Exploration for Deep VMS Ore Bodies: The Hudbay Lalor Case Study

3D ore shells courtesy of Hudbay; inset courtesy of Mira Geoscience
Producing a Bright Future

Having completed the construction of Lalor and achieved commercial production at the Reed mine, we are seeing another wave of growth beginning in northern Manitoba.

Hudbay is a Canadian integrated mining company with a vision to become a top-tier operator of long-life, low-cost mines in the Americas.

TSX/NYSE: HBM

hudbayminerals.com
Robert (Bob) Frazer (1935 - 2014) was a pioneering Canadian geophysicist with a diverse career in mining exploration involved in projects around the world spanning the period 1960 to 2010. Bob's particular notable technical contributions were in the area of developing improved computer software for data capture and analysis, principally airborne and borehole EM.

Bob’s career centered on two periods (1960-65 and 1985-98 when he was employed by Hudson Bay Exploration & Development based in Toronto and Flin Flon, where his efforts as staff geophysicist and then Chief Geophysicist directly contributed to a remarkable number of discoveries, including the Namew Lake Nickel Mine in west-central Manitoba, and a number of economic polymetallic VMS deposits in the Snow Lake - Flin Flon camp (among them, the Chisel North Mine, Photo Lake Mine, Konuto Lake Mine, and Callinan ore lenses). His achievements in enhancing ground time-domain EM underpinned the EM methodologies used in the discovery of the deep 777 ore lenses and the Lalor mine, which have ensured that Flin Flon will remain a vital mining district for at least another decade.

During the period (1965 to 1970) when Bob was employed by St. Joe Minerals, he was also principally responsible for the discovery a new zinc deposit at the Balmat-Edwards Pb-Zn complex in upstate New York using resistivity surveys.

Bob, always very modest in characterizing his efforts and successes, was honoured for his major contributions to sustaining the economy of Flin Flon both by HBED and by the community in which he was actively involved. He was also honoured for his achievements at the 2010 KEGS breakfast in Toronto, and by inclusion in the list of geophysical pioneers recognized by the KEGS Pioneers Scholarship established by the KEGS Foundation. The legacy of his life and career is to be found in his surviving family (wife Betty and children Bryant, Cheri and Robby, the latter also a geophysicist) and in the many colleagues whom he collaborated with and inspired by his dedication and geophysical acumen.

Jerry Roth, KEGS Foundation, October 2014
# Lalor Symposium Program

**Co-Chairs:** Dennis Woods, BCGS and Peter Dueck, Hudbay

<table>
<thead>
<tr>
<th>Session</th>
<th>Start Time</th>
<th>End Time</th>
<th>Organization</th>
<th>Authors</th>
<th>Title</th>
<th>Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>08:00</td>
<td>08:30</td>
<td>Registration</td>
<td></td>
<td>Registration - Distribute Proceedings Booklet</td>
<td>Adam Shales</td>
</tr>
<tr>
<td></td>
<td>08:30</td>
<td>08:40</td>
<td>BCGS</td>
<td>Adam Shales</td>
<td>Welcome and opening remarks</td>
<td>Adam Shales</td>
</tr>
<tr>
<td>Introduction</td>
<td>08:40</td>
<td>09:00</td>
<td>CMIC / GSC</td>
<td>Alan Galley, Doreen Ames</td>
<td>Important characteristics of VMS deposits for deep exploration</td>
<td>Alan Galley</td>
</tr>
<tr>
<td></td>
<td>09:15</td>
<td>09:55</td>
<td>Bailes Geosciences</td>
<td>Alan Bailes</td>
<td>Regional geological setting of the Zn- and Au-rich Lalor VMS deposit, Snow Lake, Manitoba</td>
<td>Alan Bailes</td>
</tr>
<tr>
<td></td>
<td>10:00</td>
<td>10:20</td>
<td>Laurentian University</td>
<td>Margaret Engelbert, Bruno Lafrance, Harold Gibson</td>
<td>Structural and stratigraphic characterization of the Chisel Basin, Snow Lake, Manitoba</td>
<td>Margaret Engelbert</td>
</tr>
<tr>
<td></td>
<td>10:25</td>
<td>10:45</td>
<td>Hudbay</td>
<td>Craig Taylor</td>
<td>Mine scale description of the mineralization at the Lalor deposit, Snow Lake, Manitoba</td>
<td>Craig Taylor</td>
</tr>
<tr>
<td></td>
<td>11:10</td>
<td>11:35</td>
<td>DGI</td>
<td>Vince Gerrie, Chris Drielsma, Patrick Hooker, Roxanne Leblanc, Pamela Patraskovic</td>
<td>Quantitative Classification Techniques applied to Physical Rock Property and Lithogeochemistry data at the Hudbay Lalor Deposit</td>
<td>Vince Gerrie</td>
</tr>
<tr>
<td></td>
<td>11:40</td>
<td>11:55</td>
<td>Hudbay</td>
<td>Alan Vowles, Peter Dueck</td>
<td>Historical setting and exploration in the Chisel Basin, Snow Lake, Manitoba</td>
<td>Peter Dueck</td>
</tr>
<tr>
<td>Lunch</td>
<td>12:00</td>
<td>13:00</td>
<td>CGG</td>
<td>Greg Hodges, Tianyou Chen</td>
<td>Lator HELITEM Test Results</td>
<td>Greg Hodges</td>
</tr>
<tr>
<td>Airborne</td>
<td>13:00</td>
<td>14:00</td>
<td>Geotech</td>
<td>Jean Legault, Geoffrey Plastow, Shengkai Zhao, Nasreddine Bouras, Alexander Prikhodko, Marta Orta, Thomas Wade</td>
<td>ZTEM and VTEM airborne EM and magnetic results over the Lalor Copper-Gold VMS Deposit region, near Snow Lake, Manitoba</td>
<td>Thomas Wade</td>
</tr>
<tr>
<td></td>
<td>13:35</td>
<td>14:05</td>
<td>Koop Geotechnical</td>
<td>David Koop, Alan Vowles, Chris Roney</td>
<td>New TDEM Technique Aids in Discovery of Lalor Mine, Snow Lake, MB, Canada</td>
<td>David Koop</td>
</tr>
<tr>
<td></td>
<td>14:10</td>
<td>14:25</td>
<td>Discovery</td>
<td>David Bingham, Grant Nimeck, Dennis Woods</td>
<td>New generation JESSY HTS SQUID TEM results over the Lalor deposit</td>
<td>Dennis Woods</td>
</tr>
<tr>
<td></td>
<td>14:30</td>
<td>14:45</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>14:50</td>
<td>15:10</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Surface</td>
<td>15:10</td>
<td>15:30</td>
<td>Lamontagne</td>
<td>Rob Langridge, Yves Lamontagne, Owen Fernley</td>
<td>Then and now: UTEM3 and UTEMS comparison over the Hudbay Lalor deposit</td>
<td>Rob Langridge</td>
</tr>
<tr>
<td></td>
<td>15:35</td>
<td>15:55</td>
<td>Boliden</td>
<td>Bertil Sandstrom</td>
<td>Lalor Boliden ground electromagnetic survey</td>
<td>Bertil Sandstrom</td>
</tr>
<tr>
<td></td>
<td>16:00</td>
<td>16:15</td>
<td>Aurora</td>
<td>Dave Hildes</td>
<td>Extremely Low Frequency EM (ELF), a ground-based tipper survey at the Lalor Deposit</td>
<td>Dave Hildes</td>
</tr>
<tr>
<td></td>
<td>16:20</td>
<td>16:35</td>
<td>Phoenix</td>
<td>Caroline Finateu</td>
<td>Winter AMT survey over the Lalor deposit</td>
<td>Caroline Finateu</td>
</tr>
<tr>
<td></td>
<td>16:40</td>
<td>17:00</td>
<td>Quantec</td>
<td>Roger Sharpe, Asif Mirza, Jamar Regis</td>
<td>Titan24: Three lines of deep DCIP and MT at the Lalor deposit</td>
<td>Roger Sharpe</td>
</tr>
<tr>
<td></td>
<td>17:30</td>
<td>19:30</td>
<td></td>
<td></td>
<td>Reception - The Pint, 455 Abbott Street (at West Pender)</td>
<td></td>
</tr>
</tbody>
</table>
## Lalor Symposium Program

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<table>
<thead>
<tr>
<th>Session</th>
<th>Start Time</th>
<th>End Time</th>
<th>Organization</th>
<th>Authors</th>
<th>Title</th>
<th>Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surface 2</strong></td>
<td>08:30</td>
<td>08:50</td>
<td>NRCan - GSC</td>
<td>Gilles Bellefleur, Ernst Schetselaar</td>
<td>Multi-component 3D seismic survey over the Lalor VMS deposit, Manitoba</td>
<td>Gilles Bellefleur</td>
</tr>
<tr>
<td></td>
<td>08:55</td>
<td>09:15</td>
<td>NRCan - GSC</td>
<td>Jim Craven, Saeid Cheraghi, Gilles Bellefleur, Eric Roots</td>
<td>Seismic interferometry: a new tool for brownfield mineral exploration? Preliminary results from Lalor, MB.</td>
<td>Jim Craven</td>
</tr>
<tr>
<td></td>
<td>09:20</td>
<td>09:40</td>
<td>SJ Geophysics</td>
<td>Syd Visser</td>
<td>Volterra borehole TDEM, Surface TDEM, and 3D-IP test surveys over the Lalor deposit</td>
<td>Syd Visser</td>
</tr>
<tr>
<td></td>
<td>09:45</td>
<td>10:05</td>
<td>Gap / Discovery</td>
<td>Chris Parker, Jonathan Rudd, Malcolm Cattach, Johnathan Kuttai</td>
<td>The results of a HeliSAM test survey over the Lalor VMS deposit, Snow Lake, Manitoba</td>
<td>Jonathan Rudd</td>
</tr>
<tr>
<td></td>
<td><strong>10:10</strong></td>
<td><strong>10:30</strong></td>
<td><strong>Coffee Break</strong></td>
<td><strong>Borehole</strong></td>
<td>10:30</td>
<td>10:50</td>
</tr>
<tr>
<td></td>
<td>10:55</td>
<td>11:15</td>
<td>EMIT</td>
<td>Andrew Duncan</td>
<td>DigiAtlantis borehole TEM at Lalor</td>
<td>Andrew Duncan</td>
</tr>
<tr>
<td></td>
<td>11:20</td>
<td>11:40</td>
<td>Abitibi</td>
<td>Roman Wasylechko</td>
<td>Borehole Gravity over the Lalor deposit</td>
<td>Roman Wasylechko</td>
</tr>
<tr>
<td></td>
<td><strong>11:45</strong></td>
<td><strong>13:00</strong></td>
<td><strong>Lunch</strong></td>
<td><strong>Day 2 - Friday October 17th</strong></td>
<td>13:00</td>
<td>13:25</td>
</tr>
<tr>
<td></td>
<td>13:30</td>
<td>13:55</td>
<td>Bem Geoscience</td>
<td>Bruce McMonnies</td>
<td>Multi-Disciplinary 3D Data Integration at Snow Lake (Chisel Basin)</td>
<td>Bruce McMonnies</td>
</tr>
<tr>
<td></td>
<td>14:00</td>
<td>14:25</td>
<td>Mira</td>
<td>Dianne Mitchinson, Nigel Phillips, Gervais Perron, Chrissy Williston, Bruce McMonnies, Kelly Gilmour</td>
<td>District-scale 3D targeting over the Chisel and Lalor properties using multidisciplinary criteria and weights of evidence methods</td>
<td>Dianne Mitchinson</td>
</tr>
<tr>
<td></td>
<td><strong>14:30</strong></td>
<td><strong>14:50</strong></td>
<td><strong>Coffee Break</strong></td>
<td>14:30</td>
<td>14:55</td>
<td>NRCAN - GSC</td>
</tr>
<tr>
<td></td>
<td>15:00</td>
<td>15:10</td>
<td>Hudbay</td>
<td>Alan Vowles</td>
<td>Concluding Remarks</td>
<td>Alan Vowles</td>
</tr>
</tbody>
</table>
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Volcanogenic massive sulphide deposits (VMS) or volcanic-hosted massive sulphide deposits (VHMS) continue to be attractive exploration targets due to their polymetallic nature and the concentration of metals in massive to semi-massive bodies, particularly those with anomalous precious metal contents. Because the potential for making future significant surface discoveries has dwindled, it is more important than ever to have a good understanding of the physical and chemical characteristics of not only the deposits themselves, but also of the more encompassing VMS ore systems and the submarine depositional environments in which they form. By ore systems, we mean the package of rocks that are responsible for supplying heat, fluids and metals, the host rocks and contained structures that channel both fluid input and outflow, and finally the rocks defining the immediate depositional environment in which fluids were trapped, and the deposits formed. An understanding of the character and scale of the ore system thereby defines its “footprint”, parts of which will have distinctive physical and chemical attributes that can be used to vector towards ore.

The extent and nature of this ore system footprint is in many ways controlled by the particular submarine tectonic environment in which it formed. VMS systems may form in primitive submarine oceanic rift environments, but are more commonly observed in suprasubduction environments where volcanic arcs form above subducting plate margins. Even though these are considered compressive tectonic regimes, there are sections that undergo extension at times, thereby allowing the focused magmatic and hydrothermal activity needed for VMS formation. These include fore arc, or nascent arc environments, and various stages of arc rifting and back arc basin development. These can occur at the junction between ocean plates, or between ocean and continental margins. The resultant submarine volcanic and sedimentary successions are distinctive physically and geochemically, which in turn can determine the size and characterize of contained VMS deposits.

In general, the base of the VMS ore system is defined by the presence of high level, synvolcanic intrusions, or intrusive complexes. These intrusive complexes rise up to <2000m from the seafloor, usually along fault-fissure systems that form within what is called a “thermal corridor” that may extend all the way to the base of the crust. These high level, submarine intrusive complexes are responsible for supplying the magmas for the overlying volcanic terrane, which commonly includes felsic volcanic centres around which VMS deposit commonly form. The reason for this is that these felsic centres define the top of upwelling thermal anomalies resulting from the cooling of the underlying intrusive complex. This cooling heats up pore water in the overlying volcanic host rock.
Figure 1. Variations in tectonic environments hosting VMS systems (Galley, 2007)

Figure 2. The spectrum of depositional environments hosting a spectrum of VMS types, the character of each environment largely dependent on its tectonic setting (from Piercey, 2007).
The rise of this heated water causes cooler seawater to be drawn in along the margins of the intrusive complex. As these waters are heated, they become more reactive with the surrounding rock, thereby developing alteration zones whose geochemical and mineralogical character are defined by rock composition and the changing nature of the descending fluid. At some point the altered seawater becomes a low pH, hot hydrothermal fluid capable of stripping out metals and maintaining them in solution as principally chloride and sulphur complexes. As these hot hydrothermal fluids rise to the seafloor along predefined fracture systems (commonly defined by dike swarms) they mix with cold seawater at, or near the rock-water interface, which causes the sulphides and associated sulphates and silicates to precipitate to form sulphide mounds and/or underlying replacement features.

This hydrothermal alteration process can affect vast volumes of rock that may also include parts of the underlying subvolcanic intrusion. This alteration intensity can be reinforced by the development and expulsion of a magmatic fluid phase, whose passage not only alters the intrusive carapace, but most likely supplies additional metals to the sub seafloor hydrothermal system.

How big an exploration target are we talking about, and what are it’s identifying physical, chemical and mineralogical features? Subvolcanic intrusive complexes can have strike lengths of over 20 kilometres and are usually 2-3 km thick. The development of hydrothermal convection cells above this cooling mass can therefore result in the formation of not one VMS deposit, but an entire VMS district, or cluster. Each VMS deposit will therefore have a characteristic proximal alteration zone within a larger, semi-concordant alteration system that can be over 20 km in strike length and perhaps 2000 m in thickness. The character of this large, semi-concordant alteration system is controlled by the temperatures at which the causitive fluid-rock interactions took place. The high temperature (>400°C) reaction zone affects the carapace of the subvolcanic intrusive complex and perhaps several hundred metres of the overlying rock. In basaltic terranes these clinzoisite-Ca plagioclase-amphibole-magnetite-garnet rich zones commonly have a corresponding high magnetic signature that defines the underlying intrusive complex as having taken part in the development of a VMS hydrothermal system. Because the hydrothermal plumbing system that released hydrothermal fluids from this zone to the seafloor is never 100% effective, this zone may contain zones of disseminated sulphides that form distal, stratabound IP anomalies. The reaction zone in places can be overlain by relatively thin but areally extensive zone of silica replacement that acted as a thermal “cap” to the reaction zone. The presence of similar stratabound silica zones in the Athabasca Basin uranium systems have been identified through pole-dipole generated resistivity maps.

Furthermore, the areal extent of such an ore system can be defined in certain VMS districts by the presence of a thin (1-5 m) but extensive blanket of chemical sediment that is the result of widespread, low temperature hydrothermal venting over the strike length of the district-scale hydrothermal system. These “exhalites” therefore define preferred paleo seafloor intervals along which VMS deposits are most likely to form. In Archean VMS systems these exhalite units consist of finely laminated chert, carbonate, fine-grained tuffaceous material, and disseminated to bedded sulphide. In both Archean and younger VMS terranes, exhalites may be quite areally extensive, and consist of banded iron formation that changes composition in proximity to areas of focused, higher temperature hydrothermal activity. Facies changes can include silicate to chert through carbonate to sulphide facies, thereby being excellent mineralogical and geochemical markers. A combination of high
definition magnetics and EM may well be useful vectoring tools for the identification and vectoring of exhalative units.

Figure 3. A cartoon depicting the generic evolution of a VMS ore system. Horizontal scale is approximately 20 km (Galley, 2007).

In mafic volcanic dominated VMS terranes the development of exhalite units from widespread, low temperature hydrothermal activity can be accompanied by the formation on underlying zones of silica precipitation and clay-chlorite formation that focuses within inter-flow volcaniclastic units, interpillow breccias and pillow rims, thus widening the zone identifying potential VMS hosting paleoseafloor intervals.

The discordant hydrothermal upflow zones within the broader zones of semi-concordant alteration are generally less than 10’s of meters wide, but can extend up section for several thousand metres, following synvolcanic faults and dike swarms. These are zones of dominantly chlorite-quartz alteration, which, as the paleo seafloor is approached, contain sulphide vein stockworks that represent the feeder system to an overlying massive sulphide deposit. The alteration feeder zone, or pipe, tends to widen at this point, and the chlorite-quartz core extends outwards into a zone of sericite rich alteration. The development of the sericite rich rim is a product of interaction between the
hydrothermal fluid upflow and surrounding circulating cold seawater. Whereas these hydrothermal fluid upflow zones are dominantly discordant to stratigraphy in volcanic flow dominated successions, the presence of more permeable volcaniclastic strata allows a degree of lateral fluid flow. If these volcaniclastic strata form the immediate subsea-floor this lateral fluid flow can result in sulphide precipitation and the formation of stratiform massive sulphide replacement deposits.

There are now well documented instances where the continuation of highly focused hydrothermal activity accompanies the deposition of volcanic and volcaniclastic units over top of the VMS hosting stratigraphic interval. This is commonly a function of continued synvolcanic faulting activity along which the footwall hydrothermal activity was channeled. The resultant hydrothermal “plumes” leave a distinctive geochemical and mineralogical trace through alteration and deposition of silicates, sulphides, and oxides in the more permeable parts of the hanging wall strata. This can also result in the presence of stacked massive sulphide horizons all related to the same hydrothermal fluid pathway.

The number of geochemical discriminates available to identify both potential VMS-hosting terranes and the presence of large VMS ore systems is becoming more refined through the availability of cheap, high definition geochemical analysis, the increased agility of GIS-based software, and new generations of cloud-based statistical analytics. Despite these advances, our basic knowledge of the geochemical signatures of both VMS-related tectonic environments and alteration associated with VMS ore systems has not radically changed over the past decade. Potentially fertile submarine tectonic environments are largely identified through a combination of lithostratigraphic facies analysis and trace element geochemistry. This includes the use of relatively immobile trace element ratios, and a suite of light field strength, rare earth, and high field strength elements commonly normalized to a standard mid ocean ridge (MORB) or mantle composition. The resultant fields and patterns will commonly define magmatic origin, and therefore identify distinctive tectonic regimes.

The geochemical and mineralogical identification of alteration footprints and their internal zoning can be done through an understanding of the element substitutions that take place through subsea floor interaction of rocks with hydrothermal-magmatic fluids. Older discriminate methods relied on changes in major element geochemistry, whereas newer methods commonly use immobile element ratios to determine departures from geochemical igneous trends, and attempt to calculate quantitative element net losses and gains as a vectoring tool. Oxygen, hydrogen and sulphur isotopes can also be useful tools. Generations of factor analysis have been used to identify key element suites typical of certain alteration facies.

The mineralogical characteristics of VMS hydrothermal alteration facies can be highly extenuated through regional metamorphism. Where a subsea floor hydrothermal alteration assemblage is usually quite fine-grained, upper greenschist to amphibolite regional metamorphism will morph and coarsen the original assemblage into something easily identified and mapped in the field. These mineral assemblages can be plotted on ternary composition plots to help vector towards proximal VMS alteration.
Figure 4. Examples of discriminate ratios commonly used to define the presence and nature of VMS-related hydrothermal alteration (Ames and Franklin, 2007).

Irrespective of which method, or combination of methods used, the user must acquire a sound knowledge of the petrogenetic and hydrothermal processes involved in creating a fertile VMS environment before they can be used effectively and consistently.
REGIONAL GEOLOGICAL SETTING OF THE ZN- AND AU-RICH LALOR VMS DEPOSIT, SNOW LAKE, MANITOBA, CANADA

Alan H. Bailes

1. Bailes Geoscience. bailesgeoscience@mts.net

The Lalor VMS deposit is located in the Eastern Flin Flon Domain (EFFD) of the Paleoproterozoic Trans Hudson Orogen. The EFFD consists of tectonically interleaved 1.90-1.88 Ga volcanic rocks of the Flin Flon Domain (FFD) and younger 1.85-1.83 Ga sedimentary rocks of the Kisseynew Domain (KD). This tectonic collage consists of disparate volcanic assemblages (sub-domains), each with differing lithotectonic affinities and mineral potential, separated by panels of the younger sedimentary rocks. Between 1.82-1.81G the northern and northwestern part of the domain was metamorphosed at high temperature and low to medium pressure resulting in coarse re-crystallization of volcanic rocks and their contained VMS systems. The 1.89 Ga Snow Lake arc assemblage (SLAA) at the centre of the EFFD is host to 9 producing and past-producing VMS mines, including the large Zn-and Au-rich Lalor deposit.

The SLAA is exposed in an over 20km wide allochthon that is cored by a major, shallow north-dipping, nearly recumbent fold. The SLAA, which is >6 km thick, consists of three distinct subdivisions: a lower >2.5 km thick primitive arc succession (Anderson sequence), a middle ca. 3 km thick mature arc succession (Chisel sequence), and an upper 0.5 km thick MORB-like basalt succession (Snow Creek sequence). The Anderson and Chisel sequences contain mainly Cu-rich and Zn-rich deposits, respectively, with the Snow Creek sequence containing no known VMS deposits. The Zn-Au-rich Lalor mine, which is by far the largest VMS deposit in the SLAA, is contained in the Chisel sequence.

The Chisel sequence consists of a lithologically and geochemically diverse succession of 1.89Ga mafic, intermediate and felsic flows and volcaniclastic rocks. VMS mineralization in the Chisel sequence is spatially associated with transitional calc-alkaline volcanic rocks, a large shallow subvolcanic intrusive complex, and a 9 × 2 km alteration zone that was produced by a VMS-forming hydrothermal system linked in space and time to the subvolcanic intrusive complex. Seventy-five million years later the altered volcanic rocks were recrystallized to almandine amphibolite facies mineral assemblages during a 1.815 Ga regional metamorphic event.

The subconcordant 9 × 2 km alteration in the lower Chisel sequence is largely confined to volcaniclastic units 1-2 km beneath the Zn-rich VMS deposit of the Chisel sequence. It merges with disconformable zones of alteration that can be traced up section to not only the Au-rich Lalor Zn-Cu deposit but also a number of smaller Zn-Cu VMS deposits, including the Chisel Lake and Chisel North deposits. A thick accumulation of permeable, volcaniclastic rocks in the stratigraphic footwall is speculated to have played an important role in not only the hydrology of the hydrothermal system but also, possibly, to the generation of metals now resident in the overlying VMS deposits. The alteration zone beneath the Lalor VMS deposit developed in two stages. The first produced a semi-conformable zone of silicification, albitization and epidotization, which is spatially related to areas with abundant synvolcanic dykes and intrusions. Many of the dykes are feeders for overlying extrusive volcanic rocks and were intruded into unconsolidated, water-saturated volcanic tuff and tuff breccia. The second stage produced a sub-concordant zone manifest by metamorphic mineral assemblages rich in staurolite,
garnet, amphibole, biotite, chlorite and/or muscovite. In drill core the sub-concordant alteration zone includes kyanite, cordierite, anthophyllite and gahnite, and merges with sulphide-rich footwall alteration (disconformable alteration) directly below the deposit. Carbonate-tremolite-chlorite/talc rich rocks are common in proximity to the sulphide mineralization at the Lalor VMS deposit. The extensive aluminosilicate-sericite alteration, abundance of carbonate sediments and high precious metal content of the sulphide zones and stringers suggest shallow water hydrothermal activity with probable subcritical phase separation (boiling) of the hydrothermal fluids.

The Lalor VMS deposit consists of a number of ore lenses that occur 600 to 1200 m below surface. The considerable depth to mineralization, absence of direct correlation to equivalent less altered rocks at surface, strong hydrothermal alteration that rendered original protoliths largely unrecognizable, and limited understanding of structural controls for mineralization makes this a challenging deposit to model. One of the earliest features recognized was that the rocks in the deposit hanging wall are unaltered and dip steeply to the north and top southwest whereas the host strata for the mineralization are intensely altered and dip shallowly to the northeast. An early interpretation of this feature was that it reflects a shallow north dipping thrust fault in the hanging wall to the mineralization. This interpretation is controversial and, as yet, unproven. Volcanic rocks below this “structure” typically display calc-alkaline geochemical affinities, whereas above it these rocks are virtually absent. An interesting feature of the Chisel Lake area is that widely spaced deep drill holes in the “Chisel basin” have without exception encountered highly altered rocks at depth. This suggests that a regionally extensive, shallow NNE dipping alteration zone likely underlies much of the “Chisel basin”. This is important as this zone of altered rock extends well beyond the area of presently known VMS deposits.
STRUCTURAL AND STRATIGRAPHIC CHARACTERIZATION OF THE
CHISEL BASIN, SNOW LAKE, MANITOBA

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The Chisel sequence is a 3 – 5 km thick succession of volcanic rocks that occurs within the Snow Lake arc assemblage of the Paleoproterozoic Trans-Hudson Orogen. It is host to six economic Zn-Pb-Cu-Ag-Au VMS deposits (the Chisel Lake, Lost Lake, Ghost Lake, Chisel North, Photo Lake, and Lalor deposits) that are now interpreted to have formed within a single time-stratigraphic ore interval. This ore interval occurs at the contact between the Lower Chisel and Upper Chisel sequences and marks a break in voluminous, continuous emplacement of volcaniclastic material. The ore interval represents a period of volcanic quiescence and subsidence following rhyolite dome development that constituted an ideal environment for VMS formation. The stratigraphy of the ore interval and its bounding units consists of, in ascending order, the Powderhouse dacite, the Chisel-Ghost (-Photo?) rhyolite, and the Threehouse mafic volcaniclastic rocks. VMS deposits occur at the contact between the Chisel-Ghost rhyolite and Threehouse unit (e.g. Chisel Lake deposit) and, where the rhyolite does not occur, at the contact between the Powderhouse dacite and the Threehouse unit (e.g. Lost Lake deposit).

Three main deformational events associated with the Hudsonian orogeny are recognized in the Snow Lake district and have influenced the current geometry and location of the Chisel sequence VMS deposits. D₁ is characterized by tight, isoclinal F₁ folds without a preserved S₁ foliation. D₂ produced a strong S₂ foliation that is the dominant planar fabric in the volcanic rocks of the Snow Lake district. Elongate amygdules and clasts, stretched quartz aggregates, and aligned amphibole crystals define an L₂ lineation. D₃ is characterized by upright, open to closed NE-striking F₃ folds with a weak axial planar S₃ foliation.

This investigation provides a new understanding of the location and structural modification of the VMS deposits in the Chisel sequence by expanding on previous deposit-scale structural studies at the Chisel, Chisel North, and Photo Lake deposits and by incorporating new findings at the Lalor deposit. The dominant structures controlling the current geometry of the VMS deposits are the D₁ and D₂ structures present on the scale of the Chisel sequence. At the Photo Lake deposit, the two base metal lenses (#1 lens and #2 lens) have been folded about an isoclinal F₁ fold and elongated along L₂. The #2 lens is overturned and the #1 lens is the folded, transposed stringer zone to the #2 lens. These findings are consistent with the geometry of the Chisel and Chisel North deposits, which are also folded by isoclinal F₁ folds and elongated along L₂. The Lalor deposit occurs in the footwall to a fault and consists of several base metal lenses that have been folded about a recumbent isoclinal fold. Both of these structures dip shallowly to the northeast and may be either D₁ or D₂ structures. These findings
have major implications for future exploration in the area because they indicate that folding and potentially faulting have repeated the productive Chisel ore interval.
MINE SCALE DESCRIPTION OF THE MINERALIZATION AT THE LALOR DEPOSIT,

SNOW LAKE, MANITOBA, CANADA

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The Lalor deposit is a typical bi-modal felsic, volcanogenic massive sulphide (VMS) deposit. The deposit has a current reserve of 15.2 Mt and an inferred resource of 10.1 Mt which is five times the average tonnage for Canadian VMS deposits. The gold grade of the deposit is also exceptional at more than 130% of the average.

The deposit was formed through subaqueous volcanic activity as metal-rich, hot hydrothermal fluids travelled along fractures until reaching the seafloor. When the fluids approached and reached the rock-water interface, the dissolved metals and other elements precipitated as sulphide minerals from the resulting cooling and chemical changes. The sulphides accumulated within the host rock and also as massive layers. Subsequent to the sulphide accumulation, the deposit underwent both metamorphic and structural deformation.

Mineralization in the Lalor deposit includes a variety of types such as near-solid sulphide. It is important to note that the different types of mineralization do not represent end members of a sulphide mineralization trend but are unique mineralization types.

Near-solid sulphide mineralization within the deposit is categorized as being generally comprised of more than 40% sulphide minerals which occur as 1 to 10 mm diameter subhedral grains. Pyrite is the dominant sulphide with subordinate amounts of sphalerite and even lesser amounts of pyrrhotite, chalcopyrite and galena. Other minerals occurring with the sulphides include quartz and a variety of carbonates and silicates. Near-solid sulphide mineralization typically occurs as layers 5 to 20 metres thick with lateral extents of up to 200 metres. These can be stacked vertically with up to ten layers over a 300 metre interval. Figure 1 is an example of near-solid sulphide sample from Lalor Lens 10.

Stringer sulphide mineralization occurs as a discontinuous web of intertwined sulphide rich veins in a near barren host rock. The sulphide content of the veining is generally greater than 50%, although the overall total sulphide content of the host rock is between 10 to 40%. Sulphide veins vary in thickness from 1 centimeter to more than 1 metre. Sulphide minerals are predominately pyrrhotite with subordinate chalcopyrite and lesser amounts of pyrite, sphalerite and galena. In places, veins can exceed higher than average gold grades for the deposit. Stringer sulphide zones are typically less than 10 metres thick and may occur in contact with the near-solid sulphide layers or in isolation.
Figure 2 shows the general distribution of the near-solid sulphide and stringer sulphide mineralization. The bottom of the shaft in the background is approximately 1,100 metres below surface.

**Disseminated sulphide mineralization** usually contains less than 20% sulphide minerals and often less than 10%. Pyrite is by far the most common sulphide mineral which is usually accompanied by small amounts of sphalerite and pyrrhotite. The disseminated mineralization likely formed during a large scale alteration of the host rocks and encompasses an area approximately 300 metres thick, 350 metres wide and at least 1300 metres long.
Figure 2. View of the Lalor Deposit looking west – near massive sulphide in red and stringer sulphide in yellow – shaft in the background.
The Decennial Mineral Exploration Conferences (DMEC) is pleased to announce that the 6th Decennial Conference will be held Oct 21-25th 2017 in Toronto, Ontario, Canada.

The theme for the conference will be:-

“Exploration ’17: Integrating the Geosciences”

The organizing committee is headed by Chris Nind, General Chairman and John McGaughey and Charles Beaudry Technical Co-Chairs. Further information on the conference will be found at www.exploration17.com in the New Year.

Plan to attend!
QUANTITATIVE CLASSIFICATION TECHNIQUES APPLIED TO PHYSICAL ROCK PROPERTY AND LITHOGEOCHEMISTRY DATA AT THE HUDBAY LALOR DEPOSIT

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Summary

Comprehensive physical rock property measurements provide the critical quantitative link between geology and geophysics, thereby improving 3-D geologic modelling.

Machine learning, cluster analysis, and classical statistics are used to classify the rock into petrophysical (physical rock properties) and lithogeochemistry domains to produce independent, objective classification schemes.

Traditional lithological classification schemes, i.e. visual core logging, are compared to rock property and lithogeochemistry domains, presenting an opportunity to improve geological understanding. Relationships between geology, geophysics, and geochemistry are identified and explored.

Additionally, in-situ structural measurements combined with structural analysis can aid in the development of structural models. Understanding the distribution of fault zones and their relationship with mineralization, can lead to better exploration targeting, and decreased operational risk.

Introduction

Using in-situ physical rock property measurements to quantitatively link geology to geophysics is a standard practice in the oil and gas industry, but to date this approach has had limited adoption in the minerals industry. Although the technology exists to acquire high quality petrophysical data, it is not currently a routine part of the traditional mineral exploration and mining workflow.

In 2009 and 2010, DGI Geoscience Inc., acquired downhole petrophysical and televiewer data from 17 strategically chosen boreholes at the Hudbay Lalor Deposit. Innovative approaches aimed at maximizing value from petrophysical and lithogeochemistry data are explored with the goal of improving deposit understanding.

In-situ physical rock property measurements have attributes (multi-parameter, high data density, quantitative) that are ideally suited to data driven approaches, however there are several challenges that arise when using petrophysical domains to link geology to geophysics. Four key issues are
discussed with respect to petrophysical domains, linking geology to geophysics, establishing proxy relationships, and in-situ structural measurements:

1. Data Quality and Consistency: Data driven approaches can only be effective if the input data is consistent and variation in the data set is not artificially induced via instrument drift, calibration errors, and changes in instrumentation over the life of a project etc.

2. Traditional lithological classification schemes rely on a potentially subjective visual inspection of drill core leading to inconsistent results over the lifetime of a project. There is often a lack of correlation between traditional geologic classification and the petrophysical data. A high degree of variance within each lithological unit can often be found across the physical rock properties; such as magnetic susceptibility, density, induced polarization, resistivity, and so forth.

3. Many ex-situ measurements such as geotechnical, geochemical and geometallurgical parameters can be time and cost intensive over very small sample sizes. This often results in sparse and non-representative sampling, and analysis that lacks statistical relevance and accuracy into the geologic model. It can be challenging to relate continuous (densely sampled) petrophysical data to sparse ex-situ measurements.

4. Insufficient measurement and/or collection of structural orientation data. Although there has been an increase of using various core orientation techniques, they are limited by the application and core recovery.

Methodology

Instrument Calibration and Data Validation

In order to collect valid, consistent data ideally suited to quantitative analytical techniques, proper calibration procedures must be followed. These procedures include establishing a calibration borehole with known well-studied geology, lab measured physical properties and validated geophysical reference logs. Probes must be calibrated periodically at such a site.

During collection, the probes must be checked daily for any drift or error that may occur, using either a locally established reference borehole or calibration / test jigs. A thorough process in regards to calibration and quality assurance is key in acquiring quantitative petrophysical data.

Petrophysical Domains

Since in-situ acquired physical rock properties are densely sampled multi-parameter datasets, they are suitable for analysis via machine learning, cluster analysis and classical statistical techniques to create quantitative petrophysical domains. These domains can then be analyzed and compared with the logged geology by using frequency analysis, principle component analysis (PCA), cross-correlation, and other statistical methods. Viewing and interpreting the domains in 3-D space allows improvements to be made to the existing geologic model and a greater project level understanding.
Dataset Integration – Proxy Relationships

Using machine learning techniques, geometallurgical, geochemical and geotechnical parameters can be correlated to in-situ physical rock properties to establish proxy relationships. These relationships allow proxy predictions to be made from in-situ rock property data to estimate values where no ex-situ measurements were conducted, or to get quick estimates for results that are traditionally slow to obtain in a lab. For example, geometallurgical milling parameters that are time and cost intensive to collect can be estimated in advance using downhole physical rock properties once a proxy relationship has been established.

Structural Measurements

In-situ structural measurements can be acquired using acoustic (ATV) and optical (OTV) televiewers. Each probe will generate a 360° image of the borehole wall. The ATV generates an acoustic pulse that reflects from the borehole wall back to a receiver; generating two images: the amplitude of the signal and the travel time. On the other hand, OTV uses a high-resolution digital camera to create a RGB image of the borehole wall. ATV is superior for identifying and classifying fractures, stress induced breakouts and fault zones, whereas OTV excels at identification of bedding/banding/foliation, veins and lithological contrasts. These images are processed, features are identified and classified using a standard scheme or one defined by project objectives. These features are oriented using tilt and azimuth measurements acquired by on-board motion sensors. Oriented features can be plotted on stereonets or polar frequency graphs (rose diagrams) to analyze the trends in the data.

Ultimately, the data can be interpreted and analyzed to create accurate 3-D structural models that define the structural controls on mineralization, and in conjunction with geotechnical logging, define geotechnical and rock mass domains.

Conclusions

Using physical rock properties to create petrophysical domains and proxy relationships allows for a greater understanding of the geologic setting. The petrophysical domains are an objective classification scheme that can help refine a geologic model. The proxy relationships increase the understanding in areas where there may not have been sufficient data collected in the past or assist in finding the most effective and efficient approach to getting answers project-wide, whether the questions are geophysical, geotechnical, geochemical or geometallurgical in nature.

Oriented structural measurements acquired in-situ from the televiewers can lead to an increased comprehension of the structural trends of the environment and mineralization. The increased geotechnical knowledge provides better risk assessment; the structural knowledge better targeting; in combination a better geologic model.
HISTORICAL SETTING AND EXPLORATION IN THE CHISEL BASIN, SNOW LAKE, MANITOBA, CANADA

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Historical Setting (2002)

In an attempt to find another large ore body, Hudson Bay Exploration and Development identified the Chisel Basin as high potential for discovery. They knew the favorable Chisel stratigraphy was getting progressively deeper so they asked the geophysical group to investigate methods to explore at greater depths.

Chris Roney was the Project Geologist in charge of Chisel Basin exploration program and collaborated with Alan Vowles as to which method to use to test for deep deposits. At that time Crone Geophysics had just developed a high speed time domain electromagnetic (TDEM) receiver which was capable of collecting higher quality data in a fraction of the time than their current receiver was capable of. The first task was to convince management the need for a high speed receiver so a test was designed to determine if a new receiver would be a prudent purchase. This was a strategic step in testing new and future technologies and future technologies for Hudbay.

The initial strategy was to ensure that TDEM surveys would indeed be successful to define typical VMS deposits at depth. For this reason, a borehole survey was conducted on a deep drillhole (DDH CH93-05W2) that penetrated the Chisel Basin stratigraphy at a vertical depth at approximately 1100 metres. As shown in Figure 1, the Crone H(z) probe could see the build-up to the horizon right from surface. This confirmed that large, extensive conductors could be detected at depths in excess of one kilometer.

It was then decided to do a test with the “slow speed” Crone receiver over the deepest lenses of Chisel North Mine. The test was simple – if the Chisel North Lenses (~600m below surface) could be imaged, then Hudson Bay Mining and Smelting could buy this new high speed receiver. To mimic the new high speed Crone receiver, the sample rate was set to 16384 stacks. The idea behind this was that the new receiver had the capability of collecting this amount of data in minutes where, with the current technology, the test survey took approximately half hour to average and store that many stacks. Ultimately, the test was a success as the data showed a clean decay throughout the full range of time channels. This confirmed that there was a strong, measurable secondary field present at surface which was interpreted to be produced from the highly conductive Chisel North lenses approximately 600 metres below surface.
With these successful tests, Hudson Bay Mining and Smelting purchased the new Crone receiver for their future geophysical programs.

**Figure 1:** Profiles collected from DDH CH93-05W2 showing an anomalous response ~1100m below surface seen even at the top of the drillhole

**Historical Exploration (Pre-2007)**

The Chisel Basin hosts many VMS ore bodies, and for this reason the basin has been fairly heavily explored by geophysics and drilling. Figure 2a shows the deposits in the vicinity of the Lalor Mine while Figure 2b shows the grid outlines of all the previously completed geophysical surveys. These surveys included Turam, Horizontal Loop Electromagnetic (HLEM), Fixed Loop Electromagnetic (FLEM), Very Low Frequency (VLF), Moving Loop Electromagnetic (MLEM) and UTEM surveys. Although a significant amount of geophysics was completed, the depth penetration of these surveys is relatively shallow, typically less than 200m. Some surveys, like MLEM and FLEM, have the ability to see to a greater depth but due to the acquisition parameters (8.3ms timebase) or equipment historically used (2.4Kw transmitter) none of these surveys had the ability to see a significant ore body at large depths (greater than 400m).

Historical drilling is similar. Figure 2c shows all the drilling pre-2007 where the purple dots are drillholes where the end-of-hole (EOH) is shallower than 500m. The yellow dots are drillholes where the EOH is greater than 500m. Finally, Figure 2d only shows where deeper drilling was completed in the Chisel Basin. As you can see, the majority of the drilling was completed on known deposits with a small amount of drilling completed outside of these areas. This figure does emphasize that very little deep Greenfield exploration was completed in the Chisel Basin.
Ultimately, despite the fact that the Chisel Basin was adequately explored with both geophysics and drilling, neither of these practices adequately explored for a significantly sized ore body at depth. These are important lessons learned because as explorationists, we need to consider the type of data available and what the limits of the data are. Realistically, there could be other world class deposits in areas that were previously considered adequately explored or considered to have little potential.

*Figure 2: A) Historical deposits within the Chisel Basin; B) Pre-2007 geophysical grid locations; C) Geophysical grids with pre-2007 drillholes (purple <500m, yellow >500m), D) Only holes greater than 500m*
LALOR HELITEM TEST RESULTS

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CGG flew the HELITEM\textsuperscript{®} time-domain EM as a test survey over The Lalor VHMS deposit in early 2012. Pre-survey modeling using a range of transmitter pulse widths at both 30Hz and 15Hz base frequency indicated that detection was marginal at best, but it was decided to proceed with the test. The deposit was flown with the HELITEM transmitting at 2MAm$^2$ dipole moment, and 6ms pulse at 30Hz, and 10ms pulse at 15Hz. A block of lines between Lalor and the Chisel Lake area were covered. Initial results were exciting, as a broad, strong conductor of low amplitude was immediately apparent in the field data, and in preliminary Differential Conductivity\textsuperscript{TM} sections. The conductor was most apparent in late-time data, and particularly in the derived B-Field results.

\textbf{HELITEM Differential Conductivity\textsuperscript{TM} Sections}

A broad conductive belt was mapped, with two higher conductivity “cores” that correlated with the Lalor deposit and the “South Bullseye” conductor previously detected with ground TDEM. The best results were achieved at 30Hz with a 6ms halsisine pulse (10.7ms off-time). The 15Hz (10ms pulse) data also showed the conductor, and although the improved induction into a strong conductor of the 10ms pulse enhanced the signal, the reduction in data stacking at 15Hz base frequency resulted in very little net gain of signal-to-noise over the 30Hz data.

The survey data were inverse-modeled with two approaches: Multiple plate-like conductors were forward modeled and adjusted until a reasonable fit was achieved using LeroiAir; and the UBC 3D TDEM modeling inversion was run independently. The plate modeling returned a reasonable match to known geology, although the fit of the model decay curve to the full off-time of the field data was not optimal. This can be explained in part by the non-platelike conductivity that is in the area of the deposit, including a reported “thick zone of hydrothermal alteration” (Hudbay).
The 3D finite element inversion performed at UBC also showed a thick zone of conductivity, with cores at the location and depth of the Lalor deposit and the South Bullseye conductor (depth unknown).
An Ideal Tool for VMS Exploration

The CGG GRYPHON™ system is capable of collecting simultaneous measurements of the following parameters:

- Time Domain Electromagnetics (MEGATEM®, TEMPEST® or MULTIPLE™)
- High Resolution Magnetics
- FALCON® Airborne Gravity Gradiometer
- Gamma Ray Spectrometry
- Laser Scanner Digital Terrain
- Digital Video

The ability to collect a full range of geophysical measurements in a single pass with GRYPHON provides unparalleled information for general mapping and target delineation.

Gamma Ray Spectrometry, DTM and the high frequency component of the EM signal are excellent tools for mapping terrain, surficial geology and near-surface alterations.

The combination of TEMPEST, Magnetics and Gravity is used to map sub-surface features such as overburden thickness, paleochannels, shallow gas and coal as well as to detect mineralized targets.

The MEGATEM system, able to penetrate much deeper, is combined with Magnetics and Gravity to map basement domains and explore deep seated mineralization.

Measurements of different rock properties (magnetic susceptibility, density and resistivity) are provided in a co-located database, facilitating joint inversion and integrated interpretation, leading to 3D Earth Model solutions.

Data Interpretation and Targeting

In one pass of the GRYPHON system, information on the conductivity, susceptibility, and density contrasts is recorded. This information is later integrated to provide a complete geophysical interpretation of the property, including geology, conductive zones and exploration targets.

The combination of gravity and electromagnetics is a powerful tool for VMS exploration. Assessing conductive targets using density information provided by FALCON is an effective method to discriminate potential targets of interest from ones of minimal value, such as low density graphite lenses.
Data collected by the **GRYPHON** system is geared towards the next challenge of providing a 3D Earth model solution for exploration, primarily for the following rock properties:

- Magnetic susceptibility
- Density
- Conductivity
ZTEM AND VTEM AIRBORNE EM AND MAGNETIC RESULTS OVER THE LALOR COPPER-GOLD VMS DEPOSIT REGION, NEAR SNOW LAKE, MANITOBA

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SUMMARY

In late March, 2007, soon after the drill discovery of the Lalor VMS deposit, Hudson Bay Exploration contracted Geotech to fly VTEM time-domain EM surveys over the region west of Snow Lake, Manitoba. The deposit escaped detection due to its large depth of burial (>550m) and the lack of magnetic response. In 2009 Geotech carried out a ZTEM test survey over the Lalor deposit, which was successful and led to a larger survey over the area. In 2012 a second VTEM survey test was flown, using the more deeply penetrating VTEM\textsuperscript{MAX} system. The mine-site development appears to overprint the deeper deposit response. However a deep conductive anomaly above South Bull’s Eye, south of Lalor, is well resolved in the two later EM surveys.

Key words: Airborne, ZTEM, VTEM, electromagnetics, magnetics, 2D-3D inversion, Lalor, VMS

INTRODUCTION

In March, 2007, the Lalor Deposit polymetallic zinc-copper-gold-silver-lead volcanogenic massive sulphide, approximately 3km northwest of Chisel North mine near Snow Lake Manitoba (Fig. 1), was discovered by drill testing a Crone fixed-loop time-domain electromagnetic (DPEM) anomaly from 2003 (Fig. 2). The Lalor drillhole intersected high grade zinc mineralization at a depth of approximately 800 m below surface and would eventually lead to the 14.4 Mt Lalor deposit (Gilmore et al., 2010).

Soon after, in late March, 2007, Hudbay Minerals contracted Geotech Ltd. to carry out a large helicopter time-domain EM survey of the Snow Lake region using its newest VTEM (Witherly et al., 2004) B-field and dB/dt system. Unfortunately the deposit was not detected due to its large depth of burial (>550m) that fell below the ~400m depth of investigation limits imposed by the S/N of the VTEM system at that time.

In November, 2009, Geotech carried out a test of its new ZTEM (Lo and Zang, 2008) passive helicopter-EM system, with the objective to test its ability to map the deeply buried Lalor VMS deposit that had escaped detection in previous airborne geophysical surveys. Initial survey results,
complemented by 2d inversions, confirmed the deposit location and vertical extent, and becoming the first AEM survey to successfully detect Lalor. The survey was subsequently extended across the Lalor Lake-Chisel Lake-Snow Lake region.

In November, 2012, a second VEM survey test was flown, using the VTEM\textsuperscript{MAX} large-loop/large dipole moment system. With the Lalor mine-site development well underway, the deposit area was masked by powerline noise and metallic culture. However, the survey resolved another deeply buried, mineralized but subeconomical stringer-sulphide body southeast of Lalor that was also defined in previous large loop TDEM survey (see South Bull’s Eye anomaly in Fig. 2).

This paper presents the results of these three airborne EM surveys and compares them with the known Lalor VMS and surrounding deposit region.

![LALOR VMS DEPOSIT](image)

Figure 1. General location of Lalor VMS deposit and 2009 ZTEM survey flight lines, in Snow Lake district (modified after Blakley, 2008).

**Deposit Geology and Mineralization**

The Lalor deposit is situated in the Flin Flon Greenstone Belt and is a classic volcanogenic massive sulphide (VMS) deposit similar to other massive sulphide bodies in the Chisel sequence (Chisel Lake (C), Ghost-Lost Lake (G-L), Chisel North (CN), and Photo Lake (P) – see Fig. 3). The Chisel sequence that hosts them contains thin and discontinuous volcanioclastic horizons and intermediate to felsic complexes. Lalor ((L) – see Fig. 3) lies along the same stratigraphic horizon as these other ore bodies and its top is interpreted to lie below a decollement (fault) contact with overturned hanging wall rocks at the surface. The Chisel Lake pluton is a nearby (Fig. 3) late 1.8km x 9.8km layered ultramafic intrusion that truncates the Chisel Lake VMS deposit. Footwall rocks have been extensively hydrothermally altered and metamorphosed to chlorite, sericite and cordierite-anthophylite schist and gneiss (Carter et al., 2012).
Figure 2. Crone fixed loop time-domain EM (DPEM) survey results from 2003, showing Lalor & South Bull’s Eye DPEM anomalies (after Gilmore, 2010).

Figure 3. Snow Lake simplified geology map and legend, showing AEM survey polygons (cyan-blue-violet hatched polygons) and highlighting Lalor and Chisel Lake deposit regions (modified after Bailes et al., 2013).
Figure 4. Lalor VMS deposit shown in: A) Plan view and B) cross-section, showing drillholes and zinc-rich orebody outlines (after Blakley, 2008).
The Lalor Deposit mineralization occurs as massive to disseminated sulphides consisting of mainly of sphalerite, pyrite and chalcopyrite, with lesser galena and arsenopyrite, as well as occasional massive pyrrhotite. Rock units in the hanging wall include mafic and felsic volcanic rocks that have been overturned and are in unconformable possibly fault contact with the footwall rocks. The mineralization is immediately underlain by a thick zone of intense metamorphosed, hydrothermally altered rocks (Carter et al., 2012).

The deposit’s mineral reserves are 14.43M tonnes at 1.86 g/t Au, 23.55 g/t Ag, 0.60% Cu and 6.95% Zn. The deposit has a lateral extent of about 900 metres in the north-south direction, and 700 metres in the east-west direction (Fig. 4a), and it dips shallowly to the northeast. The deposit is geologically interpreted as six stacked massive sulphide base-metal lenses extending from 550-1200m (Fig. 4b) and also six separate, disseminated mineralized gold zones extending from 750-1500m (Carter et al., 2012).

**AEM & MAGNETIC SURVEYS**

The 2007 VTEM (VTEM\textsuperscript{2007}) survey comprised 1743 line-km (104 km\textsuperscript{2}) over the Lalor deposit region (see Fig. 3 & 7a) and was flown at a nominal spacing of 100-200m along NS and EW lines. The VTEM\textsuperscript{2007} system measured 24 off-time channels of vertical dB/dt and calculated B-field (120-6578us) data after a 7.2ms wide trapezoidal waveform pulse at a repetition rate of 30Hz and 390k-410k NIA dipole-moments from a 26m x 4 turn transmitter loop. The EM and caesium magnetic sensors were flown at 35m and 60m avg. terrain clearances, respectively.

The 2009 ZTEM survey consisted of a total of 372 km, flown at a nominal line-spacing of 100-200m, over a 66 km\textsuperscript{2} area (see Fig. 3 & 9). The ZTEM vertical axis receiver coil (7.4m dia.) and caesium magnetometer were flown at an avg. sensor height of 88m and 105m, respectively. Two orthogonal (3.5m dia.) horizontal axis coils (3.5m dia.) measured the horizontal EM reference fields. Data from the three coils were used to obtain the Tzx (In-line) and Tzy (cross-line) AFMAG tipper vector transfer functions (In-phase and Quadrature) at five frequencies in the 30 to 360 Hz band.

The 2012 VTEM\textsuperscript{MAX} test survey, totaling 112.5 line-km (20 km\textsuperscript{2}), was flown along 100-200m spaced NE-SW flight-lines that roughly coincided with the ZTEM coverage and extended southeast from the Lalor deposit (see Fig. 3 & 7b). The VTEM system measured x- and z-components of dB/dt and B-field (83-9286us) from a 5.8msec wide trapezoidal waveform at 30Hz and 1.4M NIA dipole-moments from a 35m x 4 turn transmitter loop. The EM and caesium magnetic sensors were flown at avg. bird heights of 43 m and 60m, respectively.

**Magnetic Survey Results**

Figure 5 presents the total magnetic intensity (TMI) results over the Lalor deposit area, from the ZTEM airborne survey. Strong (>500nT) magnetic highs identify the synvolcanic Richard Lake intrusive complex (RLIC) and the Chisel Lake gabbro (CLG), whose outlines coincide well with the mapped geology map (black hatches traced from Fig. 3). None of the known VMS deposits features a distinctive magnetic anomaly, possibly reflecting weak po-sulphide content. However a weak, SE arcuate magnetic high lineament is seen extending from the Lalor to the Chisel Lake deposit region and roughly coincides with the Ghost rhyolite horizon (G – see Fig. 3) that caps/overlies the Lalor.
deposit. Another weak SE-trending magnetic lineament is seen over the South Bull’s Eye occurrence. More prominent moderate-strong magnetic highs seen further northeast roughly coincide with the Photo rhyolite (P) and Treehouse volcanicleastic-breccia (T) horizons (see Fig. 3) and the Snow Lake fault zone (SLFZ) that suggests it is possibly po-rich as well as graphitic.

Figure 5. Magnetic TMI results, showing outlines of mapped Richard Lake intrusive complex (RLIC) & Chisel Lake gabbro (CLG) and VMS deposit locations (see Fig. 3), and highlighting weak magnetic high extending from Lalor to Chisel Lake (G), relative to responses from intrusions and other units/features (P, T, SLFZ – see Fig. 3).

Figure 6 presents a magnetic susceptibility (mag-susc.) depth-slice at 500m depth obtained from a 3D inversion of the TMI from the VTEM\textsuperscript{MAX} survey using the UBC Mag3d code (Li and Oldenburg, 1996). The 3D inversion revealed a broad range of magnetic susceptibilities, varying between 0 to 0.1 SI units, but with the strongest values within the upper 500m of the surface. As expected, the image shows generally high mag-susc. values inside the RLIC and CLG intrusions and the northern part of the Photo rhyolite (P) to the NE. However the Ghost rhyolite magnetic high (G) lineament is barely visible and nearly disappears entirely below 500m, which is consistent with its cap-rock nature described earlier. More importantly, both the Lalor VMS and the South Bull’s Eye zone coincide with distinct magnetic susceptibility lows, which is consistent with a Mag/Po-poor mineralogy.
VTEM Survey Results

Figures 7ab presents the late off-time time constant (Tau) dBz/dt response from the VTEM\textsuperscript{2007} and VTEM\textsuperscript{MAX} surveys over the Lalor deposit area. These images highlight the responses from shallow sulphide units just north of Lalor, relative to the weak response over the Lalor VMS itself and the absence of powerline-cultural overprint over the Lalor deposit area in 2007 relative to 2012. Also noticeable is the NS conductive zone just west of South Bull’s Eye, the Chisel Lake powerline, and strong responses from barren Foot Mud sulphide horizon (FMSH) and Snow Lake Fault zone (SLFZ).

Figures 8ab present the resistivity depth slices at 400-500m from the VTEM\textsuperscript{2007} and VTEM\textsuperscript{MAX} surveys over the Lalor region. They were obtained from the resistivity-depth imaging of the dBz/dt response using the Geotech RDI technique that is based on the transformation scheme described by Meju (1998). These images highlight a broad, NNE-trending resistivity low feature that extends across Lalor to Chisel Mine, versus the relatively weaker response over Lalor VMS deposit in 2007, as well as 2012 that has also been overprinted by the powerline and minesite culture that post-date the VTEM\textsuperscript{2007} survey. However, the large resistivity lows that are centred over the South Bull’s Eye occurrence in both the 2007 and 2012 surveys are also highlighted. Also noticeable are the strong responses over the barren Foot Mud sulphide horizon (FMSH), the Snow Lake Fault zone (SLFZ) and shallow barren sulphide units just north of the Lalor Mine.
Figure 7. VTEM survey late time Tau from dBz/dt responses for: A) 2007 VTEM and b) 2012 VTEM MAX surveys, highlighting weak response over Lalor VMS deposit, the NS conductive response west of South Bull’s Eye and absence of cultural overprint over Lalor deposit area in 2007 vs. 2012 data.
Figure 8. RDI resistivity depth slices from dBz/dt at: A) 400m depth from VTEM\textsuperscript{2007} surveys, and B) 500m depth from VTEM\textsuperscript{MAX} survey. Also shown are locations of RDI model sections in Fig. 11-12.

ZTEM Survey Results

Figure 9 presents the In-phase ZTEM results in plan at two frequencies (A: 180Hz & B: 45Hz), designed to highlight the relatively shallow (180Hz) and deeper (45Hz) tipper responses, based on relative EM skin depths. They are presented using the DT (Total Divergence; Lo et al., 2009) that converts the tipper cross-overs into peaks using horizontal derivatives. The DT images also show the outline of the Lalor deposit and drill holes overlain. In the DT image, warm colours represent conductive structures and contacts; cool colours represent more resistive units. The Lalor deposit is not well defined in the 180Hz high frequency data to the presence of conductive sulphide units in the
footwall rocks to the north – also defined in the VTEM²007 data (see Fig. 7a). Whereas, in the lower frequency 45Hz image that represents a greater skin-depth of investigation, the Lalor deposit and Bull’s Eye occurrences are both better contrasted from their surroundings. The effect of the NE-SW powerline to the Chisel mine is strongly felt, effectively masking the Chisel Lake-Chisel North-Photo Lake deposit responses at all frequencies. However the Lalor Mine and South Bull’s Eye deposit responses, as well as surrounding Snow Lake Fault (SLFZ) and Footwall Mud sulphide horizon (FMSH), are easily resolved in the ZTEM data.

Figure 9. ZTEM In-phase DT at: A) 180Hz and B) 45Hz, highlighting both relatively shallow and deep conductive responses, respectively, over Lalor VMS & Chisel Centre as well as overprint of Chisel Lake powerline.
Figure 10ab present the resistivity depth-slices at 500m obtained from the 2D and 3D inversion of the ZTEM tipper data using the Geotech’s Av2Dtopo code (ref. Legault et al., 2012) and UBC MT3dinv code (ref. Holtham and Oldenburg, 2008), respectively. As shown, both inversion images feature well defined resistivity low anomalies directly over the Lalor VMS deposit and South Bull’s Eye occurrences.

**Multi-parameter Model Comparisons**

Figure 11 compares the multi-parameter cross-sections across the Lalor deposit obtained from 1D-2D-3D inversion and imaging applied to the VTEM, ZTEM and Magnetic data, with the deposit outline and drillholes (ref. Blakley, 2008). Figure 11a shows the RDI results for L4370 from the VTEM\textsuperscript{2007} survey that highlights a ~1.5km wide resistivity low that is perched at ~200-390m depths above the Lalor deposit - possibly clay-altered volcanic rocks or sulphide mineralization in the upper footwall units. The deposit itself lies undetected at greater depths (~600-1200m), below the estimated depth-of-investigation (DOI) limits for the 2007 VTEM system.

Figure 11b presents the VTEM\textsuperscript{MAX} RDI cross-section for L5020 from 2012 that features a similar perched conductive layer above the deposit that is slightly wider (~2km) extends from 200-500m depths to below 900-1000m, which is the significantly larger DOI for the VTEM\textsuperscript{MAX} system. However, a shallower, more conductive body is also resolved at approx. 50-400m depths, directly above the Lalor orebody that wasn’t detected in earlier VTEM\textsuperscript{2007} survey. This NE-dipping, thin-plate conductor must therefore be related to man-made metallic structure, from the Lalor Mine development that was underway in 2012. The Lalor deposit itself, though partially correlated with the broad low resistivity half-space feature, is undetected/unresolved as a distinct conductive feature at depth. In spite of the fact that it lies within the DOI limits of the VTEM\textsuperscript{MAX} system, the evidence suggests that Lalor is being masked by mine-culture at shallower depth.

Figures 11cd present the 2D and 3D inversion results from ZTEM survey data for L1020 from 2009. The 2D model section in figure 11c highlights a distinctive resistivity low feature that correlates well with the actual depth-extent but is slightly broader (~1km) than the lateral width of the Lalor deposit. The 3D model in Figure 11d highlights a more complex anomaly shape, with a shallower, <1km wide more weakly conductive body that correlates well with the VTEM zone, and a deeper, more conductive anomaly that seems to correlates well with the width, vertical extent and possibly also the dip of the Lalor orebody.
Figure 10. ZTEM Resistivity depth-slice (z=500m) from: A) 2D inversion (Tzx In-line), and B) UBC 3D inversion, highlighting buried conductive responses above Lalor and South Bull’s Eye and location of L1020 & L1100 model sections in Fig. 11-12.

Figure 11e presents the magnetic susceptibility section obtained for L5020 using the UBC Mag3D inversion of the VTEM Max survey TEM data. It shows the Lalor deposit lying within a region of low magnetic susceptibility, with slightly higher susceptibility footwall rocks extending from surface to ~400m depths directly above it.
Figure 11. Lalor Mine section: A) VTEM\textsuperscript{2007} RDI 1D resistivity cross-section for L4370 (see Fig. 8a); B) VTEM\textsuperscript{MAX} RDI 1D resistivity cross-section for L5020 (see Fig. 8b); C) & D) ZTEM 2D & UBC 3D resistivity section for L1020 (see Fig. 10); and E) UBC 3D Magnetic Susceptibility section for L5020 (see Fig. 6); with drillholes and deposit outlines (modified after Blakely, 2010).

Figure 12 presents a similar the multi-parameter comparison for sections across the South Bull’s eye (SBE) EM anomaly that lies approx. 1.5km southeast of Lalor deposit (see Fig. 2) and relates to a subeconomic stringer sulphide mineralized occurrence buried at similar depth to Lalor. The outline of the Maxwell\textsuperscript{TM} conductive 3D plate and model parameters, obtained from the VTEM\textsuperscript{MAX} data that compare well with the ground EM modeling (Hudbay, pers. comm., 2009), are shown for reference. In the absence of cultural contamination, the results from the 3 different surveys can be compared directly to the known geology. As seen in Figure 12a, the VTEM\textsuperscript{2007} RDI image for L4530 shows a 2km wide resistivity low (<120 $\Omega$m) that is perched above the SBE at ~200m depths and extends to ~350-390m depths, the maximum DOI estimate for VTEM\textsuperscript{2007}. A subcropping, steeply dipping conductive zone that is defined near 426500mE and relates to a sulphide mineralized unit in the...
overlying footwall rocks is poorly resolved in this RDI. Another shallow-buried, broad conductive feature situated further east near 429600mE correlates with the Chisel Lake Mine powerline.

The VTEM\textsuperscript{MAX} RDI image for L5100 in figure 12b reveals a similar >1.5km wide-body resistivity low that is slightly deeper (~300m) than in the earlier data but extends to depths close to the 900-1000m DOI depths estimated for the VTEM\textsuperscript{MAX} system. As shown, the Maxwell plate model fits well within the limits of wide-body conductive feature. The subcropping conductive sulphide unit in the overlying footwall rocks is well resolved near 426500mE in this RDI image and the 3D mag-susc. section in figure 12e indicates that it is also highly magnetic, possibly related to pyrrhotite.
The ZTEM resistivity cross-sections obtained from 2D and 3D inversion are shown in Figures 12cd. Both images highlight a buried (~400m), NE-dipping, wide-body (>500m) conductive feature that appears to extend below 1.5km depths. The shallower footwall sulphide conductor near 426500mE is also imaged. The ZTEM and VTEM results are therefore in good agreement.

CONCLUSIONS

Results from three different airborne EM surveys over a 5-year span have allowed us to compare the system responses over the Lalor VMS deposit region, near Snow Lake. The initial VTEM\textsuperscript{2007} survey that was undertaken shortly after the Lalor deposit discovery reveals that the orebody escaped detection due to its large depth of burial (>550m) relative to the depth-of-investigation limits of the VTEM\textsuperscript{2007} system as well as the absence of a magnetic response. A shallower, wide-body conductive feature that was resolved at 300m-depths in both the VTEM\textsuperscript{2007} and later VTEM\textsuperscript{MAX} results above Lalor might represent clay alteration related to the VMS deposit or else sulphide mineralization in the overlying footwall rocks. Although the improved DOI limits for VTEM\textsuperscript{MAX} should have allowed it to penetrate to Lalor, a conductive feature that is defined at shallower depth is instead related to mine-site culture and masks the deeper deposit signature. ZTEM survey results from 2009, prior to mine development, appear to detect the Lalor VMS deposit, which seems to be confirmed in 2D-3D inversion results. Another comparison with all three systems over a similar, but culturally uncontaminated, deeply buried EM anomaly, known as South Bull’s Eye that is related to subeconomic stringer sulphides, proves it to be well resolved in the VTEM\textsuperscript{MAX} and ZTEM results.

ACKNOWLEDGMENTS

We wish to thank BCGS for initiating the Lalor Symposium and Hudbay Minerals for graciously releasing these Lalor ZTEM and VTEM data for use in our study.

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Fact Sheet: SkyTEM\textsuperscript{512} at Caber

Overview

In February 2014 SkyTEM conducted a test survey mapping the well-known Caber deposit 30 km west of Matagami in Québec, Canada. The massive sulphide deposit is located at an approximate depth of 150 m and is partly covered by conductive overburden.

The survey was flown with the recently developed SkyTEM\textsuperscript{512} system, which has the highest dipole moment of all SkyTEM systems. The results presented below demonstrate the high spatial resolution and low noise properties which characterize SkyTEM data.

Key Facts

- 536 m\textsuperscript{2} transmitter area
- 12 turns transmitter coil
- 775,000 NIA peak dipole moment
- Superior late-time signal to noise ratio and depth penetration
- Patented MultiMoment\textsuperscript{®} technology ensures detailed shallow resolution and depth penetration

The High Moment gates presented in panel A cover the time range from 200 µs to 10 ms and clearly resolve the Caber Anomaly in the central part of the profile. The magnified view in panel B displays only late gates, which cover the time range from 1.6 to 10 ms. The low noise level allows for a high signal to noise ratio and late time anomaly definition. Panel C displays the simultaneously recorded magnetic data supporting the exact location of the EM anomaly.
NEW TDEM TECHNIQUE AIDS IN DISCOVERY OF LALOR MINE, SNOW LAKE, MB, CANADA

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   3. North America Palladium Ltd.

Date of Surveys Dec (2002), Jan-Mar (2003), Mar 2007

In the winter of 2002-2003 Koop Geotechnical Services was the geophysical contractor hired to conduct the Deep Penetrating EM surveys in the Chisel Basin Mine Stratigraphy. Senior Geologist, Chris Roney implicated the survey to create more targets for his 2002-2003 drill program. Six months earlier Chris was approached by Alan Vowles on trying a new Deep EM Late Time method he thought would work and Chris lobbied for the money for Alan to test his idea out. Alan got the money and hired Koop Geotechnical to help test the new survey out. After it was successful, Alan with Chris planned a systematic coverage of the Chisel Basin with a series of large loops numbered consecutively from #1 through #4.

Loop #1 was laid over a thick (>400 m) gabbro sill which is known to overlay the Chisel stratigraphy. No new anomalies were revealed but when Koop observed the conductivity was increasing to the north east, Loop #2 was laid in that direction. The survey result was a large anomaly centered in the middle of the loop. Loop #3 was then laid down-dip of the Chisel North Mine to see if it would produce a similar response. Still the best anomaly of all three loops was centered beneath Loop #2.

Loop #4 was then laid north of Loop #2 where the Chisel Horizon was known to be increasing in depth. To increase field strength and cover more area the loop was made larger however the amps were low so the wire was doubled to decrease resistance. Coincidentally another anomaly occurred in the center of Loop #4 similar to the anomaly produced from Loop #2.

During the spring of 2003 Chris Roney had little time to drill one hole into the Loop #2 South bull’s eye anomaly. The hole intersected stringer chalcopyrite, pyrite and pyrrhotite in a chlorite, biotite, and garnet schist from 640-750 meters. Unfortunately it was not ore grade so the decision was made not to test the anomaly in Loop #4 to the north as time and money ran out.

2005 – Chisel Basin was once again on the books for more exploration. It seemed like too much of a coincidence that there would be two circular anomalies in the centre of two loops so it was decided to lay one long rectangular loop #5 to encompass both anomalies to see if there would only be one anomaly centered in Loop #5. The survey reproduced the two bull’s eye anomalies in the same location as seen from Loops 2 and 4.
2007 – Craig Taylor was Project Manager for Snow Lake exploration and decided to test the north bull’s eye and asked Alan Vowles to model the anomaly in order to plan a drill hole. The anomaly was modeled in EMIT Maxwell program and indicated a plate approximately 800 x 800 meters and dipping at 20 degrees. The centre of the plate where the drill hole was projected to pierce it was at a depth of 800 meters.

2007 Koop Borehole TDEM on Discovery hole Dub-168 using the Crone system.

Koop Geotechnical was then hired to do the borehole TDEM survey on all the Lalor holes from 2007 to 2010. The discovery hole Dub168 was a very exciting hole to survey as it showed much more to come and it was the TDEM borehole surveys that really gave a lot of aid on drilling off the Lalor deposit.

Koop Geotechnical would like to give special recognition to the explorationists that were a big part of this being the highlight of Dave Koop’s career. Alan Vowles, Chris Roney, Craig Taylor, and Jerry Kitzler. These gentlemen played a very big part in the Chisel Basin modern exploration projects that made this possible. Yes there are many others who contributed but these guys really put a lot of effort into this area and deserve recognition.
Geophysical Time Domain Contractors in the Snow Lake/Flin Flon VMS Greenstone Belt

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THE NEW GENERATION JESSY HTS SQUID TEM RESULTS
OVER THE LALOR DEPOSIT

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INTRODUCTION
This paper presents data acquired in December 2009 using the new generation of high temperature Jessy HTS SQUID sensor over the Lalor Zn-Cu-Au deposit. The Jessy HTS SQUID sensor is manufactured by IPHT (Institute of Photonic Technology) in Jena, Germany, and operated by Discovery International Geophysics Inc.

ABOUT LALOR
The Lalor deposit is approximately 15 kilometres from the HudBay concentrator in Snow Lake, Manitoba, an area that is a significant past producer of gold. The ongoing evaluation, exploration and development of the Lalor deposit is a primary focus for the company, as the Lalor deposit could be of significant financial benefit to HudBay and support substantial long term activity in the Snow Lake area.

The Lalor Deposit is located within the meta-volcanics, meta-sediments and granitoids of the Churchill province near Snow lake, Manitoba. The Lalor deposit was discovered in March 2007. The deposit is located in the Chisel Basin portion of the Flin Flon Greenstone Belt and is believed to be the largest VMS deposit found in this region to date.

Zinc rich base metal zone: Mineralization occurs in six separate stacked lenses of zinc rich polymetallic, near massive to massive sulphide mineralization approximately 570 meters to 1,170 meters below surface. In October 2009 an indicated resource of 12.3MT 1.6 g/t Au, 24.2 g/t Ag, 0.66% Cu, 8.70% Zn, and an inferred resource of 5.0MT 1.4 g/t Au, 25.5 g/t Ag, 0.57% Cu, 9.39% Zn were disclosed.

Gold zone: Low sulphide precious metal intersections associated with chalcopyrite and galena. In January 2009, HudBay reported the discovery of a new gold zone with the potential to have principal credits derived from gold mining, and on October 8, 2009 announced a conceptual estimate of a potential gold zone, interpreted as five discrete mineralized lenses that can contact the near massive sulphide zinc-rich mineralization.
Copper-Gold zone: Disseminated to near solid chalcopyrite with lesser pyrrhotite and minor pyrite, sphalerite and galena located to the north of Gold zone 27 at approximately 15 to 20 degrees down plunge and at vertical depths of between 1,200 and 1,300 meters.

For more details on the Lalor deposit, including the resource estimate for the zinc-rich base metals zone and the conceptual estimate of the potential Gold zone, please refer to the NI 43-101 compliant technical report for Lalor dated October 8, 2009 and the company's September 22, 2009, October 8, 2009 and December 17, 2009 news releases, available at www.sedar.com.

![Figure 1. Regional Geology over the Lalor Deposit](image)

**SURVEY LAYOUT**

The survey was conducted using transmitter loops already in place as shown in Figure 2.

Lines 18400 and Lines 17600 were surveyed with the Jessy HTS SQUID at a transmitter frequency of 1.66 Hz using the large transmitter loop. Line 17600 was also surveyed with an induction coil at a transmitter frequency of 5 Hz with the large transmitter loop.

Lines 19200 and T2650 were surveyed with the Jessy HTS SQUID at a transmitter frequency of 0.5 Hz using the smaller east loop.
ABOUT HTS SQUID

The SQUID (Superconducting QUantum Interference Device) consists of a small sensor (typically a cm in size) which becomes a super conductor at low temperatures ~ 69 degrees Kelvin for HTS and ~ 4 degrees Kelvin for LTS applications. The sensor is located within a cryostat and is cooled with liquid nitrogen for HTS SQUIDs and liquid helium for LTS SQUIDs.

SQUID EM sensors have been in service for ground electromagnetic surveys for approximately 10 years, including the CSIRO LandTEM HTS SQUID system and the proprietary Jessy LTS SQUID sensor developed for Anglo American.

The new generation Jessy HTS SQUID sensor was developed by IPHT under agreement with Discovery International Geophysics Inc. The Jessy HTS SQUID is a robust sensor contained within a glass fibre reinforced ceramic cryostat. The Jessy HTS SQUID is optimised for easy and fast operations and is suitable for all field conditions. After positioning the measuring unit, the control unit is connected and placed in a few meters distance. A measurement is initiated with the button auto tune. Batteries need overnight recharging and the system is refilled with liquid nitrogen every day.

Figure 2. Survey Layout and Ore Body Location.
Coupled with the SMARTem receiver from ElectreMagnetic Imaging Technology (EMIT) and a Phoenix Geophysics high-powered TXU-30 transmitter, the Jessy HTS SQUID sensor is capable of directly measuring magnetic fields (the B-field in electromagnetics) to an accuracy of about 10 femtoTesla.

![B FIELD VS INDUCTION MEASUREMENTS](image)

**Figure 3. SQUID Sensitivity.**

**B FIELD VS INDUCTION MEASUREMENTS**

A number of authors have championed the advantages of B-field measurements including Osmond and LeRoux. The Jessy HTS SQUID EM sensor offers the advantages of B-field measurement as well as the unparalleled accuracy of SQUID sensors. Sources have cited accuracy improvements of up to 10 to 20 times that of conventional Induction coil receivers.

Conventional induction coil receivers measures the time derivative of the magnetic field resulting from electric currents induced in the ground. With a square transmitter waveform, this measurement of dB/dt is an approximation of the "impulse response".

The Jessy HTS SQUID sensor enables the collection of higher quality B-field data at lower frequencies. The time-integral of the impulse response, which is called "step response", is obtained by measuring the B-field TEM response with the Jessy HTS SQUID sensor. The time-integral is an important "filter" and attenuates decays which are rapid (from weaker or unconfined conductors) in preference to decays which are slow (from strong conductors).
A significant advantage of the Jessy HTS SQUID is the ability to measure increasingly later time gates, resulting in better definition of highly conductive targets at increasingly greater depths. For base metal sulphide targets with high conductivities, the later time gates are crucial to defining deeper zones or targets that are undetected below other less conductive shallow bodies or conductive overburden.

As a result of the preferential attenuation of fast decays in a B-field TEM survey, it is easier to observe the response of a good conductor in the presence of a weaker conductor such as a host, overburden or less conductive bedrock feature. The response of a good conductor is observed in a B-field TEM survey earlier in time than it is in an equivalent dB/dt survey which means that it is more likely to be above the noise level.

Some indirect advantages of using the Jessy HTS SQUID sensor is the increased accuracy of the measurement may aid in the design of a more focussed EM survey array with a smaller transmitter loop to further reduce the background or layered response. Additionally, the higher accuracy of the resulting data collected with the Jessy HTS SQUID sensor will result in more accurate models and interpretations of the data for exploration purposes.

**TIME GATES**

An essential factor in the discovery and evaluation of high conductivity targets with Time Domain EM surveys is the ability to measure later time gates at lower frequencies.

*Figure 4. Time Gates.*
This was initially accomplished with the use of very large transmitter loops with high dipole moments and long stacking times to improve signal quality. The traditional TDEM surveys at 30Hz which measured decays out to about 8 milliseconds are not suitable for the task. Increasing the decay measurement to ~ 50 milliseconds with long stacking improved the signal significantly at late times and resulted in the detection of the Lalor deposit. Another leap forward in signal quality at later times of up to 130 milliseconds was obtained with the use of fluxgate and SQUID sensors (Mark Shore, et. al., 2009).

The Jessy HTS SQUID is also capable of these late times and perhaps even later decay times of up to several hundred milliseconds.

DECAYS

The Jessy HTS SQUID shows very stable and clean decays. Figure 5 shows a comparison of the induction coil (6 repeats at 256 stacks) and the Jessy HTS SQUID (10 repeats at 64 stacks). Figure 6 shows the Jessy HTS SQUID at 1.6 Hz (10 repeats at 64 stacks) and 0.5 Hz (16 repeat measurements at 32 stacks).

*Figure 5. Induction Coil (5 Hz) and Jessy HTS SQUID (1.6 Hz).*
PROFILE COMPARISONS

The profile data using the Jessy HTS SQUID is cleaner than the existing fluxgate and LandTEM SQUID data at late gate times, although the target is easily detected by all three sensors.

Figure 6. Jessy HTS SQUID Decays (1.6 Hz and 0.5 Hz).

Figure 7. Profiles.
MAXWELL MODEL INTERPRETATION

The Maxwell program from ElectroMagnetic Imaging Technology (EMIT) was used to model the Jessy SQUID TEM survey data. This program is a fast and accurate plate modeling algorithm with inversion optimization capabilities.

Model studies have suggested that characteristic peaks (or troughs) of complex conductors in close proximity may be displaced from the actual conductor location. Some further modeling shows the peak displacements are also affected by the conductor dips, conductivity and transmitter-receiver configurations. This suggests it is important to generate models to determine the actual conductor locations.

The procedure for interpreting EM data is to create relatively simple models with Maxwell to determine dips, positions and relative conductivity of complex conductors. This helps to compensate for any geometric effects of complex conductor systems.

Simple or complex conductors are initially based on the width of the anomaly. A single conductor appears as a well-defined anomaly. A complex conductor (either wide or multiple) appears as a much wider anomaly, which may be skewed depending on the conductivity differences within a wide conductor or among multiple conductors. The layered (or background response) is simulated by a horizontal sheet. For fixed loop surveys a large sheet (~10x loop size) is placed centered under each transmitter loop. The data may be further complicated by areas of conductive background (conductive blocks). The elevated background due to the conductive blocks is not immediately apparent until conductor models are examined.

Figure 8. Maxwell Model and Ore Body Locations.
The modeling / interpretation process consists of a controlled inversion with the Maxwell software. Quite often only a single component and a narrow range of channels can be used to determine an inverted model for the late time responses. In this case, an interpreted model was made with Maxwell with all 4 profiles simultaneously. A constrained inversion using late time channels 25 - 34 (22 ms to 125 ms) was performed with the only rigid constraint being the strike and dip direction derived from the geological data.

The Maxwell model was an attempt to fit the later time data on all 4 profiles from two separate loops simultaneously within a range of channels for both the Z and X components. It was almost immediately evident this is a complex model. For electromagnetic surveys, a complex model is anything more than a single plate in a homogenous background.

The model does a very good job of capturing a first order approximation of the ore bodies. Not surprisingly, the green Maxwell plate is located near the surface of the complex ore bodies. The magenta plate suggests the anomalous area continues at depth with an increased dip. There is also strong evidence of a nearer surface feature and an off-line response. The model conductivities interpreted from the Maxwell inversion are approximately consistent with those measured from down-hole EM surveys.

In particular, the final, best-fitting model (Figure 10) demonstrates that the 1200m deep Copper-Gold zone has been detected and resolved with the superior signal-to-noise of the Jessy HTS SQUID sensor.
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¹Highest Signal-to-Noise  ²Less than 1 Hz  ³Commercially Available

A potent combination of leading technologies: Jessy Deep HT SQUID - the most sensitive commercially-available B-field sensor; EMIT SMARTem24 - the most advanced 24-bit, time-series TDEM receiver; and Phoenix TXU-30 - high power transmitter - 20 kW - 40 A.

Benefits

♦ Direct B-field measurement at low frequency (0.1 to 5.0 Hz) optimizes sensitivity to strong conductors.
♦ High signal-to-noise ratio enables unrivalled depth search capability.
♦ Detect and define good conductors in the presence of more weakly conductive formations and overburden.
♦ High data resolution leads to a more accurate interpretation.
♦ High sensitivity and high power enables survey efficiencies.

Slingram survey over a 750 m deep conductor

3Hz SQUID B-field (pT/A)  3Hz Coil dB/dt (nV/Am²)

B-Field EM Sensor Noise Characteristics

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Figure 10. Maxwell Model Fit with and without the Deep Cu-Au Zone.
CONCLUSIONS

The Jessy HTS SQUID (developed by IPHT and operated by Discovery Geophysics), is an impressive new tool for electromagnetic surveys which require high accuracy and later time gates of the transient EM decay.

The Jessy HTS SQUID offers all the advantages of direct B-field measurement including:

- The potential to see through other conductive bodies or conductive layers.
- Better conductivity resolution of good and “super” conductors with conductivities above 1000 Siemens.
- Suppression of the background response and the ability to image good conductors in early- and late-time transient decays.
- The unparalleled accuracy of SQUID sensors with accuracies of up to 10 to 20 times that of induction coil measurements.

The Jessy HTS SQUID’s high accuracy lends new strength to model interpretations and inversions.
THEN AND NOW: UTEM3 AND UTEM5 COMPARISON OVER THE HUDBAY LALOR DEPOSIT

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Summary

UTEM test surveys were carried out over the Hudbay Lalor deposit using two generations of UTEM equipment: UTEM3 (then) and UTEM5 (now). The results of two UTEM test surveys are presented, compared and modeling results are shown. The UTEM surveys were carried out by Lamontagne Geophysics Ltd. with the support of Hudbay.

The initial UTEM3 surveying was carried out using the Hudbay test loop - Loop 5, designed to test the deeper extent of the deposit - as the transmitter loop. Further UTEM3 and all UTEM5 surveying was carried out using a modified version of the test loop – labeled Loop 5L – designed to better couple with the overall Lalor deposit.

Pertinent details of the two UTEM surveys are as follows (map Figure 1):

- **UTEM3**: January 2011 – earlier in construction phase on Lalor site: no power line installed single-component surface coil, Hz (vertical) and Hx (inline horizontal) components collected data collected on survey lines: 176N, 182N, 196N and Line 63E, transmitter Loop 5 and Loop 5L 10Channel UTEM data collected at 30/4/2Hz modeling results (MultiLoop 2) are shown

- **UTEM5**: April 2014 – late-stage of Lalor site construction, power line in place. 3-component surface coil:HZ (vertical) HL/HT (inline/transverse horizontal) components collected data collected on survey lines: 176N, 182N and Line 63E using transmitter Loop 5L 12Channel UTEM data collected at ~1.0/0.25Hz modeling results (MultiLoop X) are shown

The UTEM SYSTEM - Now

UTEM uses a large, fixed transmitter loop as its source. Transmitter loops range in size from 300x300m to dimensions as large as 4km by 4km. Loops less than 800x800m are rarely used. In general smaller loops are used for surveys over very conductive ground and for some depth-sounding applications. The larger loops are typically used over resistive terrain.

The UTEM instruments are synchronized together at the beginning of a survey day. The instruments have precision clocks and can operate remotely for a full survey day – even underground – without
any timing reference. In surface surveys measurements are routinely taken to a distance 1.5 to 2 times the loop size. Survey distance can be extended beyond this - depending on the ambient noise level and stacking time allowed. Lines can be surveyed inside the loop, outside the loop or through the loop depending on the orientation of the intended targets. BHUTEM surveys – the borehole version of UTEM surveys – have been carried out to depths of 3000m.

System Waveform

The UTEM transmitter passes a low frequency current waveform of precisely regulated shape through the large loop antenna. The frequency is set to minimize the interaction of power line effects. Using automated frequency interleaving, the receiver can do simultaneous multi-transmitter 3-axis measurements with up to three transmitters.

The transmitted current has a pre-emphasized triangular waveform which is optimized for signal-to-noise and power efficiency. The base frequency of the waveform can be set to any value with great accuracy. The usual range is 0.25Hz to 32Hz. The UTEM sensors are very linear nulling coils that generate feedback signals proportional to the B field. The signal from the sensor consists of digital data sampled at 100kHz rate for each of three components. The signals are deconvolved in the receiver into square wave responses using a filter which exactly inverts the effect of the transmitter pre-emphasis filter. All channels after stacking should have amplitudes equal to the primary field in the direction of the particular sensor axis - in the absence of any conductor. The sampled channel data on every successive half-cycle should be equal in magnitude and of alternating polarity. The channel sampling methods of UTEM3 and UTEM5 are similar, but the UTEM 5 sampling method includes a number of enhancements.
UTEM3 10Ch Sampling

The UTEM3 receiver measures the time variation of the magnetic field in the direction of the receiver coil at 10 delay times (channels). UTEM channels are spaced in a binary, geometric progression across each half-cycle of the received waveform. Channel 10 is the earliest channel and it is $1/2^{10}$ of the half-cycle wide. Channel 1, the latest channel, is $1/2^1$ of the half-cycle wide (Figure 2). The measurements obtained for each of 10 channels are accumulated over many half-cycles. Each final channel value, as stored, is the average of the measurements for that time channel. The number of half-cycles averaged generally ranges between 512 (256 full-cycles) to 32768 (16K) depending on the level of ambient noise and the signal strength.

Figure 2. UTEM3 10Ch boxcar sampling.

UTEM5 12Ch Sampling

The UTEM5 system collects 3-component EM data from up to 3 transmitter loops - three coupling angles - simultaneously - translating to improved target definition and greater sensitivity to all targets. UTEM5 surface equipment has a greater advantage at low frequency – below 4Hz. And the UTEM5 technical advantage is greatest in the search for targets that are deeper and more highly-conductive using large transmitter loops – the geometry of the applied field is simpler. UTEM5, however, was designed to be useful in numerous other applications.

UTEM5 12Ch sampling is detailed in Figure 3. Both boxcar (equivalent to UTEM3) and tapered sampling are shown. The use of UTEM4/5 Transmitters and UTEM5 Receivers allows for the implementation of:

- Ch0 - a narrow Ch later than Ch1 and making Ch0 normalization - normalization at a later point in time - possible.
- 3 timing channels - Ch13/14/15 for 12Ch UTEM5 - these improve the operator’s ability to monitor Rx/Tx(s) synchronization and allows more precise phase correction/improved post-measurement deconvolution.
The ability to simultaneously collect higher-precision, 3-component data from multiple transmitters (multiple coupling angles) at low frequency is really what the UTEM5 system is designed for - to be efficient and precise. To date UTEM5 surveys using multiple transmitters operating at base frequencies as low as 0.25Hz have confirmed that both the sensitivity of the system and the rejection of non-survey frequencies (power line noise etc.) is far superior to previous UTEM systems.

Figure 3. UTEM5 12Ch sampling.
Lalor Deposit UTEM3 Profiles (Figure 4)

UTEM 3 survey data collected (February 2011) over the Lalor Deposit of HudBay Minerals Inc. The deposit is located in the Chisel Basin portion of the Flin Flon Greenstone Belt and is believed to be the largest VMS deposit found in this region to date. Mineralization occurs (2011) in six separate stacked lenses of zinc rich-polymetallic near-solid to solid sulphide mineralization ~570-1,170m below surface. Exploration continues to focus down-plunge. The discovery of Lalor by the HudBay team won the 2008 Bill Dennis Award for a Canadian discovery by the Prospectors and Developers Association of Canada (PDAC).

![Lalor Deposit UTEM3 Profiles](image-url)
Profiles are shown for Loop 05 and Loop 05L reduced with UTM easting/northings but not topography.

The deposit is clearly detectable with UTEM 3.

**UTEM3 MultiLoop 2 Modeling Results - Lalor Deposit**

MultiLoop 2 modeling results for the 4Hz UTEM Loop 05L profiles - Lines 176N, 184N and cross-Line 63E - are shown below. The aim of the modeling is to show that the results are consistent with the known deposit.

Notes on the model:

- a single 300S plate modeling the Upper Chisel/Lower Chisel contact surface
- a broader, 50m deeper, 50S plate modeling the response of the footwall alteration/mineralization package
- Zinc-rich Base Metal Zones -10,11,20,30,31,40 - roughed in as 300S plates (from the 43-101 information) erring a bit on the large size - cut off is ~grade, not conductivity.

---

![Figure 5. UTEM3 MultiLoop 2 Modeling Results – Lalor Deposit.](image-url)
Lalor Deposit UTEM5 Profiles (Figure 6)

UTEM 5 survey data collected (April 2014) over the Lalor Deposit of HudBay Minerals Inc. Profiles are shown for Loop 05L reduced with UTM easting/northings and DEM topography.

Figure 6. Lalor Deposit UTEM5 Profiles.
MultiLoop X Modeling Results - Lalor Deposit

Initial MultiLoop X modeling results for the 1Hz UTEM Loop 05L profiles - Lines 176N, 184N and cross-Line 63E - are shown below. The aim of the modeling is to show that the results are consistent with the known deposit.

The deposit is clearly detectable.

MultiLoop X - EM Modeling in Your Browser - is a cross-platform version of MultiLoop 3. The user interface runs in a browser as a client HTML5 application - taking advantage of powerful JavaScript libraries - whereas the computations are done in an application that can be either local or on a server. MlpX presents the user with a 3D-modeling scene in which it is easy to compose and modify models by using WebGL based tools. Modeled responses are presented as plots embedded in 3D. An svg plotting layer makes it possible to present and compare the results in the same format as regular 2D plots that can be saved in pdf or kept in svg format for large or detailed presentations.

![Figure 7: UTEM5 MultiLoop X Modeling Results – Lalor Deposit](image)
Lundin Mining Corporation is a diversified base metals mining company with operations in Portugal, Sweden, Spain and USA, producing copper, zinc, lead and nickel.

In addition, Lundin Mining holds a 24% equity stake in the world class Tenke Fungurume copper/cobalt mine in the Democratic Republic of Congo and a 24% ownership in the Freeport Cobalt Oy business, which includes a cobalt refinery located in Kokkola, Finland.

### Production Assets

<table>
<thead>
<tr>
<th>Location</th>
<th>Neves-Corvo</th>
<th>Zinkgruvan</th>
<th>Aguablanca</th>
<th>Eagle</th>
<th>Tenke</th>
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<tr>
<td>Ownership</td>
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<td>100%</td>
<td>100%</td>
<td>24%</td>
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<tr>
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<td>Producing</td>
<td>Constructing</td>
<td>Producing</td>
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<tr>
<td>Growth potential</td>
<td>World-class Zn deposit</td>
<td>10%+ throughput, Cu</td>
<td>Producing in Q4</td>
<td>Production in Q4</td>
<td>Very high</td>
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<tr>
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<td>Underground</td>
<td>Open pit</td>
<td>Underground</td>
<td>Open pit</td>
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<tr>
<td>End product</td>
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<td>Concentrate</td>
<td>Concentrate</td>
<td>Concentrate</td>
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<td>8</td>
<td>40+</td>
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<td>5,500 tpd</td>
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<td>n/a</td>
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### 2P Reserves –

**June 2014**

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<th>Mt</th>
<th>25.4</th>
<th>11.6</th>
<th>4.4</th>
<th>5.2</th>
<th>144.1 (100% basis)</th>
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<tr>
<td>grade</td>
<td></td>
<td>2.8% Cu</td>
<td>8.5% Zn;</td>
<td>3.4% Pb</td>
<td>0.6% Ni;</td>
<td>3.1% Ni;</td>
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<tr>
<td>Secondary</td>
<td>Mt</td>
<td>20.6</td>
<td>3.4</td>
<td></td>
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<td>grade</td>
<td>7.5% Zn</td>
<td>2.2% Cu</td>
<td></td>
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</tr>
</tbody>
</table>

**2014 Estimates**

**June 2014**

| Production tonnes | 50,000-55,000 Cu | 75,000-80,000 Zn | 7,500-8,500 Ni (commissioning) | 2,000-3,000 Ni (attributable) | 47,900 Cu |
| Production tonnes | 60,000-65,000 Zn | 29,000 - 32,000 Pb | 6,000-7,000 Cu | 2,000-3,000 Cu | 12,700 Co |
| Cash costs US$/lb after by-product credits | 1.85 Cu | 0.35 Zn | 4.25 Ni | n/a | 1.21 Cu |

### Exploration

Total exploration expenses for 2014 (excluding Tenke) are estimated to be $35 million (2013: $34 million). These expenditures will be principally directed towards underground and surface mine exploration at Neves-Corvo, Zinkgruvan and Eagle, and on select greenfields exploration programs and new business development activities in South America and Eastern Europe.
Eagle Resource Exploration, USA (Copper, Nickel)

Exploration in the second quarter of 2014 continued to focus on underground drilling, underground borehole geophysics, and planning for surface geophysical surveys. A gravity survey was completed and regional drill targets will be tested in the third quarter of 2014. Planning progresses for a seismic survey to take place in the third quarter of 2014.

Eagle East is a second ultramafic intrusion separated from the Eagle intrusion, which hosts the Eagle orebody, by one kilometer. Surface drilling at Eagle East has focused on tracing the feeder dike at depth using directional drilling. The semi-massive sulphide breccia textures and metal contents in the drill intercepts from Eagle East are similar to parts of Eagle. There is evidence that with depth, Eagle East becomes a more dynamic magmatic system that is more analogous to Eagle than was previously thought, which improves its potential for higher grade nickel-copper sulphide concentrations as seen with initial drill hole results recently reported.

Neves Corvo Resource Exploration, Portugal (Copper, Zinc)

Drill rigs were stepped down in the second quarter of 2014 to facilitate a suspension of surface exploration efforts at the mine. Mine exploration will continue through underground drilling focusing on resource expansion targets at Lombador and Corvo.

Los Rulos Joint Venture Exploration, Chile (Copper, Gold)

A 50/50 Joint Venture (JV) agreement with Southern Hemisphere Mining was executed in late 2013 to explore copper-gold prospects across an extensive package of low altitude mineral properties in the Coquimbo region of the Chilean coastal copper belt. Fieldwork completed to date, including trenching, mapping and geophysics, has resulted in two promising targets, Polvareda and Armandino. In Polvareda, geophysical target definition was completed during the second quarter of 2014 and the target is being advanced towards drill testing in the third quarter of 2014. Drilling commenced late in the second quarter of 2014 at Armandino following the completion of geophysical target definition.

Peru (Copper)

Work in Peru has focused on new copper project evaluations. Two new exploration properties have been optioned, including an undrilled porphyry copper prospect located close to the coast in central Peru. Initial targeting and permitting work has been underway since the first quarter of 2014 with plans to drill in the third quarter of 2014.

Eastern Europe (Copper Gold)

Project evaluation work advanced during the quarter targeting new copper opportunities in favourable parts of Eastern Europe, including Turkey and Serbia. An exploration property located in central Turkey hosting an undrilled, outcropping porphyry copper prospect, was optioned in the second quarter of 2014. Drill target definition work is planned for the third quarter of 2014.
LALOR BOLIDEN GROUND ELECTROMAGNETIC SURVEY

Bertil Sandstrom

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A ground electromagnetic survey was performed in Lalor with the Boliden frequency domain system, EM3-2001. Four profiles, separated by 250 m, were surveyed with a station distance of 20 m and a total profile length of 14120 m. The survey was performed by two Boliden survey technicians and completed in one day.

Geophysics has always played an important role in exploration work carried out by Boliden Mineral. In particular, various electromagnetic techniques have been extensively used. Since 1980 a three-component (3D) frequency domain down-hole EM system has been routinely used in exploration for sulphide mineralisation. That system was later developed into a ground EM system. Both systems utilise the same transmitter and operate at four different frequencies. Transmitting an alternating current through a loop source at surface creates an electromagnetic field. The receivers measure the amplitude and phase of the electromagnetic field in three different directions for each frequency. The measured field is the combined effect of the primary surface field and the response from the subsurface (the secondary field). The primary field is calculated utilizing the XYZ-coordinates from both the loop and stations.

In the Lalor survey the frequencies used were 88, 264, 616 and 2024 Hz. Interpretation is done with an inhouse application, assuming that secondary currents flow along the edges of conductors. The interpretation gives a 3D representation of the conductors described as polygons.

An interpretation of the survey describes a solution where the conductor’s central part of its upper edge is located approximately 800 m below surface, while the upper edge is located closer to surface towards NW. The conductor exhibits a shallow dip towards NE and is open towards depth and in the strike direction.
EXTREMELY LOW FREQUENCY EM (ELF), A GROUND-BASED TIPPER SURVEY

AT THE LALOR DEPOSIT

Dave Hildes¹

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The extremely low frequency electromagnetic system (ELF) is a new passive ground geophysical technique, closely related to Geotech’s ZTEM airborne system. The ELF unit is very portable and cut lines are not necessary. Daily production for a two-person crew is typically between two and four line-km depending on terrain, station spacing and geomagnetic conditions. The survey measures vertical and horizontal components of the natural time-varying geomagnetic field originating primarily from global lightning activity. The system calculates the tilt angle, or tipper, of the magnetic fields from 11 to 1440 Hz which are sensitive to 2D and 3D conductivity contrasts. The system is designed to image resistivity from depths of 10s of metres to two kilometers dependant on the host conductivity structure. The ELF system offers a very cost-effective alternative to other deep imaging EM techniques such as MT / CSAMT / large-loop TEM. The data can be inverted in three dimensions to provide a full conductivity structure of the earth which can be efficiently integrated with other geological knowledge. The results can be useful in mapping both small shallow features and larger regional geological structures.

Data over the Lalor Deposit were collected in a small orientation survey with a prototype of the ELF in the Fall of 2010 and the resultant data are inverted to produce a three dimensional representation of the conductivity structure. A description of the system, field procedures, case studies and results from the Lalor survey are discussed in the presentation.
WINTER AMT SURVEY OVER THE LALOR DEPOSIT

Caroline Finateu¹

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This paper describes an AMT (Audio Magneto-Telluric) test survey done during March/April 2014 over the Lalor VMS deposit located near Snow Lake, Manitoba. AMT has increasingly been used worldwide in exploration for deep ore deposits since the Ecole Polytechnique 1991 and Phoenix 1992-1993 surveys at Trillabelle (Sudbury), which detected a Ni-Cu deposit 1750 m below surface (Livelybrooks et al., GEOPHYSICS, Vol. 61, NO.4 (JULY-AUGUST 1996), P. 971-986).

The advantages of AMT include: lightweight equipment, small footprint, no requirement for a controlled source, deep penetration, small field crew (3 persons in this survey) and a rich suite of information from the full tensor data.

For several years, Phoenix Geophysics and HudBay discussed trying a tensor AMT survey at Lalor, but could not find a mutually acceptable time window before the Lalor deposit went into production. However, because of the impending Lalor symposium, early in 2014 Hudbay and Phoenix decided it was “now or never.”

The objective was to determine whether AMT could be useful in greenfield reconnaissance exploration for such deposits.

So the survey went ahead in spite of the non-optimal conditions, some of which are mentioned next. The 24/7 mining operation in close proximity was a source of substantial cultural noise. The winter of 2013–14 in Canada was exceptionally cold, with heavy snowfall, which limited the daily production. The wintertime AMT signal was weak, and increased the width of the AMT “dead-band” (the signal minimum between ~1 kHz and 5 kHz).

The survey comprises 18 tensor AMT stations at 100 m spacing on two parallel NE-SW profiles (Lines L176 and L184), 200 m apart. These lines cross the centre of the deposit and extend approx. 150 m on either side. Longer lines were desirable, but this was not possible under the working conditions and in the limited time window available. As well, for the same reasons, it was not feasible to install a “far remote reference station” which is the usual Phoenix practice; a near remote (~900 m) was used instead.

Data editing was able to mitigate the EM noise from the mining operation, allowing the interpretation to proceed.

Lalor is a 3D deposit; the data set is insufficient for 3D inversion; and 2-D inversions proved unsatisfactory. Experience has shown that 1-D inversion can give surprisingly good results over 3D targets. The talk is limited to 1D inversions.
The results show a resistivity anomaly in good spatial registration with the known deposit. Line 184 shows stronger anomalies than Line 176. There is evidence of another conductor to the SW end of the profiles. The Bostick inversion on Line 184 shows a closed anomaly with hypocenter at approx. 900 m subsurface.

As well, the data set shows a compact high phase anomaly, somewhat similar to those observed in tensor AMT surveys at Sudbury. [ {Livelybrooks et al., MAGNETOTELLURIC DELINEATION OF THE TRILABELLE MASSIVE SULFIDE BODY IN SUDBURY, ONTARIO, GEOPHYSICS, Vol. 61, NO.4 (JULY-AUGUST 1996), P. 971-986}; {Stevens et al., ON THE DETECTION OF NI-CU ORE HOSTING STRUCTURES IN THE SUDBURY IGNEOUS COMPLEX USING THE MAGNETOTELLURIC METHOD, SEG 1998}; {Chouteau et al., ANALYSIS OF MAGNETOTELLURIC DATA SHOWING PHASE ROLLING OUT OF QUADRANT (PROQ) SEG 2000 EM4.6} ]

The limited results from this small test survey suggest that AMT (with simple inversions) can be a useful VMS exploration tool in this region in either greenfield or brownfield environments.
TITAN 24: THREE LINES OF DEEP DCIP AND MT AT THE

LALOR DEPOSIT

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DC-IP and MT data were acquired over the Lalor deposit using the Titan 24 DCIP & MT acquisition system in March and April of 2009.

Project Geology

1.1 Project Geology and Mineralization (Compiled from Blakley, I. T., 2008)

The Lalor VMS deposit is flat lying (Figure 1), with mineralization beginning at approximately 570 m from surface and extending to a depth of approximately 1,170 m. The mineralization trends about 260° to 310° azimuth and dips between 10° and 30° to the north. It has a lateral extent of about 900 m in the north-south direction and 700 m in the east-west direction.

Sulphide mineralization is pyrite and sphalerite dominant. In the near solid to solid (massive) sulphide sections, pyrite occurs as fine to coarse grained crystals averaging 2 to 3 mm. Sphalerite occurs interstitial to the pyrite. A crude bedding or lamination is locally discernable and coarse grained sphalerite occurs locally as bands that strongly suggest that remobilization took place during metamorphism.

Hydrothermally altered rocks in the footwall commonly contain some very low concentrations of sulphide minerals.

Some sections of massive pyrrhotite occur.

Six distinct stacked copper and zinc mineralized zones have been interpreted within the Lalor deposit based on the Zinc Equivalency (ZNEQ) of 4% over a minimum two meters interval.

Zones of the Lalor deposit are generally near solid to solid sulphides, but portions can occur as disseminated to stringer sulphides. The lenses in the footwall tend to be disseminated and stringer sulphides, but near massive to massive sections do occur.

Gold and silver enriched zones occur near the margins of the sulphide lenses and in local silicified footwall alteration. These silicified areas often correlate with disseminated to stringer chalcopyrite and galena.
Magnetite is not common, often <1% and <1 mm in size, but can range up to 5% and from 1 to 3 mm in size when associated with rhyolites of the hanging wall and felsic gneisses of the footwall. Magnetite rarely occurs as porphyroblasts in chlorite schists, sometimes up to one cm in size.

Galena occurs as disseminations mostly in the altered footwall rock and at or near the immediate hanging wall of the massive sulphide sections. Arsenopyrite is present, but rare. Gahnite, like galena, is locally present in the altered country rocks and often seems to be in vein-like structures.

A.1 TITAN 24 IP

Titan 24 is a 24-bit multi-channel, distributed acquisition system for the collection of Direct Current (DC) Resistivity and Induced Polarization (IP) data (Sheard 1998). The system records full-waveform time-series utilizing 24-bit Sigma Delta Analog to Digital (A/D) conversion. Acquisition is performed using full duty cycle\(^1\) square pulses, transmitted into the ground with a pole-dipole array.

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\(\text{\footnotesize \*Lalor VMS deposit schematic picture captured from Hudson Bay Mining & Smelting Co. website, 2009.}\)

\(\text{\footnotesize \(1\) Duty cycle is the ratio between the pulse duration and the period of a square waveform.}\)
Resistivity is among the most variable of all geophysical parameters, with a range exceeding $10^6 \, \Omega \cdot m$. The resistivity of rocks depends primarily on their porosity, permeability and particularly the salinity of fluids contained, according to Archie’s Law. DC is used mainly for mapping of resistivity structures (lithologies) and locating of conductive targets.

Chargeability responds to the presence of polarizable minerals (metals, sub-metallic sulphides and oxides, and graphite), in minute amounts. Both the quantity of individual chargeable grains present and their distributions within subsurface current flow paths are significant in controlling the level of response. The IP method can be used to directly detect disseminated to massive sulphides.

A detailed introduction to DC-IP is given in Telford, et al. (1976).

At Lalor the DCIP acquisition utilized a pole-dipole (PRL-PDR) configuration with 200 meter receiver dipoles. In a standard Titan 24 survey, the transmitter (Tx) and receiver (Rx) configuration is a pole-dipole-dipole array, combining pole-dipole right (PDR) and pole-dipole left (PDL). The current is typically injected at the midpoint between two potential electrodes.
A.2  **TITAN 24 DCIP DATA PROCESSING**

For one potential electrode pair, the data acquired with one current injection event is a time series of measured voltages at the electrodes normalized by the current, \( V_p \) in mV/A. A typical Titan 24 time series is shown below.

![Typical Titan 24 DCIP time series and stack.](image)

1. Stack the time series of the current monitor and received signal.
2. FFT and apply calibration to obtain amplitude and phase of the two signals.
3. Combine transmit and receive to extract the ground response.
4. Apply time-domain and ADC sigma-delta response filters.
5. Apply FIR AC filter (at power-line frequency).
6. Extract signal (\( V_p \) and IP).

A.3  **TITAN 24 IP CHARGEABILITY**

Quantec estimates IP responses using a time domain half-duty square-wave excitation standard and very late time window that usually starts at .8 seconds (versus a more typical .4 seconds). The late time window is chosen to mitigate EM coupling. To standardize, we map the chargeability results to units of phase. Quantec’s time-domain based phase is linearly scaled from the calculated chargeability. Justification is based on calculations performed using standardized Halverson-Wait chargeability models.

A.4  **DCIP2D INVERSION**

An excellent overview and introduction to both the theory and use of inversions in geophysics is available on the University of British Columbia (UBC) website (Oldenburg et al., 1998).

The DCIP2D inversion algorithms are developed by UBC-Geophysical Inversion Facility.
A.5 TITAN 24 MT

The Audio-Magnetotelluric (AMT) method is a natural source method that measures the variation of both the electric (E) and magnetic (H) field on the surface of the earth in order to determine the distribution at depth of the resistivity of the underlying rocks. A complete review of the method is presented in Vozoff (1972) and Orange (1989).

At frequencies below 1Hz the EM signal source is due to oscillations of the Earth’s ionosphere as it interacts with the solar wind. At frequencies above 1Hz the signal source is due to worldwide lightning activities. There is a lack of natural signal around 1Hz, often referred to as the “low frequency dead-band”.

Between about 8Hz and 300Hz the signal from worldwide lightning activity propagates in a “resonant” cavity (the resistive atmosphere) between the conductive ionosphere and the conductive Earth’s surface. Above 3 kHz the signal propagates as a ground wave. Between 300Hz and 3 kHz there is a “dead-band” where the signal does not propagate well. When signal (atmospheric activity) is present within several hundreds of miles of the survey area the data quality improves. When no signal is being generated in the vicinity of the survey area the data quality is poor.

A.6 DATA PROCESSING

Time series are transformed into the frequency domain and the MT impedance tensor is estimated from the measured electric and magnetic fields. Remote referencing is used to mitigate noise.

The geophysical parameters are estimated after the processing is completed. In frequency domain, the ratio between the two measured components (E and H) is called electrical impedance (Z) and is defined as $|Z| = |E/H|$. The impedance tensor is then used to calculate apparent resistivity and phase. The impedance values are used to calculate apparent resistivity and phase data as follows:

$$\rho_a(\Omega m) = \frac{1}{\mu_0 \omega} |Z|^2 \quad \text{and} \quad \varphi = \text{arg}(Z)$$

These primary geophysical parameters are then represented versus frequency. The apparent resistivity is considered as a volumetric weighted average of the resistivity of the subsurface material.

The depth of investigation is determined primarily by the frequency content of the measurement. Depth estimates from any individual sounding may easily exceed 20 km. However, the data can only be confidently interpreted in 2d to a depth comparable to the length of the profile.

At Lalor, the MT data were acquired over the bandwidth of 0.1 Hertz to 10,000 Hertz. The configuration used in-line contiguous 200 m dipoles to measure the in-line electric field (Ex) and orthogonal 100 meter dipoles at every second site (every 400 meters) for measuring the cross-line component (Ey). Two pairs of orthogonal magnetometers, one pair for the high frequency data and one pair for the low frequency data were used to record the Hx and Hy magnetic fields, respectively. The coils were located at one station along each survey line. The aperture of these lines was over 4 km so depending on frequency content and resistivity, a depth of investigation on the order of 2 km would be anticipated.
A remote reference site located approximately 5-10 kilometers away from the survey area was used for local noise reduction and monitoring. The remote reference station consisted of one pair of orthogonal dipoles for measuring the electric field (Ex and Ey) and two pairs of orthogonal magnetometers orientated in the same direction as the survey lines.

The work is reported in “Geophysical Survey Logistics Report, (Eadie, T. and Martinez, E. April, 2009)” which provides more information on the Titan Survey configuration and parameters.

Figure 4: Titan 24 2009 survey location Map over Lalor deposit shown in red. Drilling shown as purple dots.
Results

Figure 5: Voxelized sections of MT showing Lalor lenses and top) line 176, middle) line 184 and bottom) Line 192
Figure 6: Voxelized sections of DC showing Lalor lenses and top) line 176, middle) line 184 and bottom) Line 192
Figure 7: Voxelized sections of IP showing Lalor lenses and (top) line 176, (middle) line 184 and **bottom** Line 192
Figure 8: Soft constraint of MT for line 176 showing top) original, middle) constrained model, bottom) starting model.
Discussion

With the introduction of Titan 24 in 2000 we brought production MT to the mining industry. But working at the bleeding edge has had consequences. Educating ourselves and our clients about the meaning in the data was the critical component of the success. Most of the time we've been fortunate and the meaning has dropped right out in more favorite environments. But more complicated environments such as those hosting resistivity extremes, sub-vertical stratigraphy, worse yet combinations of sub-vertical and sub-horizontal stratigraphy and truly deep targets (>> 500 m depth) require a high level of sophistication.

During that period we followed some rather outdated paths for decomposition of data in to principal axes, or geo-electric strike components, for 2d inversion. Nearly every dataset was run through a Latoraca rotation prior to modelling. Similarly, we routinely 'pre-conditioned' our data to impose a 1d fit. Fortunately, our data acquisition has always been rigorous; assuring that the expected information is adequately represented by the data itself. Since about 2010, our interpretation group has been influenced by a series of Ph -D. experts, some of whom have moved on such as Dr.’s Nasreddine Bournas and Ersan Turkoglu and some of whom are integral to the group today such as Dr.’s Mehran Gharibi, Benoit Tournerie and Jimmy Stephen. Although he has never directly worked for us, we have always used the inversion codes of Dr. Phil Wannamaker of the University of Utah. In recent years we have invited his more critical review of our use of the codes (and the codes themselves have evolved).

This project provides an excellent example of procedural shortcoming in the past and an opportunity to demonstrate that the information content in the data is a high as we ever expected. It also provides clarity about the modelling process itself, about non-uniqueness and how a little a priori information can significantly improve outcomes. We always ask our clients to provide as much information as they can about their projects, but frequently we're met with the resistance that we're, justifiably, to tell first about the information in the data: the thought is, if we’re told too much the final model will simply return the anomalies 'where they want them'.

Titan acquisition has evolved. Initial development of the distributed acquisition system (DAS) was all about improving IP and in particular improving it for the sub-horizontal, conductive Australian environment (Sheard et al). MT was a convenient add-on to be acquired for little extra cost and to be applied mostly as a method to improve the quality of the IP (for Telluric Cancelation). Quanteck took these ideas and improved the MT methodology by adding multiple orthogonal electrical measurements. However we take advantage of the fact that the magnetic field does not change so rapidly as electrics and most historical datasets were collected with a single set of coils. In this case, despite expanding the array to 200 m dipoles (so the survey expanse is up to 5 km) and operating over subvertical geology, the single coil-set paradigm was maintained. These days, we are more cautious and quicker to add another coil-set, sometimes a couple of extra coil-sets along the line, when data inspection during the acquisition indicates strong heterogeneity in the subsurface.

For these data it’s too late to improve the acquisition (by adding another coil set) but we can certainly demonstrate enhanced inversion methodology.
For the DCIP component, the software has improved to some extent in last decade, but our approaches are basically the same. The huge contrast between conductive ore and resistive metamorphic greenstone, coupled with the isolated and plate-like nature of the ore lenses means Lalor is a much better EM (including MT) target than DC or IP.

**Conclusion**

While EM ought to be a better direct targeting tool for such a high resistivity, flat lying target, one would not have missed the chargeability signature of Lalor. The best use of DC and resistivity in general in this environment is for mapping. With more integrated work with the HudBay team, we could likely map some of the sub-vertical structure and constrain the sub-horizontal deposits. But to appreciate real value in the DC, one needs to include a priori information. We have presented a simple constrain of the MT data and the results of a model that fits the data and an approximation of Lalor. Similar constraint of the DC and IP would likely produce interesting results. The chargeability results show a strong anomaly associated with Lalor. This needs to be constrained, but certainly under line 176 over the center of the deposit, one would not have missed this exceptional target.

**Acknowledgements**

We wish to thank BCGS for initiating the Lalor Symposium, Dennis Woods for his organization, and HudBay Minerals for releasing these Titan 24 data for this presentation.

**References**

**TITAN-24 METHOD AND APPLICATION**


DIRECT CURRENT (DC) AND INDUCED POLARISATION (IP) METHODS


MAGNETOTELLURIC (MT) METHOD


Geotools MT, © copyright Geotools corp. Austin TX


Advancing a Major Undeveloped Canadian Zinc-Copper Deposit

The Foran Advantage
- Management team with a depth of industry experience
- Solid shareholder base - mining industry executives
- Superior project location & existing infrastructure
- McIlvenna Bay: 100% ownership of a large base metal deposit
- Resource growth & discovery potential

Foran Mining Corporation is a zinc-copper exploration and development company focused on central Canada’s prolific Flin Flon mining belt. Foran’s flagship McIlvenna Bay Deposit is located in east central Saskatchewan, 65 km west of Flin Flon, Manitoba.

McIlvenna Bay is one of the largest undeveloped VMS deposits in Canada, with a mineral resource of:
- 13.9 Mt of 13.2% ZnEq (indicated) and
- 11.3 Mt of 13.5% ZnEq (inferred)

(See next page for additional information)

Foran has commenced a PEA at McIlvenna Bay, with results expected in Q4/14.

Foran Mining Corporation
September 2014

Management
Patrick Soares - President & CEO
Tim Thiessen - Chief Financial Officer
Fiona Childe - VP Corporate Development
Roger March - VP Project Exploration
Dave Fleming - VP Exploration

Board of Directors
Darren Morcombe - Chairman
Patrick Soares
Sharon Dowdall
Maurice Tagami
Bradley Summach
David M. Petroff

Capital Structure & Ownership

| Shares I/O | 83.4 M |
| Warrants | 4.0 M |
| Options | 7.1 M |
| Shares Fully Diluted | 94.5 M |
| Recent Share Price | $0.18 - $0.20 |
| 52 Week High-Low | $0.34 - $0.14 |
| Cash Position | $3.9 M |
| Market Cap | $15 M |
| Board & Mgmt Ownership | ~ 19% |

1 As at September 15, 2014
2 As at June 30, 2014
3 Based on 750 Shares; All figures in CDN$
100% Ownership of the McIlvenna Bay Deposit – the Largest Undeveloped Zinc-Copper Deposit in a World Class Mining District

Superior Growth Potential – Both in the McIlvenna Bay Deposit & in Satellite Deposits in the Hanson Lake Camp

Excellent Access & Infrastructure - Year-Round Road Access; Close to Highway, Rail & Hydroelectricity

Situated in a Safe, Stable Pro-Mining Jurisdiction

Positive Relationship with First Nations

McIlvenna Bay PEA Underway - results expected Q4/14

McIlvenna Bay Mineral Resource Estimate

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<tr>
<th>Indicated Resource</th>
<th>Zone</th>
<th>Tonnes (kt)</th>
<th>Zn (%)</th>
<th>Cu (%)</th>
<th>Au (g/t)</th>
<th>Ag (g/t)</th>
<th>ZnEq (%)</th>
<th>CuEq (%)</th>
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<th>Inferred Resource</th>
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<th>Zn (%)</th>
<th>Cu (%)</th>
<th>Au (g/t)</th>
<th>Ag (g/t)</th>
<th>ZnEq (%)</th>
<th>CuEq (%)</th>
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Effective date January 1, 2013; CIM definitions were followed for Mineral Resources. ZnEq = zinc equivalent; CuEq = copper equivalent; NSR = Net Smelter Return. The base case mineral resource is estimated based on a NSR cut-off grade of US$60/mt. NSR grades were calculated and high grade caps were applied and include provisions for metallurgical recovery and estimates of current shipping terms and smelter rates for similar concentrates. Metal prices used are US$3.25/lb Cu, US$1.50/lb Zn, US$1.40/lb Oz Au, and US$25/lb Ag. Specific gravity was interpolated for each block based on measurements taken from core specimens; Mr. David Rennie, P.Eng., of RPA, prepared this mineral resource estimate. Mr. Rennie is independent of Foran and is a “Qualified Person” within the meaning of NI 43-101. Mineral resources which are not mineral reserves do not have demonstrated economic viability. The estimate of mineral resources may be materially affected by environmental, permitting, legal, marketing or other issues. ZnEq and CuEq values were estimated based on $0.11 per lb Zn, $5.50 per oz Cu, $35.15 per oz Au and $0.03 per oz Ag. For additional information see the Foran news release dated March 27, 2013 at www.foranmining.com

Fiona Childe, Ph.D., P.Geo., VP Corporate Development for Foran is the Qualified Person who has reviewed the technical disclosure in this fact sheet.

Forward Looking Statements: This fact sheet contains forward-looking statements. These statements are based on information currently available to the Company and the Company provides no assurance that actual results will meet management’s expectations. Since forward-looking statements are based on assumptions and address future events and conditions, by their very nature they involve inherent risks and uncertainties. Actual results relating to the Company’s mineral properties, and the Company’s financial condition and prospects, could differ materially from those currently anticipated in such statements for many reasons.

Investor Contact
Fiona Childe
VP Corporate Development
T: 416-363-9229
ir@foranmining.com
GETTING TO THE PINT

BCGS Lalor Reception 5:30 – 7:30 pm

Directions from BCIT to The Pint

1. Head northeast on Seymour St toward W Pender St
   - 81 m

2. Turn right onto W Pender St
   - 680 m

3. Turn left onto Abbott St
   - Destination will be on the left
   - 10 m

BCIT
555 Seymour St, Vancouver, BC V6B 3H6

The Pint
455 Abbott St, Vancouver, BC V6B 1S5

Walk 700 m, 8 min
As part of the methodology project of the TGI-4 program, the Geological Survey of Canada acquired a multi-component 3D seismic data set over the Lalor volcanogenic massive sulphide (VMS) deposit, located near Snow Lake, Manitoba, Canada. The 3C-3D seismic data were acquired to develop and test seismic imaging methods for deep exploration of VMS deposits. The Lalor VMS deposit was chosen as a test site as it provided an intact, well-characterized 29 Mt deep ore deposit with a rich catalog of geological and geophysical data, as well as extensive drill-core, and drillhole geophysical and geological logs. An analysis of physical rock properties from borehole logging indicates that massive sulphides associated with the zinc-rich zones could produce prominent reflections whereas acoustic impedances of gold-disseminated zones do not contrast sufficiently with impedances of host rocks to produce reflections. The interpretation of the seismic data is constrained with a detailed 3D lithofacies model built from the geological contacts mapped at surface or intersected in boreholes. The 3D model is particularly accurate near the deposit but less reliable near the edges or at greater depths where the distribution of boreholes is sparse. Processing of the data following a DMO-poststack migration approach revealed strong reflections associated with the zinc-rich massive sulphide zones. Contacts between felsic and mafic protoliths in the footwall also produce prominent and continuous reflections. The shallowest of these reflections can be used as a proxy for the hangingwall-footwall contact which is only locally observed on the seismic data. At depth, a series of strong and continuous reflections provide indications on the general geometry of the volcanic sequences in the area of the 3D seismic survey.
SEISMIC INTERFEROMETRY: A NEW TOOL FOR BROWNFIELD MINERAL EXPLORATION? PRELIMINARY RESULTS FROM LALOR, MB

Jim Craven¹

¹ Geological Survey of Canada. jim.craven@nrcan-rncan.gc.ca

Preliminary results from a test survey evaluating the suitability of interferometry for mineral exploration will be presented. Interferometry is a method by which one can reproduce the seismic response of the subsurface without using active sources. As such, the technique may be suitable where it is difficult or impossible to deploy active seismic sources such as dynamite or Vibroseis trucks.

Seismic receivers were deployed in the Lalor test survey at 336 locations along a grid. Virtual shot gathers have been created at every receiver location. A few of the virtual gathers are compared against shot gathers from an active source survey, collected after the passive recordings were complete. There are differences, but there are intriguing similarities. Processed 3D cubes from the two surveys will also be compared. There are differences in the two results requiring further study however these preliminary results indicate the technique is promising and may be a new tool in the arsenal of exploration methods for mineral exploration.
VOLterra Surface and Borehole TDEM and 3D-IP Test Surveys

Over the Lalor Deposit

Syd Visser¹

1. SJ Geophysics Ltd. sydv@sjgeophysics.com

SJ Geophysics collected Volterra Borehole-TDEM, Surface-TDEM, and 3DIP test surveys over the Lalor deposit during the summer 2014. All three surveys utilized the Volterra full-waveform acquisition system. With active mining now taking place at Lalor, a large new power line runs directly over the deposit along the main access road, making the survey environment more challenging.

The Volterra Borehole Time-domain Electromagnetic (TDEM) survey was carried out within borehole DUB033W01, located approximately 800m east of the main deposit. EM data was collected using a very sensitive B-field coil for the axial component, along with a 3-component fluxgate magnetometer for the cross-components.

The Volterra Surface TDEM survey was completed over 3 surface lines. A combination of a very sensitive B-field coil and a 3-component fluxgate magnetometer were connected to Volterra-Dabtube data loggers for collection of the Z, X, and Y components of the EM data.

Utilizing the same 3 lines as the Surface TDEM, a small Volterra-3DIP survey was also carried out. The 3DIP survey used 200m x 100m dipoles in a diamond array pattern with an active array length of 2400m. Current injections were offset along two lines parallel to the receiver array. The survey extent was less than ideal for the depth of the deposit due to time and personnel constraints. After completion of the 3DIP survey, the receiver array was left out overnight in order to collect MT data, which will be processed at a later date.

All three surveys were completed during the summer of 2014, where access in the vicinity of the deposit was greatly reduced due to the presence of swamps and lakes. As a result, modifications to the EM and IP survey designs were required; meaning the loop size and line lengths were smaller and shorter than originally planned.

The Volterra acquisition system consists of proprietary, full waveform, autonomous dataloggers, referred to as Dabtubes, that are able to record output signals from multiple kinds of sensors. They can be used for any type of survey requiring a datalogger, including EM, IP, MT, CSAMT, etc. Full waveform data is post-processed using an inhouse developed processing software package. The results can be displayed and modelled using most commercially available software packages.

We would like to thank Hudbay for allowing us the opportunity to complete these test surveys and providing support for our crew; including 2 technicians, 2 ATV’s, and accommodations.
VOLTERRA'S ACQUISITION UNIT

Volterra is a state-of-the-art, untethered, distributed geophysical data acquisition system. The heart of the system are the data acquisition units, internally known as Dabtubes, that allow for superior data collection of a suite of geophysical datasets including Resistivity/IP, EM, MT, CSAMT, MMR/MMIP etc.

The electronics of these data acquisition units were optimized for packaging within borehole probes. Moreover, their low power consumption, internal flash memory, Bluetooth communication and GPS timing also greatly benefited surface surveys in a variety of scenarios. The ability to utilize any number of Dabtubes, allowing large channel acquisition, provides the flexibility and strength to the Volterra Distributed Acquisition System.

FEATURES

- Four ADC Channels per unit, each providing:
  - 24-bit full waveform signal collection
  - 10V peak-to-peak input range
  - Galvanic isolation between channels
  - Variable sampling speeds, up to 128 ksps
- Battery Powered (Rechargeable Battery Pack)
  - Wide supply range (4.0 to 11.0 VDC)
  - Low power consumption (450mA at 5.2V)
  - Reverse polarity protection
  - Expand battery life by connecting additional battery packs in parallel
- Data Storage
  - Removable USB flash memory device
  - Direct USB connection with external computer for easy access to data
- Bluetooth Communication
  - Control Dabtube wirelessly
  - Monitoring capabilities of GPS, IMU and ADC data in real time
- Four RS-232 Full Duplex communication Ports
- Six Digital I/O (GPS PPS implemented)
**BENEFITS**

- **Small Form Factor**
  - Can be packaged within a slim borehole probe that allows surveying in BQ holes or through NQ rods
- **Light-weight**
  - Logistically friendly - Steep, variable or other difficult terrain conditions no longer present a challenge
  - Surface Dabtube weighs in at a low 1.1kg
- **Low Power Consumption**
  - Record all day on a single battery pack charge or connect additional battery packs for longer acquisition times
- **Signal Post-Processing**
  - Full waveform data acquisition allows for customizable processing sequences and filters
  - Not restricted by hardware filters
- **Ease of operations**
  - Local staff can be quickly trained to operate instrumentation
  - Control units via Bluetooth enabled devices including Android OS smartphones and tablets
  - Real time monitoring of GPS, IMU (inertial measurement units) and ADC data

---

Winterized Acquisition Unit configured for Large-Loop Surface TEM @ -40°C in Nunavut

For more information on

Please Contact:  
**SJ Geophysics Ltd.**  
11966 – 95A Ave., Delta, BC, Canada  
V4C 3W2  
604-582-1100  
www.sjgeophysics.com

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Acquisition Unit configured for BHEM – Surveying underground on a horizontal hole (through rods) in Mexico. No data cable required
THE RESULTS OF A HELISAM TEST SURVEY OVER THE LALOR VMS DEPOSIT,
SNOW LAKE, MANITOBA, CANADA

Chris Parker¹, Jonathan Rudd², Malcolm Cattach¹ and Johnathan Kuttai²

2. Discovery Int’l Geophysics. jonathan.rudd@discgeo.com

A HeliSAM test survey was conducted over Hudbay Mining’s Lalor VMS Deposit in August, 2014. The survey was conducted jointly by Discovery Geophysics and Gap Geophysics Australia using Gap’s proprietary HeliSAM system. The result of this test indicates that the HeliSAM method is an effective and efficient tool for the detection of conductive targets at great depth.

The Lalor Deposit is a large, shallow dipping VMS deposit which comprises a series of stacked lenses of varying size and composition. The deposit extends from a depth of 575 m to over 1.1 km. The depth of this conductive deposit makes it a challenging target for geophysical methods to detect and characterise.

Sub-Audio Magnetics (SAM) is a multi-parameter technique developed by Gap Geophysics (Gap) for the simultaneous measurement of both the magnetic and electrical properties of the earth. SAM data can be acquired at ground level, but can also be collected using a helicopter with a towed bird (HeliSAM). The HeliSAM method involves the active transmission of an electromagnetic signal into the Earth with a typical frequency range of 4 to 20 Hz using a ground (inductive) loop. The Earth response is measured using Gap’s TM-7 SAM receiver, which comprises a high-sensitivity total field magnetometer which detects the response, and a high-precision, fast-recording frequency counter.

The HeliSAM survey at Lalor pushed out a peak 20 A at a base frequency of 7.5 Hz into an existing 1.7 km by 1.7 km single turn loop. The survey acquisition totaled 93 line-km at a 100 m line spacing using an R44 helicopter. The HeliSAM data were processed to produce a virtually continuous record of total field magnetic intensity (TMI), and 16 channels of EM data along each survey line.

The TMI results are consistent with the resolution and sensitivity of a helicopter-borne TMI data set.

The HeliSAM EM results clearly identify the presence of the Lalor Deposit, and show a very similar response to the discovery ground dataset acquired by Hudbay. This favourable result is consistent with the expectation for the HeliSAM system, which is designed to provide deep search capability with a B-field sensor. As such, the HeliSAM method is ideally suited for the detection of highly conductive VMS and MMS deposits at great depth.

The HeliSAM method provides a more efficient mode of deployment than conventional ground systems. Line cutting and flagging/chaining are not required for the survey lines, and data acquisition
can be completed at a rate consistent with airborne survey operations. Helicopter deployment allows surveys to be completed in virtually any topographic environment.
A SAM survey was carried out in an area with known copper oxide / sulphide mineralization which was suspected to be structurally controlled.

Holes drilled previous to the SAM survey are shown as white diamonds and give an indication as to known mineralised targets.

Conductivity (EQMMR) results from the SAM survey correlated very well with mineralized intercepts in drill holes and have given CuDECO Ltd a new perspective on why some holes returned disappointing results.

The combination of the detailed ground magnetics and conductivity has proven very useful in targeting new drill holes.

* Images Courtesy of CuDECO Ltd.
THE ROUTINE IN-HOUSE USE OF CRONE BOREHOLE PULSE EM AT LALOR

Josh Lymburner\textsuperscript{1} and Bill Ravenhurst\textsuperscript{1}

\textsuperscript{1} Crone Geophysics. lymburj@gmail.com

Over the course of Lalor Mine’s brief history so far, many geophysical techniques have been employed in both the discovery and characterization of the deposit. The Crone Pulse EM system (PEM) has played a pivotal role in initial discovery, through surface Pulse EM and follow up borehole EM (BHEM), in guiding the drilling and in defining the deposit. The Crone PEM data were collected and interpreted by HudBay on a routine basis, under time constraints and using standard parameters, while never knowing what to expect in the next hole. As the deposit started taking shape, there were many surprises in the Borehole Pulse EM data – including the discovery of a new Gold/copper zone. The focus of this discussion will be placed on reviewing the BHEM data and characterizing the variety of responses, (in-hole, off-hole, edge...) within modelling software to determine how different responses can help define the distance and direction to potential conductive sources.
This multi-billion dollar deposit was first discovered in 2007 by HudBay Minerals from surface using the Crone Pulse EM Coil system. Based on the Surface Pulse EM data, a target was predicted at a depth of 800m. Upon drilling, mineralization was first encountered at 795m down-hole, intersecting 24 meters of high-grade zinc. Along with significant associated gold, silver, and copper, several mineralized zones have been extensively drilled and well delineated in following years.

In December 2010, a Crone Fluxgate Pulse EM demonstration survey was completed down a known non-intersecting borehole on the Lalor Lake VMS deposit near Snow Lake, in Manitoba, Canada. Traditional dB/dt Pulse EM data were collected in the same hole in 2007. The two data sets are shown below.

The deposit dips at approximately 30 degrees and has a minimum depth from surface of about 600m extending well below 1000m. The borehole under consideration missed the known mineralization by approximately 200m.

Log-scale profiles of all Crone off-time channels (LEFT: 150ms Fluxgate, RIGHT: 50ms dB/dt)
The 3-component Fluxgate data were collected at a 150ms timebase (1.67 Hz) to 1000m depth, using a 1000m by 1000m collar loop. The dB/dt survey was carried out at a 50ms timebase (5 Hz) to 860m depth using a 1350m by 650m offset loop.

The dB/dt survey used a standard Crone High-Power transmitter at 20 amps. The fluxgate survey used a Crone Tandem High-Power transmitter configuration at 34 amps.

Both the dB/dt and B-Field data showed a broad off-hole response in the late off-time channels of the axial component (Z) centered at 600m depth. The XY component data also showed well resolved crossovers with both surveys and allowed the direction-to-center of the deposit to be determined for future drilling.

The 3-component Crone Fluxgate probe showed remarkable signal-to-noise levels in all channels. This B-field sensor presents an excellent opportunity to improve the detection threshold of high-conductivity targets with slowly decaying secondary fields, pushing Crone Pulse EM exploration to greater depths than ever before possible.

Crone Digital Receiver Technology provides low-noise A/D conversion with a huge dynamic range. 26 bits of resolution combined with Smart Stacking allows our Receiver to optimize and not limit the sensitivity of our low-noise sensors. High-bandwidth 250-kHz sampling allows for excellent early channel resolution, and our proprietary high-speed A/D conversion avoids the digital ringing characteristic of sigma-delta converters.

Crone technology is fully rugged and winterized (-40°C), tried and tested from decades of experience in a full range of harsh and demanding environments.

**PLEASE ASK US ABOUT OUR:**
- **CRONE CDR2 RECEIVER WITH SMART STACKING AND PROPRIETARY A/D CONVERSION**
- **CRONE BOREHOLE AND SURFACE FLUXGATE MAG SENSORS FOR USE WITH PULSE EM, ESPECIALLY FOR HIGH CONDUCTIVITY TARGETS**
- **CRONE TANDEM HIGH-POWER TRANSMITTER CONFIGURATION FOR VERY HIGH CURRENT, LARGE LOOP, DEEP-PENETRATING EM**

Crone Geophysics & Exploration Ltd.
(905) 814-0100  surveys@cronegeophysics.com
2135 Meadowpine Blvd., Mississauga, ON, Canada
DIGIATLANTIS BOREHOLE TEM AT LALOR

Andrew Duncan

1. ElectroMagnetic Imaging Technology. aduncan@electromag.com.au

Introduction

In June, 2010, DigiAtlantis TEM data was collected in 2 boreholes (DUB33 and DUB178) at the Lalor VMS Deposit near Snow Lake, Manitoba. Data was collected mainly at 1 Hz transmitter frequency and some data was also collected at 0.5 Hz. The transmitter loop used was HudBay’s Loop 5 – a 2500m x 2000m loop that has been used for a great deal of borehole and surface TEM work at Lalor. Each survey was completed in 6 hours. Three-component TEM, magnetics and hole orientation data from the single-pass DigiAtlantis surveys in the 2 holes will be presented. The low frequency TEM data confirms that the late-time decay constant for the most conductive parts of the deposit is in excess of 100 msec.

In the DigiAtlantis system, signals from the 3 magnetometers are simultaneously digitised at approximately 25,000 samples per second and sent to the surface. DC magnetic fields are extracted in addition to the EM data. The roll and inclination of the probe are measured accurately by well-calibrated accelerometers. Operators are presented in real-time with plots of raw signals and profiles and decays of de-rotated 3-axis magnetic fields. Raw and stacked waveforms are stored for any QC or reprocessing later.

DigiAtlantis Data from DUB178

Drill hole DUB178 is a 1200m hole which passes above and to the SW of the Lalor Deposit by approximately 180m.

DigiAtlantis data was collected using a Phoenix TXU-30 transmitter operated by Discovery Int’l Geophysics. Transmitter current was 18A and the transmitter was GPS-synchronized to the DigiAtlantis receiver. The 3 components of magnetic field measured in the transmitter off-time are presented here in units of pT/A.
Above: location of borehole DUB178 and loop 5 relative to the Lalor Deposit
Is it down there?

Find out.

SMARTem24
16 channel, 24-bit electrical geophysics receiver system with GPS sync, time series recording and powerful signal processing

DigiAtlantis
Three-component digital borehole fluxgate magnetometer system for EM & MMR with simultaneous acquisition of all components

SMART Fluxgate
Rugged, low noise, calibrated, three-component fluxgate magnetometer with recording of Earth’s magnetic field, digital tilt measurement and auto-nulling

SMARTx4
Intelligent and safe 3.6 kW transmitter for EM surveys, clean 40A square wave output, inbuilt GPS sync, current waveform recording, powered from any generator

Maxwell
Industry standard software for QC, processing, display, forward modelling and inversion of airborne, ground and borehole TEM & FEM data

EMIT
Advanced electrical geophysics instrumentation and software
20 years of EMIT

Electromagnetic Imaging Technology started in October 1994 with a plan to develop a receiver system for electrical geophysics that performed well around mine sites – difficult sites with a great deal of electrical interference. By mid-1995 we were field-testing the first generation of SMARTem – a receiver system based on an embedded industrial PC that recorded and processed full signal time-series. The first surveys were carried out with WMC Resources who subsequently acquired several SMARTem receiver systems for use at their Leinster and Kambalda nickel mines in Western Australia.

The SMARTem PC architecture enabled very rapid development of powerful new instrumentation with digital filters for real-time processing. Smart routines for stacking and windowing EM data made a huge difference to surveys that were affected by noise from powerlines, VLF and sferics. At the time, storing and archiving a day of raw EM data samples was a fairly cumbersome proposition for a PC - but now you wouldn’t give it a second thought.

Since 2001 all our new equipment has been capable of GPS synchronization - an accurate (and fast) way to synchronize a transmitter to multiple receivers and geo-locate the survey data. EMIT receivers are commonly used with transmitters and sensors from Zonge, Geonics, Crone, GDD, Phoenix, Gap, Supracon and others.

Our first low-noise tri-axial fluxgate magnetometer to interface with SMARTem receivers was released in 2000. Fluxgates were a convenient and inexpensive sensor for TEM at lower frequencies and quickly became popular with nickel explorers in Western Australia. Transmitter frequencies were gradually dropping in surveys for highly-conductive targets and in areas with considerable conductive cover. By 2004 we had built a tri-axial fluxgate into a well-calibrated borehole magnetometer system - Atlantis.

By 2007 our Maxwell EM software had been under development for 10 years. It was used by HudBay to model the conductor at Lalor near Snow Lake, Manitoba, that was subsequently intersected in the first hole within a few metres of where it was expected at a drill depth of 800m. Nowadays, Maxwell is an industry-standard product with over 400 licenses used world-wide.

Around this time EMIT formed Absolute Geophysics in a JV with Gap Geophysics to exploit the low noise of total field (scalar) magnetometers at low frequency. The SAMSON technique we developed has become popular in nickel exploration under cover and regularly operates at 0.125 Hz or lower.

DigiAtlantis was released in 2008 - sending 3-components of digital EM time-series to the surface simultaneously. DigiAtlantis considerably cut the time it took to collect borehole EM data, even at fairly low frequency, making a big difference to the cost of a DHEM survey especially when a drill rig is on standby. Data was transmitted to the surface in real-time using internet-over-copper technology and standard logging cables could be used.

In 2011 a new version of the SMARTem receiver - SMARTem24 - was introduced. It is a light-weight, rugged, 16 channel system with seriously powerful processing and display capabilities. There are now 70 SMARTem24 units operating around the world doing EM and IP, in the cold climates of Northern Europe and Canada and the hot climates of Australia and Africa. SMARTem24 and fluxgate sensors were used in the moving-loop TEM survey that discovered the Nova Ni-Cu Deposit in the Fraser Range of Western Australia during 2012 – a discovery that has generated massive exploration focus there and further discoveries, along with adding more than $A1billion to Sirius Resources’ market capitalization. HudBay are currently using EMIT’s borehole and surface receiver systems and sensors for exploration around Flin-Flon and the Lalor Mine.

EMIT is a group of geophysicists, engineers and software developers with a passion for innovation, embracing new technology and solving problems in mineral exploration geophysics. We are working on new data acquisition systems, modelling, transmitters, data communication and distributed systems for measuring geophysical signals.
Above: log vertical scale profiles to 1200m depth of 1 Hz DigiAtlantis data, A, U and V components.
Each reading in the survey collected all 3 components of the magnetic field for 256 half-periods at 1 Hz (250 msec off-time), or roughly 2 minutes duration. Some repeat readings were made, along with some in-fill and several readings at 0.5 Hz (500 msec off-time) were taken around the peak of the Lalor response at 600m depth in the hole.
Above: DigiAtlantis GUI – real-time and post-acquisition display and processing.
BOREHOLE GRAVITY OVER THE LALOR DEPOSIT

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This presentation will review the Borehole Gravity technology and show the Lalor survey results.

The slim-hole gravimeter, GRAVILOG, was developed by Scintrex Limited and field tested in 2008. Since that time the system has proven itself to be robust during summer and winter conditions on three continents. Abitibi Geophysics is a licensed operator of the GRAVILOG system and is equipped to log holes from 100m to 2,300m deep using an ARGO mounted winch. Deeper holes to 3,000m can be logged using a wireline winch vehicle.

The GRAVILOG sensor is based on a miniaturized version of the CG-5 surface meter technology. It measures the gravitational field to a resolution of 1 microGal (0.001 milliGal) with a repeatable accuracy between 5 and 10 microGals (0.005 to 0.01 milliGal).

The two primary uses for borehole gravity in mining are the detection and estimate of tonnage of mineralization in or off-hole and the determination of in-situ apparent density (bulk density) of the lithology.

Explorationists use borehole gravity as a diagnostic tool to investigate the presence of excess mass around a borehole. Any electromagnetic in-hole or off-hole anomaly can be tested to determine if there is a corresponding volume of excess mass. The proximity of the borehole gravimeter to the mineralization improves the accuracy of the estimate. The prudent use of borehole gravity to prioritise EM anomalies early in the exploration cycle will save exploration companies money and time.

In-situ apparent density is useful for deposit evaluation, grade control, structure, and rock property analysis to determine relative rock strength. Borehole gravity density determinations are not affected by poor core recovery, washouts, or cementing because measurements can be made through the casing.

Borehole gravity was collected in five holes surrounding the Lalor Deposit. Numerous density variations in all the holes provide a detailed picture of the lithology and identify a potential target. The interpretation of the borehole gravity data and integration with 3-D seismic, other geophysical and geological borehole data, was undertaken by the Geological Survey of Canada, TGI-4 Indirect Sensing Project Team in partnership with Hudbay Minerals Ltd.

GRAVILOG SYSTEM

Scintrex developed the GRAVILOG borehole gravimeter for mining and geotechnical applications (Nind et al, 2007). The sensor technology is a miniaturized version of the CG-5 surface meter,
temperature stabilized and equipped with self-leveling capabilities. The associated electronics modules have been packaged to fit into a narrow diameter borehole probe with real-time data quality monitoring and recording performed on surface via a standard 4 or 7 conductor wireline cable. The GRAVILOG probe is designed to log inside NQ drill rods (57 mm inside diameter) or in BQ drill holes (60 mm inside diameter) in stable hard rock environments. It can be deployed in boreholes inclined from -30° to vertical, if downhole temperatures are between 0°C and 70°C, to maximum depths of 3,000 m (10,000 feet).

Abitibi Geophysics has leased GRAVILOG systems from Scintrex to provide borehole gravity surveys for mining exploration. Example results from recent borehole gravity surveys will be presented to demonstrate the effectiveness of borehole gravity in different applications.

**Borehole Gravity Response**

The CG-5 and GRAVILOG meters measure gravity acceleration with microGal precision, however, detection of an anomalous excess or deficiency of mass is constrained by the attenuation of the force of gravity as the square of distance from the source. A borehole gravity meter brings the sensor closer to the target, and away from surficial “noise”.

The residual borehole gravity response over a VMS target body is typically a cross-over anomaly. When the GRAVILOG sensor is above the deposit both the earth’s gravitational pull and attraction of the deposit are a cumulative downward force on the sensor. Both forces are in the same direction as the earth’s field, resulting in a positive gravitational anomaly. When the GRAVILOG sensor is below the deposit the gravitational attraction of the deposit on the sensor is upward and opposing the pull of the earth’s field, resulting in a negative gravitational anomaly. The positive peak is realized when the sensor is on the top surface of the causative body and the negative peak when the sensor just exits the lower side of the body. In the case of lower density targets such as graphite, the anomalies will be reversed in sign; the negative peak will occur at the top surface of the body and the positive peak at the bottom surface.

![Residual Gravity Anomaly](image.png)
For example, the borehole gravity test survey conducted for Vale over a nickel VMS in Norman Township illustrates a typical crossover response. The survey was conducted in December, 2008, in a borehole intersecting the VMS body at a depth of about 1400m. Using the gravity measurements from this one borehole Dr. H.O. Seigel estimated the total mass of the body to be 5.7 million tonnes. Simplified interpretation methods are discussed in First Break, Volume 25, July 2007, Development of a borehole gravimeter for mining applications by Chris Nind et al.

The second significant application of borehole gravity is mapping density variations of formations intersected by the borehole. Borehole gravity does not require active sources, and extends the density information beyond the borehole. Of particular interest in mining exploration is the determination of bulk densities in sections of poor core recovery and characterization of subtle lithological changes. The latter was particularly useful in the Lalor survey as density and lithology logs correlated remarkably well as shown in drill hole DUB282 (courtesy of GSC, TGI-4 Team).

The results from recent borehole gravity surveys show the potential of GRAVILOG surveys to detect off-hole excess mass. The development of 3-D inversion software (Pejman Shamsipour et al, 2010, Geophysics v 75) for borehole gravity improves the visualization of the anomalous mass in the subsurface. Multi-hole gravity surveys will improve the accuracy of the tonnage estimate and enable generation of a 3-D model to provide location information about the mineralized mass.

Potentially the borehole gravity method will reduce exploration cost and time by quantifying the mass of the mineralization from a few boreholes early in the exploration cycle. Similarly, by extending density measurements beyond the borehole, a continuous density profile improves information about geological formations and grade control.
3D INVERSIONS OF EM DATA AT LALOR MINE: IN PURSUIT OF A UNIFIED ELECTRICAL CONDUCTIVITY MODEL

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Being a highly conductive target, the Lalor Mine VMS Zn-Au-Cu deposit has been surveyed with many different electromagnetic (EM) methods. These include airborne, surface and borehole techniques in the time and frequency domain. The collection of data sets therefore provides us with an excellent platform to experiment with inversion methodologies to invert each data set individually and ultimately, find a unified conductivity model that is consistent with all EM data sets. We concentrate on four data sets, HELITEM (airborne time-domain), SQUID TEM (surface time-domain B-field), Crone pulse EM (borehole time-domain), and ZTEM (airborne frequency-domain natural source). These four data sets offer different types of coverage at the site. HELITEM covers a large area around the deposit with good assessment of the overall conductivity. SQUID TEM, empowered by the high-precision SQUID B-field magnetometer, can penetrate deeper. Crone pulse EM has “close-up” insight from the boreholes near to the ore body. ZTEM is good at locating the conductivity interfaces while delineating deep and regional features.

It has been a major accomplishment for us to invert each data set individually to recover a 3D conductivity. Unsurprisingly however, individual data sets give somewhat different images of the deposit; this arises primarily because of the different survey layouts. For example, the blind inversion of SQUID TEM generated some near-surface structure at the high sensitivity zone near the transmitters and receivers, whereas the model from HELITEM inversion is much smoother. At depth, the SQUID inversion finds a large and isolated dipping conductor with extremely high conductivity; the HELITEM inversion also shows the existence of the same conductor but with smaller spatial extent, weaker conductivity and consistency with the regional geology.

We have jointly inverted HELITEM and SQUID TEM data as they can be modeled simultaneously in the time domain using one program. The newly recovered model honors both data sets and can be seen as a “mid-point” between the two blind inversion results: (1) the dipping good conductor is still present but its conductivity is reduced compared to the blind SQUID result and its size is enlarged compared to the blind airborne result; (2) the conductor is better connected with the neighboring geological units; (3) the near-surface structures that could be attributed to the layout-dependent high sensitivity zone in SQUID TEM are greatly reduced. These changes make the new model more plausible and show that the joint inversion might reduce the non-uniqueness compared to single-data-set inversion/interpretations.

First pass inversions of the Crone pulse EM and ZTEM data sets also show the existence of the conductive orebody. Integration of all four conductivity models is still in progress.
MULTI-DISCIPLINARY 3D DATA INTEGRATION AT

SNOW LAKE (CHISEL BASIN)

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Hudbay aimed to leverage all of their exploration data to discover further VMS deposits in the Chisel Basin, Manitoba. Today's talk is about 3D multi-disciplinary data integration and the processes involved. This includes Geological Model building, Wireline data collection and interpretation of physical rock properties, Cluster analyses of Physical Rock Properties (PRP) and Lithogeochemistry, 3D constrained inversions of Susceptibility, Density, ZTEM, Titan, BHEM and Work Flow Targeting to deliver quantitative targets with enhanced understanding. What was achieved and the conclusions drawn are clearly stated.
Advanced 3D modelling and data management solutions

We supply the mining industry with cost-effective, multi-disciplinary, 3D and 4D earth modelling and data management solutions for mineral exploration, resource evaluation, and geotechnical hazard assessment.

We tightly integrate the industry's best earth modelling technology with advanced data processing across a range of geoscience applications. We believe in a quantitative solution that focuses asset teams on a shared interpretation that delivers better, faster business decisions.

**Mira Geoscience completed integrated modelling within Hudbay Minerals’ Chisel and Lalor mining district.** Compilation and modelling in 3D of geological, geophysical, and geochemical data from the district lead to data-driven 3D mineral potential modelling that identified extensions of mineralized zones as well as new areas of high mineral potential.
DISTRICT-SCALE 3D TARGETING OVER THE CHISEL AND LALOR PROPERTIES

USING MULTIDISCIPLINARY CRITERIA AND WEIGHTS OF EVIDENCE METHODS

Dianne Mitchinson¹, Nigel Phillips¹, Gervais Perron¹, Chrissy Williston¹,
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The abundance of 3D exploration data from Hudbay Minerals’ Chisel and Lalor properties presents an ideal opportunity for application of 3D multidisciplinary mineral potential targeting methods. Mira Geoscience compiled numerous disparate datasets and models from the Chisel and Lalor properties into a consistent 3D Common Earth Model to be used for quantitative querying of favorable exploration criteria and ranking of prospective regions within the district.

Data making up the key 3D components of the Lalor-Chisel Common Earth Model include a 3D geological model, magnetic, gravity, and ZTEM inversion models, and downhole geochemical data. Integration and evaluation of the various geological, geophysical and geochemical models and interactive discussion with the Hudbay Minerals Lalor and Chisel exploration teams lead to the establishment of the exploration criteria for 3D mineral potential modelling which included:

- occurrence of favorable felsic and mafic volcanic units (e.g. rhyolites, Powderhouse dacite);
- proximity to an unconformity representing a hiatus in volcanic activity;
- proximity to intrusive bodies which may act as heat sources driving hydrothermal fluids;
- proximity to the Chisel thrust, potential structure controlling the location of the Lalor and Chisel deposits;
- proximity to synvolcanic faults and fault intersections;
- proximity to hydrothermally-altered (sericitized, chloritized, carbonitized, silicified) zones;
- magnetite destruction (decreased magnetic susceptibility) caused by hydrothermal alteration;
- high densities indicative of dense massive sulfide bodies;
- proximity to electrical conductors indicative of potential massive sulphide mineralization.

The GOCAD Targeting Workflow employed by Mira Geoscience for this project provides an objective method of 3D exploration targeting, offering the best chance to find mineralization or extensions of mineralization based on the given set of exploration criteria. The Targeting Workflow is not a ‘black box’ method. It applies established and easily understood methods of rating the mineral...
potential of cells making up the targeting volume. Posterior probabilities, or relative mineral potential index values are output depending on whether statistical or knowledge-driven methods are applied. Targeting results are auditable, and clusters of high potential cells can be interrogated in terms of the degree to which each criteria has contributed to the target, so that each target may be fully understood.

Weights of Evidence methods were used to quantify relationships between the various evidential data at Lalor and Chisel, and was used to assign appropriate weights to each evidence layer. Three targeting results were calculated. Targeting Model 1 is derived from application of all targeting criteria, using Lalor mineralized zones as training regions for Weights of Evidence analysis. Model 2 also uses Lalor mineralized zones as training cells but omits the ZTEM conductivity model, which previously limited the extent of the targeting due to a large gap in EM data. Model 3 again omits the conductivity model generated from ZTEM inversion, and uses Chisel mineralized zones as training cells. Weights of evidence analysis results indicate that the exploration criteria most strongly related to existing mineralization are conductivity, rock type, proximity to the modelled unconformity, proximity to the Chisel thrust fault, and alteration. High potential cells where these statistically favorable criteria coexist are identified extending outward from known deposits, but also occurring along trends between deposits.

3D quantitative mineral potential modelling is an effective way to evaluate large exploration data sets in an integrative manner, to identify relationships between data and known occurrences of massive sulfides, and to find correlating criteria within 3D data that would be otherwise difficult to synthesize visually.
3-D HIGH-RESOLUTION COMMON EARTH MODELLING OF THE LALOR

VOLCANOGENIC MASSIVE SULPHIDE, MANITOBA, SNOW LAKE, CANADA

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Following the trend of shared earth modelling across multiple disciplines in hydrocarbon reservoir characterization since the 1990s, there is an increasing awareness for the need for rigorous data integration approaches in mineral exploration. This contribution of the Targeted Geoscience Initiative 4 methodology development project focuses on systematic reconciliation of multi-source geophysical, geochemical and geological data sets, also known as the Common Earth Modelling (CEM) approach. The Lalor volcanogenic massive sulphide deposit provides an ideal laboratory in Canada for developing and testing the CEM methodology. Multi-source geophysical (3D seismic, potential field and electromagnetic) survey, geophysical borehole, geological, lithogeochemical and physical property data have been acquired over the intact Lalor VMS deposit since 2008. This unique multi-component dataset allows implementing numerical grid modelling methods to upscale physical rock properties and reconcile 3-D lithofacies models with 3D seismic data and 3D geophysical inversions. Recent results of implementing the CEM methodology on the Lalor VMS deposit are reported that support geological interpretation of 3-D seismic and gravity drill hole data and provide insight in the geological origin of seismic velocity and density contrasts associated to the hanging and footwall host rocks, hydrothermal alteration, structure and sulphide mineralization itself. Three factors appear critical to the successful development of CEM at the mine camp scale: (1) geological knowledge-driven compilation of a curvi-linear (uvT) grid that captures the general structural geometry of the deposit, its host rock envelope and its hanging wall; (2) generalization of categorical variables such as lithofacies from detailed drill interval descriptions that is tailored to how they control physical rock properties under investigation and (3) Identification of continuous variables from geological and geochemical datasets that provide secondary constraints for stochastic modelling of physical rock properties to augment sparsely distributed borehole and drill core measurements of physical rock properties.
Trips to the “vault” were once routine for geoscientists combing Hudbay Minerals’ land package in the Flin Flon camp of northern Manitoba for new deposits. The dedicated room stores more than 80 years of exploration information in floor-to-ceiling filing and map cabinets, including floppy disks, project reports and drill logs: an explorer’s treasure chest, but an inconsistent one prone to gaps, duplication and incompatibility.

Now, thanks to a new data management system, the vault is becoming obsolete but the priceless files stored within are finding new and greater value on a central server.

Since 2011, Senior GIS Specialist Kenda Kozar from Hudbay’s original headquarters in Flin Flon has been working with Geosoft to upload geophysical data onto DAP, a secure geospatial server everyone can access to catalogue and manage exploration results. Concurrently, the company is implementing Microsoft’s Sharepoint to provide document control for internal links to other exploration information (reports, drill logs, etc.) related to a particular drill hole or project area.

The exploration team believes the new system will be instrumental in reaching its main goal: to find at least one new mine in the Flin Flon camp using data already collected.

The Flin Flon camp generates data faster than weeds propagate on a prairie farm. The greenstone belt that straddles the border between northern Manitoba and Saskatchewan is one of the most prospective VMS regions in the world. More than 30 deposits rich in copper, zinc, gold and silver have been discovered there and hundreds of millions has been spent on exploration over the past century. Many mines and projects, both past and current, dot the landscape.

Hudbay has been operating in the area since 1927, when the miner incorporated to develop the Flin Flon base metal deposit, considered one the largest industrial developments in the West at that time. While the company has since expanded into Peru, it remains active along the belt, with current claims covering an area of about 340,000 sq km. Hudbay’s 2007 discovery of the Lalor gold-copper-zinc mine – the belt’s second largest deposit - breathed new exploration promise into the region.

Over the decades, Hudbay has drilled about 17,000 holes, mostly within 300 m of surface. Geophysical data exceeds 260 gigabytes and more than 25,000 surface rock and soil samples have been collected, assayed and catalogued.

Managing the growing amounts of paper and digital data had become a monumental challenge. Geophysical information, mostly surface and borehole EM results, seismic data and some gravity and resistivity work, was saved in an unaudited folder system. Project files contained multiple versions of the same surveys as well as non-exploration files. Interpretations of results were often lost in personal e-mail folders, and paper maps in the vault were incompatible with digitized information.

But with the help of Geosoft’s data specialists, Hudbay is making progress scanning, reviewing, organizing and cleansing geophysical data, which represents the largest exploration database for the area. According
Having data in a central system has led to improved workflows, team collaboration and better 3D interpretations incorporating geophysics, geology and geochemistry. Shown above: A 3D model generated with data from Hudbay’s DAP server.

Back at Hudbay’s Flin Flon office, implementing the exploration information management system (EIMS) has not been without its growing pains partly because of a natural resistance to change and partly because of the state of the exploration files. Much of the data was stored in different formats and scales with inconsistent headings. Finding metadata proved challenging in some cases. GPS readings taken on or close to UTM boundaries had to be scrutinized for accuracy, and converting files from local grid systems was difficult.

But Hudbay’s data managers are gradually overcoming the challenges. “We have improved our workflow now that everything is in the same spot,” says Data Management Geologist Maggie Currie. “We can integrate geophysics, geology and geochemistry together to create better 3D models. And people don’t have to spend as much time manipulating the data, they can just access it and start their research.”

With much of the heavy slogging completed, Hudbay’s explorers are increasingly buying into the DAP concept, uploading and retrieving information to and from the server as routinely as they once made visits to the vault. The numbers speak for themselves: while just over 500 datasets were accessed on the server in the whole of 2012, more than 3,000 registered a hit in the first four months of 2014. Despite the extra time required to prepare the data for upload, having a central location where all the information about the Flin Flon camp is reliable and accessible will ultimately prove rewarding. “If we took the cumulative time that everyone will save in the exploration group, not just this year but over the next five to ten years, the minimal increase in time it takes to push the information up to the server will pay for itself many times over,” says Chief Geophysicist Peter Dueck.

He says the EIMS takes some of the worry out of staff turnover, which can be high in the cyclical exploration industry. Instead of geoscientists leaving the company with a new mine stored only in their heads and/or e-mail folder, valuable information resides securely on the server with accessibility to all. And Hudbay’s geologists and geophysicists are already working more closely together because of the ease of collaboration the system provides. “I see the integration between the three disciplines (geology, geochemistry and geophysics) becoming more commonplace,” Dueck says. “As deposits become tougher to find, that kind of collaboration will be the key to discovering our next mine.”

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MANITOBA'S NEXT COPPER MINE:
Reed Copper Project in Full Production 2014

Joint Venture between VMS Ventures Inc. (TSX-V: VMS) and Hudbay Minerals Inc. (NYSE: HBM) in production at the high grade Reed Copper Mine, near Snow Lake, Manitoba

- Pre-feasibility study completed with reserves of 2,157,000 tonnes grading 3.83% Cu.
- Commercial Production Commenced April 2014
- Underground development continues; as will surface and underground exploration activities over the life of the mine.
- VMS owns 22% of North American Nickel
- VMS has $700,000 in exploration planned for Manitoba.

VMS along with JV Partner HudBay reached a major milestone in 2014 with the completion of the construction phase of the Reed Copper Project and commencement of commercial production in April, less than 7 years from its discovery by VMS in 2007.

With the Reed Copper Mine now in production, management is focused on investigating and evaluating new projects to grow the Company in the future and build on our success at Reed.

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