW-SE trends are observed in this area.

Areas of high magnetic values generally correspond to the trachyandesitic volcanic rocks. Low magnetic values correspond to fine-grained granite and granite porphyry dykes.

The Sequence B volcanic rocks lack the clear NW-SE trends and are dominated by discontinuous segments cut by multiple structural directions. Narrow dykes are seen to cross the survey area and show both normal and reversed polarities. Areas of low magnetic relief are observed which are suggestive of magnetite destruction by hydrothermal alteration “Martization”.

3D Susceptibility Inversion, Looking Southeast
Geosoft VOXI 3D susceptibility inversion.  
Data: Ground magnetics, upward-continued 30m.  
25m voxels.

3D magnetic susceptibility inversion for data shown in the northeastern half the map shown in the previous slide. 
View is looking southeast.

Non-magnetic peralkaline granite in the northeast corner (Left) of the block. The model suggests that the intrusive extends beneath the intrusive body. This is supported by the observation of contact metamorphic effects in the Sequence A rocks (Bat Erdene, 2015, Personal Communication).

Sequence A volcanic rocks are interpreted to be steeply dipping adjacent to the large granite body.
Exploration

- Grass-roots Discovery
  - Regional exploration program targeting Paleozoic Terrain
  - Discovery of Nomin Tal Cu-Au Zone
  - Follow-up regional soil geochemistry (1610 samples)
  - Delineated broad Pb- Zn soil anomaly (5 by 2 km)
Altan Nar Exploration as of May 2015

- Drilling: 71 holes totaling 10,819 m, 6134 samples.
- Trenching: 39 totaling 2927 m, 1454 samples.
- Ground Magnetics:
  - 100m line-spacing, 41 km²
  - 25m line-spacing. 16 km²
- Gradient-Array, IP/Resistivity, 22.8 km²
- Dipole-Dipole IP/Resistivity, 55 line-km
Mineralization

- Complex ore zones with multiple phases of brecciation, silicification and mineralization

- Crustiform-Colloform, comb quartz and silicified zones. Minor Chalcedony

- Mn, Fe and Ca carbonates, in varying proportions.

- Abundant fine- and coarse-grained galena and sphalerite

- Au Mineralization generally occurs within broader zones of base-metal mineralization.

  - Quartz, sericite, pyrite halos.
Discovery Zone: 1st Hole Return 55 m 1+ g/t Au with 23m of 2.1 g/t Au; 1st hole below that 26m of 4.7 g/t Gold
Comb and Colloform Crustiform Textures
Typical Base-Metal and Gold Distribution In the Discovery Zone

Base Metal

Gold

From: Clark, et. al. Runge Pincock Minarco, 2015
• High Au, As, Ag in epithermal breccias
• Au, Ag, As occur within broad base-metal enriched zones
• Associated with broad zones of pyrite.
• Cu less than 100 ppm with minor enrichment to 300 ppm
Dipole-Dipole Line 1 - Discovery Zone “A”
Dipole-dipole line 1 across the Discovery Zone

Plots from top to bottom

Inversion Resistivity, Inversion Chargeability, Observed Resistivity, Observed Chargeability.

Shallow moderate chargeability high centered on SE portion “A” of the mineralized zone. Located within diffuse elevated chargeability background. Subtle resistivity contrast observed across zone. Observation of narrow IP highs associated with mineralization, led to a test gradient array survey over the discovery zone area.
Color image of gradient array chargeability for the Altan Nar area. Also shown on this map are the approximate, outlines for the Discovery Zone (DZ) and Union North (UN) resources. This plot also shows the location of the DZ “A” zone shown on the dipole-dipole section on the previous slide. The highest chargeability values are observed along the northeastern edge of the survey area within the Sequence A rocks. The highs within the Sequence A rocks have dominant northwesterly trends zones. High chargeability is closely associated with granitoid sills and zones of low magnetic response. Within the Altan Nar area the chargeability highs have a general northerly trend although locally northeasterly trends are observed. Local increased chargeability anomalies are observed over the DZ and UN zones. Narrow linear zones of higher chargeability locally lie within broader zones. This is particularly the case in the UN area and anomalies in the west-central portion of the grid. Broad flanks to these anomalies suggest broader zones at depth. This has been confirmed with the dipole-dipole surveys. Also shown on this map is the location of the dipole-dipole section across the DZ shown in slide 15.

Apparent resistivity map for the gradient array IP/Resistivity data. Generally decreasing resistivity away from the Sequence A rocks and the suspected underlying granite intrusive. Low resistivity is generally shown as a northwesterly-thickening low-resistivity surface unit. The source of this surface layer is presently poorly understood. Deeper weathering, decreasing thermal effects with distance from the intrusive, or decreasing silicification are possible causes. There is not a distinct resistivity signature to the presently discovered mineralized zones. However both DZ and UN lie along resistivity gradients. DZ lies along northeasterly gradient which truncates north south trending resistive highs. The strongest mineralization in DZ lies at the ends of these resistive zones. The edges of silicified breccias have been noted as loci of increased structural dilation (Cowan, 2014). North-south, northeast and northwest trending gradients imply structure and lithologic or alteration boundaries.
Gradient array chargeability showing interpreted structurally-controlled sulphide zones. Heavy lines show the priority targets thought to lie above relatively strong or larger zones of alteration. Dashed lines show secondary trends. Many of these features are thought to represent dilation zones related to shear along the contact zone between the A and B volcanics. Others appear to be networks of anastomosing structurally-hosted alteration.

Drilling and trenching have shown that even the most subtle and narrow chargeability highs may host mineralization.

Ground magnetic data: total magnetic field reduced to pole. Note association of DZ and UN mineralization with areas of low magnetic relief. This is typical of magnetite destruction in epithermal systems. The northeast trending lows immediately to the south of the DZ are thought to have a reversed remanent magnetization component. The linear northeast trending high in the southern map area indicates a dyke. This feature follows a prominent zone of discontinuity in the magnetic and the gradient resistivity data.
This Slide shoes the gradient array coverage for the area covered by the dipole-dipole survey.

**UPPER LEFT**

Gradient array chargeability map showing approximate boundaries of Discovery Zone and Union North resource area.

Mineralization in both zones exhibits a strong positive correlation with chargeability highs. Northerly and northeasterly trending intersections are suggested in both areas.

Relatively narrow linear chargeability highs are observed in the southern half of the map. This suggests sulphides in narrow, relatively tight structures. Broader, higher amplitude chargeability zones are observed in the northern half of the grid. Increased alteration is suggested at depth, with narrow, shallow zones superimposed.

**UPPER RIGHT**

Gradient array apparent resistivity map showing approximate boundaries of Discovery Zone and Union North resource areas. Discovery Zone mineralization lies along a NE trend defined by the truncation of northerly-trending resistivity highs (silicification?) North-northwest trending resistivity gradients mark likely structures. These are evident in dipole-dipole data as steps with increased thickness to the west westerly of the low-resistivity layer.

Well defined northeast trending low-resistivity zone correlates with a drainage and is likely a structural zone. Mineralization has been intersected project lies along the southeast edge of this feature.

**LOWER LEFT**

Gradient array chargeability map showing drill hole assays of Au equivalent of 2 g/t or greater. Sample locations are project vertically to surface. A very high percentage of significant mineralized intercepts lie beneath linear chargeability peaks observed in the gradient array data.
3D Inversion of dipole-dipole IP/Resistivity data. The inversion was computed using software from Geotomo.

**UPPER LEFT**

3D Chargeability extracted for an elevation of 1300m (near surface)
Strong positive correlation with Discovery Zone and Union North mineralized zones.
3D inversion enhances the northeasterly-trending highs.
Resource areas are associated with chargeability distinctly anomalous chargeability values for this elevation.

**UPPER RIGHT**

3D Inversion resistivity extracted for the 1300m elevation.
3D inversion has enhanced the northeast-trending gradient associated with the Discovery Zone.
An east-west gradient at the northern side of the Discovery Zone is roughly coincident with an EW fault mapped in drilling.
Union North lies at the intersection of northerly chargeability high and northwest trending low-resistivity zone.

**LOWER RIGHT**

Inversion resistivity extracted for the 1300m elevation.
Larger-scale resistivity trends are observed.
The Union North mineralized zone is seen to lie along a significant, likely deeper-seated north-northeasterly trending gradient/structure.
It lies at the intersection with a northeast trending low resistivity zone.
This low resistivity zone extends to the southeast to the center of another strong chargeability anomaly.

**LOWER LEFT**

Inversion chargeability extracted for the 1200m elevation.
Higher chargeability is observed within broad zones beneath the northern half of the map.
Strong correlation with the Union North mineralization and indicates continuity between the Union North and intercepts 400-500 m south (Union South)
High chargeability to the west of Union north known as North Bow.
Union North Resource Area
3D Inversion for an E-W Section Through Mineralization

Resistivity
Chargeability

Black polygons show gold zones.
From Clark, et. al., 2015
3D inversion results extracted for a section through the Union North mineralization, looking north.

A strong chargeability response is observed to be associated with the mineralization. The asymmetry of the response hints at the steep westerly dip and suggests additional alteration/mineralization down-dip. Mineralization is open at depth.

The UN lies within relatively low resistivity rock at near surface. It lies along a deeper resistivity gradient, with lower resistivity at depth to the west.
Discovery Zone Resource Area
3D Inversion - Oblique View Looking Northeast

Pink Surface: 11 mSec, Chargeability Shell
Olive Surfaces: Base-Metal Mineralization
Black Surfaces: Gold Mineralization
Resource Surfaces from Clark, et. al, 2015
Ground magnetic data for the DZ-UN Area.

**Upper Left**
Reduced to Pole (RTP) Total Magnetic Field.

**Upper Right**
Calculated First Vertical Derivative of the RTP Magnetics.

**Lower Left**
Tilt Derivative of the RTP Magnetics.
The Tilt Derivative has highlighted several lineaments.
Both DZ and UN are located along prominent northeasterly trends.

**Lower Right**
Composite map of Tilt-Derivative as grey scale and gradient array chargeability as color.
There is very close correlation with the narrower and shallower portions of the chargeability highs and TDR Lows.

This is evidence of the strong structural control on the sulphide (phyllic) alteration and associated mineralization.

These maps provide significant information on structure, alteration, and intrusive rocks.
Summary

- Mineralization encountered in trenches and drilling shows a strong correlation with chargeability highs.
- Pyrite in phyllic alteration zones is the source of the IP response.
- Increased mineralization found to date is closely associated with increased chargeability at NS and NE intersections.
- High lateral resolution, efficient areal coverage afforded by the gradient array provides an important targeting tool.
- Magnetic data show lows and quiet zones that are indicative of magnetite destruction.
- Coincident narrow magnetic lows/linears and chargeability highs are associated with most mineralized intercepts.
Summary

- Integrated approach of geochemistry and geophysics have identified multiple target zones.

- Verified by either trenching or scout drilling to host polymetallic mineralization.

- Mineralization encountered over a 6km by 1.5 km area.

- Most significant intercepts to date has been located beneath a chargeability high, albeit some are extremely subtle.

- Not all chargeability highs have been mineralized, however phyllic alteration and associated pyrite have been encountered.

- 3D Inversion of dipole-dipole data has provided enhanced detection of features that strike at moderate to low angles to the survey lines. 3D inversion appears to have enhanced the detection of major structure.
REFERENCES


3D IP: Depth and definition successes
Pierre Bérubé, Eng., President, Abitibi Geophysics Inc.

Over the last few years Abitibi Geophysics has carefully looked at how to increase the depth of investigation and resolution of induced polarization (IP). Researching the sensitivity response of various electrode configurations spawned the design of a 3-D configuration which has demonstrated depth, stable inversion characteristics and is cost-efficient.

IPower3D IP incorporates the highest sensitivity electrode arrays to increase exploration effectiveness through conductive overburden and a depth sounding array to, for instance, help resolve the overburden layer. A complex arrangement of high density measurements is made along and at multiple angles across survey lines yielding reliable data for 3-D inversion and drill targeting. To collect over 10,000 measurements per square kilometer in a cost efficient manner requires innovative field procedures and customized quality control, processing and inversion capabilities.

Hardware and software developments related to IPower3D have subsequently been used to improve the efficiency of the good old dipole-dipole configuration, allowing the measurement of up to 30 ‘n’ spacing for the same budget as a conventional n = 1 to 8 survey. This OreVision IP array is so affordable that systematic coverage at a 100 or 200 m line interval is routinely done, opening the door for a 3D product at a cheaper cost than IPower3D. This solution remains an in-line dipole-dipole array, so resolution and depth of investigation are of course more limited than with IPower3D.

This presentation will show example data from surveys over deep targets mapped for SOQUEM, Cartier Resources and Alexandria Minerals.
2ND BIENNIAL GREAT BASIN AND WESTERN CORDILLERA MINING GEOPHYSICS SYMPOSIUM
THE NUGGET, RENO, NEVADA, SATURDAY, MAY 16TH 2015

3D IP: Depth and Definition Successes

Pierre Bérubé, Eng.
President, Abitibi Geophysics Inc.
So why do we perform (3D) IP?

- To uncover mineral deposits.

- But these deposits being harder and harder to find, we must improve the sensitivity of our tools in order to see deeper and/or through conductive cover.
What’s the problem with conventional (2D) IP?

- Overburden: 50 Ω-m, 0 mV/V
- Vein: 1,000 Ω-m, 100 mV/V
- Host: 10,000 Ω-m, 10 mV/V
Dipole-dipole Response
(a = 50 m, n = 1 to 8)
Chargeability Pseudosection => Detection Limit

- Overburden: 50 Ω-m, 0 mV/V
- Vein: 1,000 Ω-m, 100 mV/V
- Host: 10,000 Ω-m, 10 mV/V
IPower3D™ Response Inverse Chargeability Section

=> No Doubt About DDH Target

Vein: 1,000 Ω-m, 100 mV/V

Host: 10,000 Ω-m, 10 mV/V

Overburden: 50 Ω-m, 0 mV/V
IPower3D™ Set-up

- 48 electrodes per line
- 240 addressable electrodes
- 28,680 possible Rx dipoles
- 25, 37.5, 50 or 100 m takeouts
IPower3D™
Readings

L-1+00E  L-2+00E  L-3+00E  L-4+00E  L-5+00E

Base Line

• Quasi-Equatorial dipole-dipole
• Quasi-perpendicular dipoles

IPower3D™
ABITIBI
GEOPHYSICS
These quasi-perpendicular dipoles readings combined with the equatorial ones taken at many ‘N’ spacing, scan the ground in all directions making of IPower3D a true 3D array. Therefore, it is able to map and resolve structures which may be obliquely oriented to the survey lines. The typical line and station intervals are 100 and 50 m respectively. In excess of 10,000 readings are recorded per square kilometre. The data density and full 3D content help resolve near-surface heterogeneities, delivering a more reliable and meaningful Earth model to depths in excess of 600 m.
IPower3D is the only 3D array offering the flexibility to compose nearly 20,000 different receiving dipole combinations for each current injection. In comparison, a distributed array system (DAS) using 50 two-dipole receivers would be limited to 100 combinations. Of course all those dipoles are not required, but IPower3D can be expanded as needed. IPower3D is an innovative unbounded true 3D approach making the smartest use of the sensitivities in order to maximize:

- horizontal resolution
- vertical resolution
- depth of investigation
IPower3D™ Readings

• (Quasi-) Equatorial dipole-dipole
• Quasi perpendicular dipoles
These quasi-perpendicular dipoles readings combined with the equatorial ones taken at many ‘N’ spacing, scan the ground in all directions making of IPower3D a true 3D array. Therefore, it is able to map and resolve structures which may be obliquely oriented to the survey lines. The typical line and station intervals are 100 and 50 m respectively. In excess of 10,000 readings are recorded per square kilometre. The data density and full 3D content help resolve near-surface heterogeneities, delivering a more reliable and meaningful Earth model to depths in excess of 600 m.
• $N = 1-20$ In-line dipole-dipole
• $N = 3-16$ Offset dipole-dipole
IPower3D™ Readings

• Schlumberger Sounding
• Quasi-Schlumberger Soundings
Sensitivity Comparison – Plan Views

Equatorial Dipole-dipole VS Equatorial Pole-dipole

Not such a good idea. Unstable in inversion.
IPower3D™  Production & QA / QC

Total of 10,650 readings / km²
IPower3D™ Light Set-up at the Receiver
IPower3D™ Production & QA / QC
IPower3D™ Production & QA / QC

Custom Cables

Custom Tester
IPower3D™ Production & QA / QC

TIPIX ready!

2400V 15000mA 2500W

2s

Rs CHECK

MENU

START / STOP
Rupert Resources Property Location and Geology in the Red Lake Camp

Geology Map

LEGEND
- Granite
- Anorthosite
- Diorite
- Ultramafic Intrusive
- Mafic Intrusive
- Felsic Volcanics
- Mafic Volcanics
- Metasediments
- Tholeiitic Suite

SYMBOLS
- Goldcorp Winze
- Highgrade Zone
- Far East Zone
- Goldcorp Property
- Cochenour Mine
- Campbell Mine
- Placer Dome Property

Red Lake PROPERTIES
- Mine Shaft
- Vein System
- Geological Contact
- Road

Approximate scales
0 1 2 3
Kilometres
0 1 2 miles

Gullrock Property
Cochenour-Dickenson deformation zone
Gullrock Lake
Ranger Lake

RUPERT RESOURCES LTD

ABITIBI GEOPHYSICS
Geology & IP Grid
IPower3D™ for Rupert Resources & Conquest Resources, Red Lake Camp

Untested Target

Shear Zone
IPower3D™ for Rupert Resources & Conquest Resources, Red Lake Camp
SOQUEM B-26 PROJECT
SELBAIE AREA, QUEBEC

B-26 is located in northern Quebec near the Ontario Border. It was discovered in the 90's. About 250 Km north of Val d'Or.
SOQUEM B26 – IPower3D Resistivity

Copper-rich Zone

Graphitic Zone
SOQUEM B26 – IPower3D Chargeability

Copper-rich Zone

Zinc-rich Zone
SOQUEM B26 – IPower3D Zinc Index

Zinc-rich Zone

Copper-rich Zone
SOQUEM B26 – Section 41+00E

Zinc-rich Zone

Copper-rich Zone
SOQUEM B26 – Metal Factor at -150m

Line 34+00E

Graphite

Sulphides

Contours du facteur métal

Formule: Mixupt(1) +
Configuration: Power3D
Inversion: Res3Dinv (GeoTom)

I-POWER3D

Abitibi Geophysics
SOQUEM B26 – Section 34+00E

Inverted Resistivity

Inverted Chargeability

Inverted Frequency Dependence

Graphite  Sulphides
Akasaba Project
IPower3D™ Chargeability Inversion

Kettle Zone
Akasaba Project
IPower3D™ Chargeability > 25 mV/V
Akasaba Project - Kettle Zone
IPower3D™ Chargeability = 28 mV/V
Akasaba Project - Kettle Zone
IPower3D™ Chargeability = 25 mV/V
Akasaba Project
IPower3D™ Chargeability = 22 mV/V
DDH IAX-14-258  AKASABA KETTLE ZONE
Depth: 325.5m, Pyrrhotite and Pyrite with Qtz-Cb veins in sheared black shales.

Rock:
Felsic tuffs and black shales
DDH IAX-14-258  AKASABA KETTLE ZONE
Depth: 105.0m Massive pyrrhotite at the contact between felsic tuffs and a dacitic unit.

Rock:
Dacite and felsic tuffs
Conclusions on IPower3D

• Conventional IP configurations have a shallow depth of investigation through conductive OB.

• IPower3D™ maximizes the sensitivities yielding enhanced responses through conductive overburden and at depth.

• IPower3D™ maximizes the vertical and horizontal resolution of target mineralization.

• 3-D inversion on quality data provides accurate DDH targets.
• 2D arrays should continue to be used in normal environments with shallow/less conductive overburden
• Large 2D arrays are effective for targets under resistive overburden, example - Athabasca Basin
• Large 2D arrays with DAS (‘data loggers’) are preferable for dipoles >100 m, example - porphyry Cu targets
• If boreholes are available, complete the investigation using H2H-3D-IP
The OreVision Difference

- Near-surface resolution
- Maximize depth of investigation
- Cost similar to conventional IP!
- 3D Inversion to avoid ‘side’ effects
So, how do we get the best of both worlds, high resolution & good depth of investigation?

There is no avoiding the physical limitation that to look deeper, we must sample a larger volume of the subsurface and as we already discussed this will result in lower resolution. The only way to ensure high resolution at depth is to conduct a borehole IP survey… which incidentally we also offer!

So, knowing that we can’t see to great depth at high resolution, how can we maintain our high resolution near surface and also look to great depth?

The solution seems obvious, design a survey that uses short dipoles for near surface, high resolution readings and larger dipoles for deep exploration.

However, every potential dipole has to be connected to the receiver. With 6 dipoles there are wires from 7 electrodes that have to be plugged into the correct terminal of the receiver. Adding more electrodes means more wires, and more time to switch wires in order to connect to the desired dipoles. The process quickly becomes logistically complicated, slow and expensive. And that is probably why this type of survey has not really caught on.
Programmable switch box

10 channel receiver

Multi-conductor cables
In 2010 Abitibi Geophysics developed the IPower3D IP system and this year we expanded it to a 240 electrode array. This is another system that we are very proud of. The unique feature of IPower3D is that it allows us to explore beneath thick, conductive cover that would normally be impenetrable to IP. It is also a true 3D IP survey. If you want to learn more about IPower3D please drop by our booth for a chat.

With the 200 electrode array, and only 10 channels on our receiver you can imagine the challenges! The solution was the 240 channel programmable switch box, shown here and the multi conductor cables. Instead of a mess of wires to be plugged into the receiver, it’s just one cable, that goes to the switch box. The electrodes are connected to specially designed take-outs on the cables. The cables are designed so that when connected end to end and plugged into the switch box each electrode is automatically connected to the correct channel.
OreVision™ Set-up

- Good old Dipole-dipole
- $N = 1$ to 20 or 30
What Makes OreVision IP Different?

Why just barely scratch the surface?

OreVision Resistivity

OreVision Chargeability
Cadillac Break Property Position
Val-d’Or to Louvicourt

Alexandria Property
Past/Present Gold Mine
Historic Deposit
Lake
Highway
Fault

Granitic Rocks
Volcanic Rocks
Sedimentary Rocks (Pontiac Group)

City of Val d’Or

Current Drilling

MID CANADA
ORENADA
ORAMAQUE

SISCOE EAST
Lac Herbin Alexis Minerals
Sigma Mine Century Mining

Bourlamaque Batholith

Norlatic Mine
Siscole Mine
Western Quebec
Sullivan Mine
Kiena Mine
Western Quebec
Goldex Deposit
Agnico Eagle
Lamaque Mine Century Mining

DUCROS
Sabourin Creek
Lourmet
Orcour
Sigma #2 Mine

SLEEPY
VAUMON

Chimo Mine
Orenada-Oramaque-Ducros Project
2D Inverted ‘Old’ Chargeability at – 50 m

Very weak Chargeability
No penetration

Area surveyed using OreVision-IP in 2014
2D Inverted ‘Old’ Chargeability at – 50 m

Area surveyed using OreVision-IP in 2014
OreVision @ Orenada

OreVision 3D Resistivity at – 50 m

Thick Overburden
OreVision @ Oramaque
OreVision 3D Chargeability at – 50 m

Thick Overburden
OreVision @ Orenada
OreVision 3D Chargeability at – 150 m

New Target
OreVision @ Orenada
OreVision 3D Chargeability at – 300 m

New Target
Hole DAX-14-01 Drilled on OreVision Target
‘...Intersected 150 m Thick of Altered & Fractured Cu-bearing Granitic Rocks’

Native Copper

Malachite

Chalcopyrite
PROJET BENOIST PROJECT
Location/Localisation
SNRC : 32F08
Projection : NAD 1983 UTM Zone 18N
Geologist/Géologue : Philippe Berthelot
GIS technician/technicienne : Julie Allostry
Date : 2012-03-01

Benoist Property Position Langlois – Bachelor Corridor

Municipality of MRC de : "Jamésie"
Composite Plan View
Pusticamica Deposit

Pusticamica Zone Extension: known down to -600m

Pusticamica Zone

Targeted Area

Vertical depth: 0m to -300m

Historical resources blocked out by Minnova [1993]
591,428 tons grading 5.5 g/t Au, 12.1 g/t Ag & 0.3% Cu
Pusticamica Deposit Longitudinal Section
Pusticamica Deposit
Cross-section 150W
NEW INNOVATION IN GEOPHYSICS MAPS PUSTICAMICA GOLD DEPOSIT AT DEPTH
BENOIST PROPERTY / 2015 WINTER

Pusticamica gold deposit

Chargeability Profile (New 2015 IP Survey)

OreVision Test Line

Target block

Pusticamica Lake

Property boundary
Benoist Property
2015
OreVision Survey Area
Conclusions on OreVision

- Excellent depth of exploration
  4 times conventional dipole-dipole survey
- Retain the near-surface resolution
- QC shows > 99% of readings have pure chargeability decay curves - basic requirement for reliable 3D inversion
- 3-D inversion on 2D array like OreVision™ with high quality data yields accurate drill targets, avoid lateral view
- Cost is comparable to conventional dipole-dipole, n=1-10
Thanks to…

• Funding: National Research Council of Canada – IRAP
• Instrumentation customization: IRIS Instruments
• Field examples:
  – SOQUEM Inc.
  – Alexandria Minerals
  – Rupert Resources / Conquest Minerals
  – Cartier Resources
• First supporters (2011-2012)
  – Sleeping Giant Mine
  – Richmont Mines
  – Sphere Resources
  – Iamgold
3D inversion of the long period EarthScope MT data over Great Basin area

Gribenko, Alexander, University of Utah, TechnoImaging LLC
Howe, Brendan, Barrick Gold Corporation
Zhdanov, Michael, University of Utah, TechnoImaging LLC
Endo, Masashi, TechnoImaging LLC

In this paper we describe the method of simultaneous inversion of the full MT impedance data for 3D conductivity distribution and for the distortion matrix with complex components. Distortion of regional electric fields by local structures represent one of the major problems facing three-dimensional magnetotelluric (MT) interpretation. Tikhonov regularization is employed to solve the resulting inverse problem. Integral equations method is used to compute MT responses. Minimization of the cost functional is achieved via pre-conditioned conjugate gradient method. We present results of inversion of regional MT dataset acquired as a part of the EarthScope project over the Great Basin region of the Western US. Conductivity features recovered by the inversion are reviewed against major tectonic and metallogenic domains within the Great Basin, with implications for exploration.
3D inversion of the long period EarthScope MT data over Great Basin area

Alexander Gribenko\textsuperscript{1,2}, Brendan Howe\textsuperscript{3}, Michael S. Zhdanov\textsuperscript{1,2}, and Masashi Endo\textsuperscript{2}

1 – University of Utah CEMI
2 – TechnoImaging LLC,
3 – Barrick Gold Corporation
OUTLINE

• Introduction
• Principles of MT inversion with a complex distortion matrix
• Implementation notes
• Dublin Secret Model 2
• Great Basin data inversion
• Conclusions
INTRODUCTION

• Effect of near-surface inhomogeneities on MT apparent resistivities (DC shift) is a well documented problem of MT data interpretation (e.g. Berdichevsky and Dmitriev, 1976)

• Distortion of regional MT impedance responses by local structures is one of the major challenges in the 3D interpretation of MT data

• Besides amplitude shifting (DC shift), the 3D effect of the local inhomogeneities involves impedance component and phase mixing (Jones, 2012)
INTRODUCTION

• Our algorithm takes into account 3D effects of the near-surface inhomogenities by inverting full MT impedance data for 3D conductivity distribution and for a distortion matrix with complex components.

• We present results of inversion of regional MT dataset over the Great Basin acquired by the EarthScope project.

• There is apparent correlation between conductivity signatures recovered by the inversion, tectonic provinces and metallogenic trends found in Great Basin.
PRINCIPLES OF MT INVERSION WITH A COMPLEX DISTORTION MATRIX
MT IMPEDANCE DISTORTION

\[ Z^{obs} = cZ^{und} \]

\[
\begin{bmatrix}
Z_{xx}^{obs} & Z_{xy}^{obs} \\
Z_{yx}^{obs} & Z_{yy}^{obs}
\end{bmatrix} =
\begin{bmatrix}
c_{11} & c_{12} \\
c_{21} & c_{22}
\end{bmatrix}
\begin{bmatrix}
Z_{xx}^{und} & Z_{xy}^{und} \\
Z_{yx}^{und} & Z_{yy}^{und}
\end{bmatrix}
\]

- \( Z^{obs} \) – Observed MT impedance tensor
- \( c \) – Distortion matrix
- \( Z^{und} \) – Undisturbed (distortion free) MT impedance tensor

\[
d = cZ^{und} = cA(\sigma)
\]

- \( A \) – based on MT transforms and IE method
INVERSE PROBLEM FORMULATION

\[ P(\sigma, c) = \|r\|^2 + \alpha \|S\|^2, \]
\[ r = W_d (cA(\sigma) - d), \]
\[ S = \begin{bmatrix} S_{\sigma} \\ S_c \end{bmatrix} = \begin{bmatrix} L(\sigma - \sigma_b) \\ c - c_0 \end{bmatrix} \]

\( W_d \) – data weights, inverse of data variances or noise floor
\( \sigma_b \) – reference conductivity model
\( c_0 \) – zero distortion identity matrix
\( L \) – first order finite difference matrix
Preconditioned steepest descent method is used to minimize parametric functional. Preconditioner:

$$P = \left( \text{diag}(F^T F) \right)^{-1/2}$$

\(F\) – the Fréchet derivative (sensitivity) matrix

The Fréchet derivatives of EM fields with respect to conductivities are computed via quasi-Born approximation.

The chain rule is applied to obtain the Fréchet derivatives of impedances.

The Fréchet derivatives of impedance with respect to distortion components are calculated analytically.
IMPLEMENTATION NOTES
Inversion is performed for logarithm of conductivity to avoid negative values.

1D optimization is applied to a sounding curve averaged over all stations to obtain initial model for 3D inversion.

The Fréchet derivatives are computed only within the sensitivity domain of the MT data, which is determined by the skin distances for the corresponding frequencies, both vertically and horizontally.
IMPLEMENTATION NOTES

• The inversion is terminated if RMS error reaches 1 or stops decreasing or if a preset number of iterations is reached.

• The code is written in MatLab®, with parallel computing toolbox.

• The forward problem is solved via rigorous parallelized 3D forward modeling code based on the integral equation (IE) method.
DUBLIN SECRET MODEL 2
This data set was used at the 2nd MT inversion workshop to test and compare results of different 3D inversion codes (Miensopust et al., 2013).

The model is a modified version of the COMMEMI 3D-2A model by Zhdanov et al. (1997).

The random galvanic distortions were applied to the synthetic data set.

Random Gaussian noise of 5% of the maximum impedance value was applied to the distorted data.
DUBLIN SECRET MODEL 2

- Full impedance data
- 30 periods from 0.0158 to 10000 sec interpolated on a new set of 24 logarithmically spaced periods from 0.04 to 10000 sec
- 144 stations were included in the inversion
- 2000 x 2000 x (200:2000) m$^3$ cells – 76,800 total
DUBLIN SECRET MODEL 2

σ only inversion

RMS = 6.9

RMS error by station

σ + c inversion

RMS = 1.4
True model

σ only inversion

σ+c inversion

1D inversion result

Sounding curves

Zxy

Zyx

Observed
Predicted, from σ only inversion
Predicted, from σ+c inversion
DUBLIN SECRET MODEL 2

Distortion components
GREAT BASIN DATA INVERSION
GREAT BASIN DATA INVERSION

The MT data were collected as a part of the EarthScope project (www.earthscope.org) over the Great Basin region of the Western US.

98 sites approximately 80 km apart over 1000 km x 500 km area covering parts of California, Oregon, Nevada, Idaho, Utah, and Wyoming.

Full impedance tensor.

Original data interpolated from 30 periods between 7.3153 and 18,724 sec to 24 log-spaced periods from 10 to 10,000 sec.

Flat surface of the earth was assumed in the inversion.

Inversion domain was 650 x 1,150 x 308.2 km$^3$ in X (N) x Y (E) x depth.

Horizontal cell size was kept constant throughout the domain at 10x10 km$^2$.

48 vertical layers from 1 to 20 km with the thicknesses increasing logarithmically.
GB is conductive at 100 km or less.

Resistive Colorado Plato to the East and Sierra Nevada mountains to the West.

Conductive region along the Wasatch fault.

Snake river shows higher conductivity.

15 - 30 Ma Basin and Range extension may have conductivity signatures at depths around 200 km.
Preliminary Observations

• **Tectonic**
  - Does model correspond with tectonics of the Great Basin
  - Compare with Dickinson (2006) model

• **Metallogenic**
  - Relationship of ore-deposits and trends to crustal scale MT features
Interpretation is split into two areas:

Tectonic & Metallogenic

Firstly, to give some confidence in the model we compare it with some of the major Tectonic features from Dickinson (2006). If we can observe similar large scale effect in the MT model than this gives confidence to make additional assertions, for example metallogenic.

30km Depth Slice

Roberts Mountain Allochthon Protolith
Stars are Au deposits > 2 Moz endowment.
Carlin Trend Extending to Robinson
Carlin trend more prominent than the Battle Mountain – Eureka Trend
Bingham and the Uinta Arc can also been seen at the intersection with the Colorado Plateau
Comstock on Edge of large conductive block
X-Section Location

~Crustal Thickness for the GB (Malde, 1991)

20km

40km

Battle Mountain Complex

Goldstrike Camp

BME Trend

Carlin Trend

Ohm-m
Metallogenic Slide

Trends and camps located on edges of crustal scale conductive block. Edges could promote upward moving of fertile fluids. Trends are crustal scale.

The edges of blocks is consistent with previous slide, e.g. Comstock also on an edge, Bingham too.

CONCLUSIONS

• We have presented an algorithm of 3D MT data inversion for both conductivity distribution and distortion matrix.

• The inversion algorithm was successfully applied to the synthetic data with significant distortions and noise from DSM 2.

• Conductivity anomalies recovered by Great Basin data inversion agreed well with several tectonic features.

• Several metallogenic trends of the Great Basin are associated with conductivity anomalies.
ACKNOWLEDGEMENTS

• The authors would like to thank Virginia Maris for helpful discussions

• Authors acknowledge support of the Consortium for Electromagnetic Modeling and Inversion at the University of Utah, TechnoImaging, and Barrick Gold

• The MT data used in this study were made available through Earth-Scope (www.earthscope.org; EAR-0323309), supported by the National Science Foundation
Results from a regional passive airborne EM and magnetic survey in Selwyn Basin obtained in 2008 that were recently purchased by the Yukon Geological Survey and publically released in November, 2013 have been analyzed from an explorer’s perspective. The analysis highlights a strong correlation between regional conductive trends and the distribution of mineral occurrences in the region. Genetic similarities between Carlin-style gold deposits in Yukon and Nevada, where regional geologic trends are well recognized, underline the potential importance of the AEM defined conductive trends in the Selwyn Basin and elsewhere.

The Selwyn Basin is a large northwest trending Paleozoic deep water sedimentary basin that extends for 1000’s of km from Alaska, through Yukon and western Northwest Territories (NWT) and into northern British Columbia (Goodfellow, 2007). In 2008, a 25,000 km² area of Selwyn Basin in east central Yukon and western NWT, northeast of Ross River (Fig. 1-2), was overflown in a regional airborne geophysical survey contracted by a private mining company (Witherly, 2013; 2014). The survey consisted of 24,675 line-km of helicopter ZTEM (z-axis tipper electromagnetic; Lo and Zang, 2008) and magnetics. In November, 2013, after purchasing the survey data and having them reprocessed, the Yukon Geological Survey (YGS) released them to the public (McFarlane and Nordling, 2014). These data were compared to the known geology and mineral resources, analyzed from an explorer’s perspective by Carne et al. (2013) and are summarized in this study.
Regional Airborne EM and Magnetic Surveys in Selwyn Basin – An Explorer’s Perspective

By: Rob Carne - ATAC Resources Ltd., Vancouver CAN
Jean M. Legault* – Geotech Ltd., Aurora CAN
Richard Phillips and Julia Lane - Archer Cathro & Associates, Vancouver CAN

Presented at GBWC Mining Geophysics Short Course at GSN 2015
Reno NV, May 14-24, 2015
OUTLINE

• Introduction

• ZTEM System & Background

• Selwyn Basin Geology

• Correlation
  • Magnetic-Geology
  • ZTEM-Geology
  • ZTEM-Ore Deposits

• Yukon-Nevada (Rodinia)

• Yukon Skarn-BC Porphyry

• Conclusion
AFMAG & ZTEM - BACKGROUND

- **AFMAG** (Audio Frequency Magnetics), an EM technique first proposed by Ward (1959), used commercially until 1970’s.

- **Passive EM (Electromagnetic)** method – in same family as Audio-Magneto-tellurics (AMT), but uses Magnetic fields only (Hx-Hy-Hz).

- **ZTEM** is Variant of AFMAG – only Hz receiver mobile, Hx-Hy at fixed base-station, first introduced by Lo and Zang (2008).

- EM source are Natural EM Fields from Lightning Strikes– mainly Equatorial Thunderstorms and other electrical storms 1000’s of km away – cause horizontal planar EM fields, available year-round.

- **Basic Principle**: Lateral resistivity contrasts cause normally horizontal passive EM fields to Tilt Vertically.

- **Vertical secondary H-field vector called “Tipper”** (also Weiss-Parkinson Vector).

- **The relation between vertical (Hz) & horizontal (Hx-Hy)-fields is:**

  \[ H_z(r) = W_{zx}(r)H_x(r) + W_{zy}(r)H_y(r), \]

  Tipper vector \((W_{zx}, W_{zy})\) is determined using FFT processing of time-series.
The ZTEM System

Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ZTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter</td>
<td>None required (Passive EM method)</td>
</tr>
<tr>
<td>Sampling Frequency</td>
<td>A/D = 2000 Hz A/D (0.0005sec) Output = 2.5Hz (0.4s~10m/sample)</td>
</tr>
<tr>
<td>Receiver</td>
<td>Bird = Hz (Vertical Dipole), Base = Hx-Hy (Horizontal Dipole)</td>
</tr>
<tr>
<td>Survey speed</td>
<td>80 km/h</td>
</tr>
<tr>
<td>Rx Clearance</td>
<td>50 m (nominal)</td>
</tr>
<tr>
<td>Rx coil diameter</td>
<td>Mobile = 7.2m, Base = 3.5m</td>
</tr>
<tr>
<td>Rx Frequencies</td>
<td>30, 45, 90, 180, 360 Hz (+/- 720Hz) (or 25,37,75,150, 300Hz +/- 600Hz)</td>
</tr>
<tr>
<td>Rx Derived Measurements</td>
<td>Tzx (in-line) &amp; Tzy (cross-line) Tippers (via Tensor FFT)</td>
</tr>
<tr>
<td>Rx Transfer Functions</td>
<td>In-Phase and Quadrature</td>
</tr>
<tr>
<td>Nominal Noise floor</td>
<td>~1% IP &amp; QD</td>
</tr>
<tr>
<td>Depth of Investigation</td>
<td>~1km-4km for 1k Ω·m avg. Host</td>
</tr>
<tr>
<td>(approx. 1.5 δ_s)</td>
<td>~300m-1.5km for 100 Ω·m avg. Host</td>
</tr>
<tr>
<td></td>
<td>~100m-400m for 10 Ω·m avg. Host</td>
</tr>
</tbody>
</table>

- **ZTEM** is Variant of AFMAG, only Hz field measured at Receiver and Hx-Hy Reference fields measured at Fixed Base-station - Provides Improved S/N) over Standard AFMAG.
- **ZTEM** maps Resistivity Variations to Great depth (>km), Based on Lateral Resistivity Contrasts.
ZTEM and ground MT Data Comparisons

- All ZTEM tipper data were found to be within ± 0.01 (1%) avg. of ground MT tipper data.

Figure: Components of tipper, estimated from ZTEM (purple) and ground MT (black) in overlapping frequency band.

Hubert et al. (SEG 2014) – University of Alberta
2D INVERSION PARAMETERS

Inversion Code: Geotech AV2DTOPO
Model Mesh: 440 wide x 112 vertical,
Average cell width: 13.53 m
Two (2) Cells between sites
Input Data: In-Phase & Quadrature,
TxRx In-Line (only)
Average sampling rate: 2.780 points,
Total data points: 1920
Frequencies: 30 45 90 180 360
Input error(%): 1.71 1.71 1.71 1.71 1.71
Half-space resistivity: 300 ohm-m
Output error: 0.999 RMS in 5 iterations

ZTEM 90Hz In-Phase Total Divergence

Exploration Syndicate, Inc
Selwyn Basin
Yukon, Canada

Geotech ZTEM System
Resistivity—Depth Image
Project 8002, Line L4730_02
Flight 82, 2008/08/09
Flown and Processed by Geotech Ltd.
245 Industrial Parkway North
Aurora, Ontario, Canada L4G 4C4
www.geotech.ca

2014/8/27
The Selwyn Basin is a large northwest trending Paleozoic deep water sedimentary basin that extends for 1000’s of km from Alaska and into northern British Columbia.

Selwyn Basin is best known for its world-class Pb-Zn-Ag SEDEX (sedimentary exhalative) deposit potential, hosting twelve major deposits, including the giant Howards Pass deposits at 180 Mt (Selwyn-Chihong Mining Ltd.).

In 2008, a 25,000 km² area of Selwyn Basin in east central Yukon was overflown in a regional airborne geophysical survey by Geotech Ltd. for Exploration Syndicate Ltd., a private mining company.

In November, 2013, after purchasing the survey data, Yukon Geological Survey released the Selwyn Basin ZTEM data set to the public.

These data were first compared to the known geology and mineral resources, and analyzed from an Explorer’s Perspective in a study by Carne et al. (2013) at YGS AEM Workshop in Yukon and Witherly (2014) at PDAC in Toronto.

That analysis forms the basis for the results presented in our paper.
ZTEM passive helicopter AFMAG EM and aeromagnetic survey of Selwyn Basin was flown between May to October, 2008.

- Consisted of 24,675 line-km of coverage using 1000 line-spacings and 500m in-fills.
- ZTEM tipper data (Tzx in-line & Tzy cross-line) were acquired at 5 frequencies (30-360Hz) and Total Field Magnetics.
- One of Few large AEM-Magnetic data sets publicly available in Yukon Territory.
Selwyn Basin Regional Airborne ZTEM-Magnetic Survey

- ZTEM-Magnetic Survey flown between May to October, 2008.

- ZTEM SURVEY: 24,675 line-km flown
- 500-1000km line-spacing
- Tzx+Tzy @ 30-360 Hz
- Magnetic TMI
Selwyn Basin Geology

Geographical Selwyn basin – 4 main stages in its development

1) NeoP-Lwr. Palaeozoic “passive” margin – “Selwyn Basin”
2) Lwr. Dev. – mid Miss. Turbidite basin (Earn Group)
3) Mid-Mississippian-Triassic clastic shelf
4) Cordilleran orogeny – deformation, intrusion, metamorphism

- Older syn-sedimentary mineralization in Palaeozoic extensional basins (Pb, Zn, Ba, Cu, Ag)
- Younger intrusion/deformation related mineralization during Mesozoic Cordilleran orogeny (Au, W, Mo, Ag, Cu)

Paleozoic syngenetic mineralization

- SEDEX deposits in Cambrian-Ordovician shale
- Anvil District (Faro):
  - Total of 120 Mt of Zn-Pb ore in 5 deposits
  - Hosted in Cambrian strata – at contact between Mount Mye and Vangorda formations
- Howards Pass (Selwyn Project):
  - Nearly 400 Mt of Zn-Pb ore
  - Hosted in Active member – top of Duo Lake Formation (Ordovician-Silurian)

Selwyn basin stratigraphy – E-W profile

Intrusion-related mineralization

- Wide-spectrum of intrusion-related mineralization in Selwyn basin (Au, W, Ag)
- Au mostly associated with post-arc 90-97 Ma plutons

(after Moynihan, YGS AEM Workshop, Nov-2013)
Selwyn Basin Geology

Selwyn Basin is a NW trending Paleozoic deep water sedimentary basin mainly composed of Ordovician to Devonian black shales and cherts. Selwyn Basin rocks were deformed-metamorphosed during the Mesozoic, lead to Intrusions in Cretaceous. Except for fold and thrust deformation and metamorphism to greenschist facies, Selwyn Basin is relatively well preserved.
Cretaceous Granitic Intrusions

- Cretaceous Granitoid Intrusions also occurred during the Mesozoic Event.
- Outlines from YGS Mineral Digital Record.
The Selwyn Basin total magnetic intensity (TMI) shows the strong correlation between prominent magnetic anomalies and mapped Cretaceous granitoid intrusions.
In spite of their low magnetic susceptibility, the intrusions cause magnetic hornfels in surrounding rocks from related contact metamorphic pyrrhotite.
ZTEM apparent conductivity was obtained by applying the VTEM transform of Becken and Pedersen (2003) to the In-phase tipper data.
Comparing this image to the geology reveals prominent circular resistivity highs (blue) and surrounding these are conductivity highs associated with igneous intrusions and the related magnetic and porphyry-rich metamorphic aureoles.
Comparing this image to the geology reveals prominent circular resistivity highs (blue) and surrounding these are conductivity highs associated with igneous intrusions and the related magnetic and porphyry-rich metamorphic aureoles.
ZTEM apparent conductivity also shows correlation between ZTEM conductive horizons and the locations of mapped faults in the district, which were not revealed in the magnetic results.
Outlines drawn around the main ZTEM apparent conductive horizons suggest the existence of major NW-SE trends within the Selwyn Basin that, at first, do not appear to be related to bedrock geology.
More Significantly, Mineral Occurrences are clearly aligned along these major AEM conductive trends—none of which were apparent or visible in the magnetic results.
Silurian Sedex Zn-Pb (Ba)

Deposit or Significant Prospect
Drilled Prospect
Significant Showing

Ross River

250,000mE 300,000mE 350,000mE 400,000mE 450,000mE 500,000mE 550,000mE

mS/m

7,050,000mN

7,000,000mN

6,950,000mN

6,900,000mN

NWT

YUKON

0 25km
Lower-mid Devonian Sedex Ba

Deposit or Significant Prospect
Drilled Prospect
Significant Showing
Upper Devonian Sedex Zn-Pb-Ba

SEG GEM Workshop - Chengdu China - 19-22 April, 2015

Deposit or Significant Prospect
Drilled Prospect
Significant Showing

Ross River

Canol Road

NWT

YUKON

250,000mE 300,000mE 350,000mE 400,000mE 450,000mE 500,000mE 550,000mE

6,900,000mN 6,950,000mN 7,000,000mN 7,050,000mN

6,900,000mN 6,950,000mN 7,000,000mN 7,050,000mN

7,050,000mN 7,000,000mN 6,950,000mN 6,900,000mN

mS/m

- Sedex Ba
- Sedex Ni-Mo
- Sedex Zn-Pb (Ba)
- Mineral Occurrence
Cretaceous Vein Ag-Pb

Deposit or Significant Prospect
Drilled Prospect
Significant Showing

GEOTECH
AIRBORNE GEOPHYSICAL SURVEYS

250,000mE 300,000mE 350,000mE 400,000mE 450,000mE 500,000mE 550,000mE

Ross River

Ross River

YUKON

NWT

Canal Road

mS/m
Cretaceous Intrusive related Au

Deposit or Significant Prospect
Drilled Prospect
Significant Showing
Tertiary Carlin type Au

Deposit or Significant Prospect
Drilled Prospect
Significant Showing

Ross River
Canol Road
NWT
YUKON

6,900,000mN
6,950,000mN
7,000,000mN
7,050,000mN

250,000mE
300,000mE
350,000mE
400,000mE
450,000mE
500,000mE
550,000mE

mS/m

GEOTECH
AIRBORNE GEOPHYSICAL SURVEYS

SEG GEM Workshop - Chengdu China - 19 - 22 April, 2015
Showings and Geology

Deposit or Significant Prospect
Drilled Prospect
Significant Showing
Based on the EM skin depth of investigation estimates, these ZTEM signatures relate to bedrock features extending to depths of 1km or more and are therefore unlikely to be related to surficial overburden origins.
If these ZTEM trends are in fact related to deeper basement structures, the alignment of deposits are likened to the research of Arehart et al. (2013) who identify close similarities in the genesis between the Carlin-type gold deposits in Nevada and Yukon.

(From Arehart et al, 2013)
Rodinia Super-Continent @ 700 Ma

- This inference is based on their alignment in the Rodinia supercontinent 700 Ma previous.

(from Arehart et al, 2013)

(formation of “passive” margin on West side of N.A.)

(from Moynihan, YGS AEM Workshop, Nov-2013)
Given the importance and recognition of aligned mineral trends in Nevada, the identification of similar possible AEM defined basement trends could also be significant guides to exploration in Yukon’s Selwyn Basin.
Showing Similarities between ZTEM responses from Porphyry Copper deposit Alteration Halos in Western Cordillera and....

- Hornfels Alteration around Cretaceous Intrusions and with Pb-Zn skarn deposits in Selwyn Basin.
Conclusion

- A ZTEM passive helicopter AFMAG EM and aeromagnetic survey of the Selwyn Basin, consisting of 24,675 line-km of coverage at 1000 line-spacings and 500m in-fills, was flown between May to October, 2008.

- The Selwyn shale-chert Basin is best known for its world-class Pb-Zn-Ag SEDEX (sedimentary exhalative) deposit potential, hosting twelve major deposits, including the giant Howards Pass deposits at 180 Mt (Selwyn-Chihong Mining Ltd.).

- Analysis of the regional passive AEM-Magnetic results in Selwyn Basin from an explorer’s perspective has highlighted a strong correlation between regional ZTEM conductive trends and the distribution of mineral occurrences in the region, which were not visible in the regional Magnetics.
Conclusion

- Because these potentially deep (>1km) AEM signatures represent possible basement structural controls, this also points to genetic similarities between Carlin-style gold deposits in Yukon and Nevada, where regional deposit trends are also well recognized.

- Similarities between zoned ZTEM signatures related to Cretaceous skarns in Selwyn Basin and porphyry copper deposits in Western Cordillera are also highlighted.

- These underline the potential importance of AEM defined structural and alteration trends for future exploration in Selwyn Basin and similar applications of deep penetrating AEM in other geologic environments around the world.
Regional Airborne EM and Magnetic Surveys in Selwyn Basin – An Explorer’s Perspective

By: Rob Carne (ATAC Resources Ltd., Vancouver CAN) Jean M. Legault* (Geotech Ltd., Aurora CAN) Richard Phillips and Julia Lane (Archer Cathro & Associates, Vancouver CAN)

“THE TREND IS YOUR FRIEND”

谢谢大家

Our Thanks to:

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Archer Cathro Associates
Geotech Ltd.
Ken Witherly – Condor Consulting
Yukon Geological Survey
SEG GEM Workshop Technical Committee

Presented at GBWC Mining Geophysics Short Course at GSN 2015
Reno NV, May 14-24, 2015
SAM (Sub-Audio Magnetics): High resolution and deep exploration case studies

Dennis Woods, Discovery International Geophysics
Scott Napier, Mira Geosciences
Mal Cattach, Gap Geophysics Australia
Glen Chubak, Discovery International Geophysics
Jonathan Rudd, Discovery International Geophysics

SAM (Sub-Audio Magnetics) is a proprietary electric/electromagnetic technique, developed by Gap Geophysics Australia, which uses a high-sensitivity cesium vapour magnetometer to measure the electromagnetic fields due to electric current flow in the ground. The source of the currents can be a grounded bipole (galvanic mode), or a large transmitter loop (inductive mode). The system allows very fast and highly detailed, continuous data acquisition from the ground or from a helicopter towed bird. The system has been in operation for 2 decades in Australia and has had considerable success mapping resistivity variations to high resolution and at depth beneath highly conductive cover such as salt pans.

We present the system and show data examples from mineral, and oil and gas exploration in western Canada. An inductive source, heli-SAM EM case study is presented over the Lalor Zn-Cu-Au VMS deposit: a 700 to 1200 m deep, massive sulphide, conductive ore body near Snow Lake, Manitoba. Inversion of the total field, magnetic component, transient EM data successfully outlines ore lenses to over 1000m depth. A forward modelling study is also presented that demonstrates that the galvanic SAM system is capable of mapping, beneath highly conductive shale cover, and with high resolution, important geological features of athabasca oil sands, including cross-cutting Quaternary channels and some types of lithofacies variation within the McMurray formation.
SAM (Sub-Audio Magnetics) for Mineral Exploration and Detection and Delineation of Bitumen Deposits

Dennis Woods
Scott Napier
Mal Cattach
Glenn Chubak
Jonathan Rudd

Discovery International Geophysics Inc.
Mira Geoscience Ltd.
Gap Geophysics Australia Pty Ltd.
Discovery International Geophysics Inc.
Outline

1. Introduction to the SAM system

2. Mineral exploration data examples
   - Grounded electric dipole - gold exploration Australia
   - Inductive loop - Lalor VMS deposit

3. SAM detection and delineation of bitumen deposits
   - Forward modelling examples
SAM system: Introduction

- Sub- Audio Magnetics (SAM)
- Proprietary electrical / EM survey technique patented, 1991
- Transmitter: large grounded electric dipole or loop transmitter with 50 percent duty cycle square wave at 4-8 Hz
- Measurement of the magnetic total field with a high sensitivity cesium vapour magnetometer
  - Ground
  - Airborne
- System in operation for 2 decades in Australia
- Demonstrated success mapping conductivity variation beneath conductive cover including conductive regolith and salt pans
SAM system: Survey configuration

- Inductive loop source
- Grounded electric dipole
SAM System: Transmitter electrode

- Wire mesh or aluminum foil electrodes in trenches
- Salt water can be added
SAM System: Transmitter

- Trailer based diesel motor generator
- Electronics to control waveform
- Safety systems
SAM System: Receiver

- Cesium vapour total field magnetometer
Measurement of magnetic total field (TF) anomalies

If $|B_0| >> |B_a|$ then

Measured field $|B|$ is approximately given by

$$|B_0 + B_a| \approx B_0 \cdot B_a$$
SAM data example

Magnetic survey

Resistivity (MMR)
Electromagnetic (EM)
*Induced polarization (MIP)
SAM data: temporal component processing

![Observed SAM Waveform](image)

**MMR**
**EM**
**IP**

- TFMMR Integration Area
- TFEM Sampling Area
- TFMMIP Integration Area
SAM TFMMR data processing workflow

- Measure TF magnetic data
- Spatial filtering to isolate temporal component
- Isolate MMR signal
- Compensate/Remove the magnetic field due to the transmitter wire.
- Compensate/Remove the magnetic field from the current entering the ground
- TFMMR anomaly shapes are dependant on the direction of the earth’s field
  - Anomaly shape dependant on location of the survey and date of survey
  - Can be difficult to interpret
- Perform Magneto-Metric Conductivity (MMC) transform to locate the conductors under MMC highs
  - Similar processing step to reduction-to-pole (RTP) filter of magnetic data
Outline

1. Introduction to the SAM System

2. Mineral Exploration Data Examples
   - Grounded electric dipole - Gold exploration Australia
   - Loop - Lalor VMS deposit

3. SAM Detection and Delineation of Bitumen Deposits
   - Forward modelling examples
SAM field data example:

Data example provided courtesy of Gold Road Resources Ltd.

Target resource is greenstone gold in Western Australia

Three Grounded electric dipole transmitters operating at 10-25 Amps

Data collected on ground (on foot) in overlapping grids and processed and merged
SAM field data example: Gold exploration in Australia
SAM field data example: Gold exploration in Australia
SAM field data example: Gold exploration in Australia
SAM field data example: Gold exploration in Australia

Magnetic Survey

SAM EM Ch 12  21.6ms

1.0 km
SAM field example – Lalor deposit

Collaboration - Gap Geophysics Australia and Discovery Int’l Geophysics with the permission of Hudbay

Surveyed in August, 2014, following a commercial HeliSAM project in Alberta
The Lalor VMS Deposit

The largest deposit of the Snow Lake camp at almost 30 Mt, comprising:

- **Reserves** - 14.4 Mt grading 1.86 g/t Au, 24 g/t Ag, 0.6 wt% Cu and 7 wt% Zn
- **Resources** - 12.6 Mt grading 3.85 g/t Au, 27.3 g/t Ag, 0.9 wt% Cu and 2.3 wt% Zn

Three zones of alteration/mineralization

- Zinc-rich, closest to surface
- Cu-Au rich, deepest portion
- Au-rich, between the other two zones
HeliSAM mag
HeliSAM EM

Channel 2: 0.833 ms
HeliSAM EM

Channel 5: 2.292 ms
HeliSAM EM

Channel 6: 2.708 ms
HeliSAM EM

Channel 8: 4.375 ms
HeliSAM EM

Channel 9: 5.833 ms
Channel 11: 9.375 ms
HeliSAM EM

Channel 12: 11.458 ms
HeliSAM EM

Channel 13: 14.375 ms
HeliSAM EM

Channel 16: 27.708 ms
Outline

1. Introduction to the SAM System

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   - Grounded electric dipole - Gold exploration Australia
   - Loop - Lalor VMS deposit

3. SAM Detection and Delineation of Bitumen Deposits
   - Forward modelling examples
SAGD method

Steam Assisted Gravity Drainage (SAGD)

Oil sands in situ recovery method for locations where McMurray formation is typically 100m + depth

Method is dependant on impermeable caprock (Clearwater shale) to contain the steam chamber

Clearwater Shale is a highly conductive unit

Using geomechanics to predict reservoir caprock integrity
Electrical and Electromagnetic methods in the oil sands

- Electrical and Electromagnetic methods in oil sands rely on the difference between the electrical resistivity of the bitumen saturated sand (McMurray) and the surrounding and overlying sediments and sedimentary rocks.

- Previous EM techniques effective in the near surface and under shallow cover:
  - Electrical Resistivity Tomography (ERT)
  - Airborne or Ground EM – TEM and Frequency Domain data

- At SAGD depths, with a thick package of conductive caprock overlying the bitumen, these methods lack resolution on underlying resistive formations.
Advantages of the SAM system

- **Advantages over ERT**
  - Highly accurate measurement can be made with sensor in motion
  - Anomalous magneto-static (MMR) fields of the target anomalies are not attenuated by conductive cover (unlike electric fields measured in ERT)

- **Advantages over airborne EM**
  - Grounded electric dipole produces current channeling anomalies (line currents) where loop based airborne EM tends to generate vortex currents
  - The signal fall-off rate with source depth of a line-current is less than that from a vortex current as typically induced by a loop based EM system
  - SAM operates at a lower base frequency than currently practical with AEM systems
SAM feasibility study for SAGD

**Objective**
- Show that SAM data can produce interpretable results for geological scenarios of interest to SAGD operators
- Show that data responses are above typical system noise levels

**Methodology**
- Use Electromagnetic modelling program EH3D - Frequency domain 3D finite volume based EM modelling code
  - Developed by UBC-GIF
- For simplicity we propose to forward model only the contribution of the fundamental frequency of the transmitter waveform (4 Hz)
- Scale responses by amplitude of the fundamental harmonic for a square wave for comparison to expected S/N levels
  - This provides a conservative estimate of anomalous responses
Lithofacies model example: Conceptual lithofacies model

Modified from Lithofacies Identification and the Implications for SAGD Well Planning in the McMurray Formation, Christina Lake Area, Alberta: Presented at the Annual Conference of the Canadian Society of Petroleum Geologists
Lithofacies model example: Statoil’s Leismer project

From AER report, 2013, Leismer SAGD Annual D-54 Performance Presentation
Lithofacies model example: Statoil’s Leismer project

- Channel shape inferred from an area of zero net bitumen thickness

Modified from (AER report, 2013, Leismer SAGD Annual D-54 Performance Presentation).
Lithofacies model example: Geological Modelling

- Cutaway showing McMurray top (yellow)
- Wabiskaw mud channel (grey) is 30m thick
- Oil-water contact (blue)
## Forward Modelling: Estimation of resistivity

<table>
<thead>
<tr>
<th>Geological Unit</th>
<th>Nominal Thickness [m]</th>
<th>Estimated Resistivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>All units above Clearwater (including Quaternary)</td>
<td>100 m</td>
<td>50 Ωm</td>
</tr>
<tr>
<td>Clearwater</td>
<td>80 m</td>
<td>5 Ωm</td>
</tr>
<tr>
<td>Wabiskaw</td>
<td>10 m</td>
<td>3 Ωm</td>
</tr>
<tr>
<td>McMurray Oil saturated</td>
<td>30 m</td>
<td>2000 Ωm</td>
</tr>
<tr>
<td>McMurray Water saturated</td>
<td>30 m</td>
<td>200 Ωm</td>
</tr>
<tr>
<td>Devonian Limestone</td>
<td>basement halfspace</td>
<td>5000 Ωm</td>
</tr>
</tbody>
</table>
Lithofacies model example: Discretization

- Discretize the geological model
- Assign estimated resistivity to each unit
Lithofacies model example: Magnetometric Conductivity (MMC) data

N-S oriented dipole Tx

E-W oriented dipole Tx
Lithofacies model example: combined magnetometric conductivity (MMC) data

- Shape of the superposed MMC data closely matches the channel shape
- MMC high over the conductive mud channel
- Amplitude of the anomalous response is more than 150 pT for this example
  - Assuming 6 Amp transmitter current
- Typical system noise floor for the SAM system is estimated at 15 pT.
Conclusion

- SAM is a proven system which provides a rich dataset combining some of the efficiency of airborne systems with the depth penetration of ground based systems.

- SAM has been demonstrated to be effective in mineral exploration examples both in Australia and in Canada.

- We have demonstrated using forward modelling examples that the SAM system is capable of mapping important geological features in the Athabasca oil sands. These include quaternary channels, lateral oil/water boundaries and electrically distinct lithofacies variations within the McMurray formation at 200m depth.
  - The forward modelling investigation is ongoing. Based on physical arguments we anticipate positive results when the depth of the McMurray formation is 400m or less.
Acknowledgements

The authors would like to thank Gold Road Resources Limited for the example SAM GED dataset along with Discovery Geophysics, GAP Geophysics and Hudbay Mining for the loop based SAM dataset AER and all SAGD operators for making the annual SAGD progress reports and other background materials publically available.

Shannon Frey of Mira Geoscience assisted with the geological modelling for the two channel examples

SAGD conceptual image from Schumberger’s website
References


HeliSAM EM

Channel 16: 27.708 ms

Questions?
Geophysical signatures of Carlin systems formed along the northern margin of ancient North America

Kenneth Witherly, Condor Consulting

Carlin type gold deposits were first recognized in Nevada in the 1960s and in the mid-2000s, similar deposits were identified in the Yukon. Geophysical techniques have generally not been regarded as primary exploration techniques for Carlin type deposits but with the advent of modern helicopter time domain EM and Afmag systems, it now seems possible to better map some of the key attributes of Carlin systems, namely major structures and wide spread but usually selective alteration that is often associated with Carlin deposits.

Helicopter time domain (HeliTEM & VTEM) and ZTEM (Afmag) data have been acquired over two properties which show strong Carlin-type attributes, the Rackla Belt in the Yukon and Cortez Hills property in the Battle Mountain trend, a well-recognized belt of Carlin-type deposits in east-central Nevada. High resolution aeromagnetic data is also available for both areas. The geophysics for the two areas are assessed in light of surface geological mapping and diamond drilling. Ground geophysics in the form of magnetics and gravity were also available at Cortez Hills.

At the Cortez Hills property, the assessment was complicated by the presence of the Northern Nevada Rift East that underlies the property. This is a major crustal lineament and is characterized by a strong magnetic high. Modeling of the data suggests the source is likely 1.5 -2 km below the current ground surface. This leaves enough Carlin-favorable stratigraphy to host a deposit but adds to the overall complexity of the geophysical responses. Major N-S and NE-SW trending structures were recognized in the survey results, with the NE-SW structure linking the property to the major Goldrush deposit located several kms to the west.

In the Rackla, the eastern end of the recognized belt has deposits with a clear Carlin style affinity. These the ZTEM magnetics and EM data outline major structures that appear to both bound and cross-cut the known zones of mineralization. Along strike to the west 100 kms, the style of mineralization has become more epithermal and both ZTEM and VTEM provide information about structures and potential mineralized zones that are more conductive than is observed further to the east.
Geophysical signatures of Carlin systems formed along the northern margin of ancient North America

Rodinian supercontinent ~700 Ma just before breakup-after Hoffman 1991
700 million years ago..........Now

Present day NA; GB and major Carlin deposits highlighted
Great Basin
GB and basic geological/structural overlay-Tectonic element map of Nevada and surrounding parts of the Great Basin showing location of Carlin-type deposits (red dots) and Paleozoic bedded barite deposits (green dots). Inferred continental crust (gray) is shown east of the SrI = 0.706 line (yellow) with accreted terranes to the west (light blue) and the Mesozoic magmatic arc (green). Lead isotope provinces of Zartman (1974) are shown in orange. The boundary between inferred Archean and Proterozoic crust is shown by the wavy blue line. Roberts Mountains thrust (RMT) and Sevier thrust (ST) are shown for reference. The area of Tertiary extension and direction of extension is shown in random dash pattern and gray arrows. Pink areas are exposed core complexes. Major linear arrays of Carlin-type deposits are Carlin trend (CT), Jerritt Canyon (JC), Getchell trend (GT) and Battle Mountain-Eureka trend (BME; also known as the Cortez trend).
YK; Terrane map of Yukon showing major crustal features (after Colpron and Nelson, 2011). Carlin-type occurrences are on the northern and eastern margin of the Selwyn basin and are shown by the red stars and include: Brewery Creek (BC); the Rackla belt (RB) that contains several occurrences including Osiris, Conrad, and Anubis; the adjacent Anthill Resources prospects (AR, including the Venus zone); and the Brick-Neve prospect (BN). Green dots show occurrences of sedimentary barite in Selwyn basin. DT = Dawson thrust; RFA = Richardson fault array; RST = Robert Service thrust; TT = Tombstone thrust. SrI = 0.706 line for Mesozoic granitoids after Armstrong (1988). Areas underlain by Stikinia (ST) and southwest of Denali fault have SrI < 0.704.
Carlin Deposits – Section across shelf thrusting

- Deep water sediments
- ‘Upper Plate’
- Roberts Mtn Thrust
- Limestones
- ‘Lower Plate’
- Transitional sediments
- Oceanic crust
- Mantle
- Archean crust
Carlin Deposits – Section across shelf collapse

- Oceanic crust
- Partial melting
- Limestones
- Archean crust
- Mantle

A Jackson-2012
Carlin Deposits - Mineralization

- Later fluids had neutral pH, 120-250°C
- Fluids filled porosity with quartz and pyrite.
- Gold introduced during one brief pulse towards the end of the event at ~40Ma and deposited as very fine grains in arsenic-rich pyrite (and other arsenic minerals).
Carlin Deposits – Mineralization

- Mineralization occurs as veins in original old faults and disseminated in favorable porous carbonate beds - ‘Christmas tree’ effect
Carlin Deposits - Genetic Model

- Displaced Leakage Anomalies
- Extensional Reactivation of RMT
- Impermeable Reservoir
- Post-mineral Detachment Fault That Roots into Thrust Fault
- Folds in Plate Area by Inversion
- Pre-Antler Normal Fault
- Pinning of Deformation by Stock
- Metamorphic Contact Aureole

A Jackson - 2012
Carlin Deposits – Exploration

Exploration targeting:
- In Carlin or Cortez ‘corridors’
- Within 500m of long-lived, inverted, crustal scale faults
- Often, but not always, within 1km vertically below the Roberts Mountain Thrust
- Within 1km of Eocene (~42Ma) intrusions
- In fault-related hanging-wall anticline (+/- carbon)
- In dirty carbonate host rock with de-calcification (gravity low)
Carlin Deposits – Exploration

• Several phases of exploration:
  – Early exploration focused on outcropping lower plate carbonate rocks with oxide ore.
  – Deeper sulfide portions of known deposits.
  – Areas under shallow upper plate gravels cover.
  – Now turning to blind deposits under deep gravels or upper plate rocks.
  – Future discoveries likely to be:
    • deep in Lower Plate rocks
    • covered by barren Upper Plate rocks
    • in valleys, covered by 100s or 1000s of feet of gravel.
Yukon Geology

Rackla belt

- Located at SE apex of Ogilvie platform (aka Yukon Stable Block)
- Junction of Selwyn basin and Richardson trough
- Region characterized by abrupt facies transitions and intermittent Neoproterozoic-Paleozoic tectonism (extension)
- Richardson trough is a long-lived early Paleozoic feature
- Antecedent in Neoproterozoic?

Maurice Colpron, David Moynihan, Steve Israel and Grant Abbott; Yukon Geological Survey; Round Up 2013/2015
Yukon Geology

Dawson thrust zone

Selwyn basin

Yukon stable block

(Wernecke Mtns)

Hyland Group

Paleo- and Mesoproterozoic "basement"

(Wernecke Supergroup,
Hart River basalt, Pinguicula Gp
Hematite Creek Gp)
Yukon Geology

Maurice Colpron, David Moynihan, Steve Israel and Grant Abbott; Yukon Geological Survey; Round Up 2013/2015

- 5 main stratigraphic domains
- 2 major structures: Dawson and Kathleen Lakes faults; both appear to lose displacement to the east
- Hanging wall of Dawson thrust – Selwyn basin strata:
  - Neoproterozoic Hyland Group
  - Devonian-Mississippian Earn Group
  - Miss. Tsichu Gp; Permian quartzite/shale
  - Triassic sills
Yukon Geology

CONRAD SECTION 450 E
Looking West

SILSTONE

CONRAD UPPER ZONE

MUDSTONE

WADALEEN FAULT

CONRAD LOWER ZONE

LIMESTONE

Previously Reported Intersections

<table>
<thead>
<tr>
<th>Hole</th>
<th>Width (m)</th>
<th>Gold (g/t)</th>
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<td>OS-11-010</td>
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Mineralized intersection Oct. 7, 2014
Previously drilled intersection
< 20 gram/metre intersection
Mineralized zone
Drill hole goes off section
Fault
Drill hole projected to section

True widths for all reported Conrad drill holes are estimated to be 60 - 100% of intersected widths.
Great Basin Examples
Cortez Summit

Geology
Geology

Cortez Summit

EXPLANATION

- Tb: Basaltic Andesite
- Td: Diorite dikes
- Tg: Gravels undivided
- Tgp: Paleozoic clast gravels
- Tr: Rhyolite
- Tri: Rhyolite intrusive
- Ji: Quartz monzonite
- RMA: Roberts Mountains Allochthon (includes some Dhc)
- Dhc: Horse Canyon Formation
- Dw: Wenban Formation

Scale 1: 12500

Gold reported in drill hole

Deposit
Cortez Summit  Drilling + Gravity 1st VD
Cortez Summit

Gravity-1\textsuperscript{st} VD
Cortez Summit

RTP/180 Hz DT/30 Hz AppCon/AdTau
Geology map from Martin and Naumann, 1995.
Bouguer gravity
ZTEM 90 Hz TPR

Reveille
Freiberg

Geology
Freiberg
The magnetic response shows shallow E-W trending body that appears to extend to depth to the north, east and south of the study area (green color). The western and eastern outcrop lines both appear to line up with magnetic gradients, suggesting possible fault contacts. The mapped intrusives both appear to be associated with shallow magnetic responses. A 3D model of the magnetic response will be helpful to define the likely contact between magnetic (intrusive) rocks and the overlying sediments.
Freiberg  Gravity + 30 Hz TPR contours

This shows the 30 Hz IP TPR as contours and the gravity; there is a very good correlation between these two results.
Gravity-horizontal gradient

Gravity hor grad response
Intrusives (white) claims (orange) thrusts (black) outcrop (light blue)
ZTEM shows area of outcrop as central high resistivity zone (cool color). Major basin fault appears as arcuate trend on eastern side (correlates with gravity gradient trend).

Good correlation between ZTEM linears and mapped/inferred faults. On west side, outcrop line corresponds closely with ZTEM gradient edge.
Freiberg

ZTEM 90 Hz TPR

ZTEM 90 Hz IP TPR result.
Similar to 30 Hz results.
Terrain

Rackla
Rackla

Ore Zones + As in soil

[Image of a geological map showing ore zones and arsenic concentrations in soil]
The TMI-Tilt image was found to have the best detail of the various filtered products; however, the dynamic range of the data is small.
Rackla

This series of images highlights the EM and magnetic response over the focus area.
This ZTEM image shows large conductive body designated C1 which has a well-defined arm to the NW (C1NW) and a more subtle arm to the (C1NE). The major zone of drilling is in effect in a ‘cup’ formed by the two arms. The major N-S faults F1 and F2 do not appear to have much of an expression in the geophysical image.
This is a depth slice from the ZTEM 3D model @ 200 m depth. This also shows the major conductivity zone C1 with arms C1NW and possibly C1NE. The eastern edge of the C1 feature appears to be conformable with the fault F2 but is off-set to the west.
This is the TMI-Tilt image. Two magnetic features are circled with a red-dashed circle that show the N-S faults F1 and F2 cross these features with no apparent change in the magnetic character.

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This series of images highlights the 3D EM response around focus area. The Conrad deposit appears associated with a small conductive zone extending up from a NE trending linear marked with a red double arrow headed line.
This view looks at the zones on their side; the conductive ‘flower’ that Conrad is associated with is highlighted with the yellow arrow.
This shows the Mag3D model with the top of ‘wall’ north of the deposits highlighted with a double-headed red arrow. Conrad is circled with a dashed red outline. Note while the thrust implies a flattish dip, the mag model comes up as quite steep.
This series of images highlights the EM and magnetic response over the focus area.
This series of images highlights the EM and magnetic response over the focus area.
Acknowledgments

Bob Thomas-Carlin Gold
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David Moynihan-Yukon Geological Survey
Case studies of exploration geophysics at McCoy-Cove

Chad E. Peters, Mia O’Neal and Warren F. Thompson
Premier Gold Mines Ltd., Battle Mountain, NV

The McCoy-Cove Property is located approximately 35 miles south of Battle Mountain in Lander County, Nevada along the prolific Battle Mountain/Eureka gold trend. The property lies approximately 11 miles south of Newmont’s Phoenix mine and is unique to Nevada in that it hosts Au-Ag skarn, polymetallic vein type Au-Ag-Pb-Zn and “Carlin Style” distal disseminated Au-Ag.

Echo Bay Mines, Ltd. conducted large scale open pit and associated underground mining at McCoy-Cove from 1986 to 2001 producing 3.3 million ounces Au and 110 million ounces Ag. Production was greatest from the polymetallic vein type and distal disseminated ore at Cove, with lesser production from McCoy skarn. Multiple generations of both air and ground magnetic (Mag), induced polarization (IP) gravity, controlled source audio magneto-telluric (CSAMT) and radiometric surveys were completed by Tenneco Minerals Corp., Echo Bay Mines Ltd., Newmont Mining Corp. and Premier Gold Mines Ltd. from 1980 to present, with the earliest focus being the McCoy skarn deposit. Each survey method was successful in adding to the geologic interpretation of the property, whether highlighting potential sulfides with the IP, or intrusive bodies with the magnetics. However, the 1987 IP survey was instrumental in highlighting a strong chargeability anomaly showing excellent correlation to strongly anomalous soil geochemistry that was responsible for the 1986 discovery of the Cove deposit. In June 2012, Premier purchased the Victoria Resources lease agreement at Cove and continued exploration drilling at the Helen Zone while completing a property wide gravity survey in efforts to further define the McCoy-Cove structural model. Premier subsequently acquired 100% of the McCoy-Cove property from Newmont in September 2014 and completed 3 lines of deep-seeing IP to follow up on a 1991 Echo Bay IP anomaly below the McCoy pit. The survey identified a significant chargeability high between the McCoy and Cove pits at a vertical depth of 1300-2500 ft. (400-800m), with follow up drilling planned for Q2 2015.

Multiple generations of geophysical data has been useful in past and present exploration success in the McCoy-Cove district. When used in conjunction with exploratory drilling, geochemistry, and field mapping data, it has proven to be a powerful tool for geologic interpretation and continues to drive Premier’s exploration strategy throughout the property.

Key words; induced polarization, magnetics, controlled source audio magneto-telluric, gravity, radiometric, skarn, polymetallic vein, “Carlin Style” distal disseminated
Proven Management – Proven Districts – Safe Jurisdictions

Case Studies of Exploration Geophysics at McCoy-Cove

Chad E. Peters, Mia O’Neal, Warren F. Thompson
This presentation may contain "forward looking information" within the meaning of Canadian securities legislation, which are based on the opinions and estimates of management and are subject to a variety of risks and uncertainties and other factors that could cause actual events or results to differ materially from those projected in the forward looking information. Such risks and uncertainties include, but are not limited to, risks associated with the mining industry, the risk of commodity price and foreign exchange rate fluctuations, the ability of Premier to fund the capital and operating expenses necessary to achieve the business objectives of Premier, as well as those risks described in public disclosure documents filed by Premier. Due to the risks, uncertainties and assumptions inherent in forward-looking information, prospective investors in securities of Premier should not place undue reliance on these forward-looking information.

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Stephen McGibbon, P. Geo., (Executive VP Corporate and Project Development) is the Qualified Person for the information contained in this presentation and is a Qualified Person within the meaning of National Instrument 43-101.

For further information on the technical data provided in this presentation, refer to the Sedar filings as listed below:

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<th>Note</th>
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<th>Company</th>
<th>Date</th>
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<tr>
<td>(1)</td>
<td>Helen (Cove)</td>
<td>Premier Gold Mines Limited</td>
<td>January 2, 2014</td>
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<tr>
<td>(2)</td>
<td>Helen (Cove)</td>
<td>Victoria Gold Corp</td>
<td>May 5, 2011</td>
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Property Location

- Property located 35 miles south of Battle Mountain on Hwy 305
Land Package

- 12,400 hectare property position
- Past-production of 3.3 Moz Au and 110+ Moz Ag between McCoy and Cove
Stratigraphy

- 245 to 230 ma Triassic carbonate and clastic sedimentary rocks sequenced over Golconda Allochthon
Simplified Geologic Map

- TR – Triassic sedimentary rocks (blue)
- Tv – Cove tuff (magenta)
- Jv – Jurassic McCoy Pluton (purple)
- Tg – Eocene Brown Stock (orange)
- Qal – Quaternary Alluvium (beige)
Faults

- Complex structural fabric provides fluid pathways for mineralization
Folds
• Intersection of anticline/fault structures leads to multiple deposits
Mineralization Styles

Skarn at McCoy Au-Ag, 300-700°C
- Adjacent to 38-42ma Eocene Brown stock
- Exoskarn in limestone, limestone/conglomerate contacts, stratabound beds
- Endoskarn within Brown stock

Polymetallic sheeted sulfide veins Au-Ag ± Zn-Pb, 225-375°C
- Distal prograde porphyry phase
- Pressure fracture, inundation with acidic sulfide fluid
- Massive sulfide adjacent to neutralizing carbonate rock

Carlin-style distal disseminated Au ± Ag, 150-300°C
- Distal retrograde porphyry phase with argillic cap
- Channelization of fluids along argillized intrusive dikes/sills and favourable carbonate beds
- Decarbonatization and sulfidation of gold
Induced Polarization (IP)

• Completed between 1981-2014 by Tenneco, Echo Bay, and Premier Gold

Ground and Airborne Magnetics (Mag)

• Ground completed between 1980-2000 by Tenneco and Echo Bay
• Airborne surveyed in between 1994-2003 by Echo Bay and Newmont

Gravity

• Surveyed between 2003-2012 by Newmont and Premier Gold

Controlled Source Audio Magneto-Telluric (CSAMT)

• 16 lines surveyed in 1992 and 1993 but the data has not been processed

Radiometrics

• Surveyed in conjunction with airborne mag
1987 Echo Bay IP Lines

- 9 Lines completed
- Correlate strongly with soil sample anomaly that defined the 1986 Cove Pit discovery

Map of all IP lines surveyed on the property with 1987 IP lines yellow
Induced Polarization

Depth slice of merged 2D inversions at 300-500m with chargeability high beneath the Cove pit
1987 IP survey correlates very well with soil sample grid responsible for the 1986 discovery of Cove and yet undeveloped Helen and Windy Point deposits.
1991 Echo Bay IP Lines

- 9 lines completed around McCoy pit area
- Line 21 defined a 400-500 m deep by 900 m long anomaly beneath the McCoy pit
- Interpreted as sulfides associated with the Brown stock and surrounding sediments
Chargeability high beneath McCoy pit begins at approximately 400 m vertical depth. Array DpDp, a=800', n=1-8. Inverted chargeability values range from 0-35 msec Newmont M331 standard.
Residual airborne RTP overlain by inverted IP section correlates well with IP anomaly.
2014 Premier Gold IP Lines

- 3 lines completed to follow up on 1991 anomaly
- Line 2 and 3 extend the anomaly to the NW towards the Cove pit at similar elevation
- Interpreted as sulfides associated with the Brown stock and surrounding sediments

2014 IP lines, L1, L2, L3 in bold black

Modified from Wright Geophysics, 2013
Depth slice of merged 2D inversions at 400–800 m depth with chargeability high extending between McCoy and Cove pits.
Exploration Targets

• 1991 and 2014 IP anomaly is between 400-800 m vertical depth, almost identical to the 1987 IP anomaly defining the Cove pit

• Deep follow up drilling required along the Gold Dome/Bay structures between the McCoy-Cove pits to test anomaly

• Additional drilling recommended around margins of Brown Stock for deeper skarn mineralization
Four generations of ground mag surveys completed on the property
RTP ground mag highlights similar anomalies to airborne mag.
1996 and 2003 Airborne mag grid, N-S and E-W lines with 25 m gridding
RTP data highlights Cove tuff as major low
RTP data masked to exclude Cove tuff in order to highlight weaker anomalies within sediments
Exploration Targets

- **M1** - Highlights Brown Stock, correlates with deep-seeing 1991, 2014 IP surveys
- **M2** - High interpreted as dike filled N-NE Lighthouse fault with only shallow historic drilling
- **M3** - Anomaly beneath pediment interpreted as possible intrusive with only shallow condemnation drilling
- **M4** - Very faint anomaly along Hidden Valley fault
- **M5** - Magnetic high rimming northwest intrusive contact, interpreted as possible skarn mineralization in sediments adjacent to intrusive.
- **M6** - Located immediately NW of the Cove pit, tested with historic drilling which suggest high is likely related to Cove tuff
1611 gravity stations were surveyed in 2012
Residual gravity with interpreted trace of Cove anticline in dashed red.
Exploration Targets

• Intersection of N/NE structures with axis of Cove anticline produced the Cove and Helen deposits

• Gravity survey suggests the Cove anticline exhibits a minimum of two offsets to the NW with multiple exploration targets at intersection between N/NE structures and anticline
Equivalent K overlying geology with Cove tuff creating natural high and pit lake a low
Equivalent Th overlying geology with Cove tuff creating natural high and pit lake a low
Equivalent U overlying geology
Exploration Targets

- Cove tuff creates a natural radiometric high of no economic significance
- R1- low priority target highlighted by K, Th, and U data
- Soil sampling and mapping recommended in target area
CSAMT Survey

- 3 lines completed to follow up on 16 CSAMT lines were surveyed in 1992 and 1993
- The data is archived but hasn’t been processed

Modified from Wright Geophysics, 2013
Summary

• Induced polarization accurately identifies sulfide mineralization at McCoy-Cove
• Magnetics highlight the Eocene intrusives but can also create “false” anomalies
• Gravity defined the multiple offsets of the Cove anticline
• CSAMT hasn’t been processed and the Radiometrics did not generate any quality targets
• Combination of multiple geophysical methods with geologic data will lead to higher confidence targeting
Enhancing exploration drill success by integrating geophysical data

Jeffery Nichols, Newmont Mining Corp.
Joseph Becker, Newmont Mining Corp.

Newmont Mining Corporation’s exploration program across the Great Basin routinely integrates a variety of geophysical collection methods and its products are often a significant component of target vectoring both on the district and prospect scales. The continued discovery and expansion of Carlin-type sediment-hosted gold deposits (SHGD) remains one of the Company’s primary exploration goals, as evidenced by the substantial effort devoted to understanding how these deposits react geophysically through a number of case studies and training datasets. Unlike other mineral deposit types, the Carlin-type SHGD lack a correlative, empirical rock property that allows for direct geophysical detection and measurement. Newmont has recognized the value various techniques bring to delineating geologic structures and their intersections, as well as revealing the potential occurrence and shape of intrusive rocks which can be a critical component of a mineralizing system. As each project area progresses, a number of commercial and proprietary methods such as gravity, magnetics, magnetotellurics, induced polarization, and seismic reflection can be used on a fit-for-purpose basis. Throughout the entire process it is critical that these methods be constrained with the best available geologic information and reinterpreted as new information becomes available. This feedback loop and progressive refinement is an essential component for successful exploration in the outcropping montane and concealed pediment environments. The development of modern computers and powerful software has greatly simplified the collection, processing, and visualization of diverse data types, while also increasing the danger of over-processing and over-interpreting the data. Diligent communication and seamless integration between geophysicists, geochemists, and geologists is essential to prevent costly errors throughout the complex exploration process.