Application of the

UTEM

INDUCTIVE SOURCE RESISTIVITY METHOD

(ISR)

for locating

WORLD CLASS MINERAL DEPOSITS

with specific reference to

GOLD IN NEVADA

Y. Lamontagne, Ph.D. P.Eng.
P Walker, Ph.D., P.Geo.
Abstract

The inductive source resistivity method (ISR) uses electric fields induced by a large transmitter loop to map the conductivity structure of the ground. The method has good lateral resolution to depths of two kilometers, and results of a test survey produced a conductivity high at 400m depth which correlated both with a resistivity log and with alteration. Previous tests have shown the method to be sensitive to quartz veins in one survey and altered volcanics and iron formation in another. Based on these results, we infer the method to have strong potential for mapping both conductive and resistive alteration.

We believe that ISR, by mapping alteration, has the potential for detecting epithermal, porphyry and sedex type deposits. ISR should be particularly applicable where such deposits are thought to have been overthrust. Nevada, where alteration is often associated with gold mineralization, is an obvious location for future ISR surveys, but it is clear that the method is applicable in a number of mining camps.

We demonstrate that ISR has the potential to detect deep structures, such as basin and range faulting. Such structures influence the location of mineral deposits. ISR thus can be applied to mapping areas with potential for mineralization on the basis of basement structure, with the potential for detecting alteration directly associated with those deposits.

ISR is less expensive than comparable methods with similar depth penetration, and has superior lateral resolution. The method has the advantage over CSAMT in that no current electrode grounding is required, eliminating the expense of deep pitting in areas with resistive cover. It has the advantage of speed over the magnetotelluric method because in many cases high precision, deep penetrating measurements can be made in less than 2 minutes per station.

Although this document discusses a geophysical method, the discussion is framed for a non-expert audience. Instead we try to focus on the key concepts that underlie the ISR method and the results that can be expected from it.
Table of Contents

Introduction .................................................................................................................. 4
The Use of EM for Gold Exploration in Nevada ......................................................... 11
The Case for UTEM-ISR: what it can do and how it works ....................................... 13
Characteristics of Gold Mineralization in Nevada & the Relevance of UTEM-ISR ......................................................... 16
Mapping Deep Electrical Structure with UTEM-ISR .............................................. 19
The Current State of the Art ...................................................................................... 22
Conclusions ............................................................................................................... 23
References ............................................................................................................... 24
Appendix – ISR Sensitivity Estimates ...................................................................... 25

Acknowledgements

The inputs from, and/or reviews by the following people are appreciated:

- Dick Irvine, Condor Consulting
- Peter Kowalczyk, Mira Geosciences
- Desmond Rainsford, Ontario Geological Survey (formerly Newmont Mining)
- Scott Thomas, Condor Consulting

We would like to acknowledge Areva Resources Canada Ltd. and thank Grant Nimeck for permission to present the data acquired at the Shea Creek property in this report.
Introduction

ISR, Inductive Source Resistivity, uses electric field measurements to infer the conductivity structure of the ground. A primary electric field is induced in the ground by a time varying current in a large wire loop, which is a square wave in free-air. The electric field is modified from its free-air pattern as it diffuses in the ground and is scattered by conductivity variations there. Electric field measurements are made with a series of grounded or capacitive electrodes.

One advantage of ISR over galvanic source methods is that the primary electric field always has an amplitude which is independent of the conductivity structure. Therefore the signal strength in ISR has a predictable magnitude, and the precision of measurements is not strongly affected by very high or low ground resistivity.

ISR is not new - it was pioneered by James Macnae and Yves Lamontagne in the early days of the UTEM system. It was a new survey configuration in which electric field profiles were measured along lines parallel to the front of a UTEM transmitter loop. Case histories were published detailing the ISR method over quartz in Australia (Macnae and Irvine, 1988, reproduced in Figure 1) and over the Windjammer gold prospect near the Porcupine-Destor fault in Ontario. The ISR method proved effective in its initial shallow high resistivity mapping application. However, for shallow mapping, ISR had competition from the inexpensive gradient array resistivity technique which also worked reasonably well. With high interest in using UTEM for detecting deep conductors in the Athabasca Basin and deep borehole exploration for nickel, the development of ISR was preempted for approximately 20 years in favour of deep-penetrating magnetic field measurements. For a detailed discussion of UTEM electric field measurements that predates ISR, the reader is referred to James Macnae’s Ph.D. thesis from the University of Toronto.

Figure 1: Results from a UTEM-ISR survey over quartz in Australia (Macnae and Irvine, 1988). The sensitivity of the method to the quartz resistors is clear as both resistivity highs correlate with quartz veins intersected in drill holes.
More recently, Lamontagne Geophysics undertook a multi-fold ISR test survey for Areva Resources Canada Inc. over its Shea Creek uranium property in the Athabasca Basin, Saskatchewan, Canada. The test consisted of collecting electric field data from four loops, stacking the data, and producing an image of the inferred conductivity cross-section. A plan view of the survey and the targeted uranium occurrences is presented in Figure 2 (shown by permission of Areva Resources). A discussion of the data processing is available in a separate document from Lamontagne Geophysics.

The processed ISR section is illustrated in Figure 3. The ISR imaging process makes use of the time domain diffusion to resolve the structure at depth. Qualitatively explained, the earliest channel after the square wave transition is sensitive only to shallow depth structures and each later channel 'sees' deeper and deeper. ISR also uses multi-fold stacking with transmitter loops at different distances from the traverse to improve the lateral and depth resolution of anomalies.

Figure 2: A plan view of the Areva test survey, showing the multiple loops used (blue tones) to collect UTEM-ISR data along the Line 7200 (red). The Saskatoon Lake conductor (orange) and the Collette, Kianna and Anne mineralization (yellow) were targets of the test.

The processed ISR section is illustrated in Figure 3. The ISR imaging process makes use of the time domain diffusion to resolve the structure at depth. Qualitatively explained, the earliest channel after the square wave transition is sensitive only to shallow depth structures and each later channel 'sees' deeper and deeper. ISR also uses multi-fold stacking with transmitter loops at different distances from the traverse to improve the lateral and depth resolution of anomalies.
A result of the survey is that the ISR method detected the existence of conductive alteration with a depth-to-top of ~ 400 meters – considerably above the unconformity at ~ 730 meters depth. The presence of alteration chimneys has been associated with several deposits of the Athabasca type, and this occurrence is confirmed by porosity and resistivity logs (Figure 4). The processed ISR section also indicates possible conductive alteration at several other positions within the sandstone, and the unconformity between the sediments of the Athabasca basin and the underlying basement rocks is also imaged. Penetration depth exceeds 3 kilometers and lateral resolution seems excellent to 2000 meters depth.

**Figure 3:** UTEM-ISR processed from data collected over the Shea Creek uranium deposit, Saskatchewan in a test survey for Areva Resources Canada Inc. The electric field data are consistently repeatable to better than 0.1%, virtually eliminating measurement noise as a source of error in any inversions. Provided the surface is not strongly conductive, the signal will be large and the S/N ratio will be very good. The contours illustrate the diffusion depths associated with each channel following the step in the electric field. The alteration chimney is at 500W, extending from a depth of 400m to the unconformity. (By permission of Areva Resources.)
Figure 4: A comparison of the UTEM-ISR Shea Creek data with a DC-resistivity pseudo-section. A resistivity log of the alteration zone is plotted over the ISR and DC-resistivity pseudo-section and confirms the ISR prediction of a low resistivity zone coinciding with an alteration chimney (as does a porosity log which is not shown). The green lines connecting the sections assist in comparing the features seen in each image. A direct comparison of the numerically inverted ISR resistivity data and the resistivity log is presented at the bottom of the figure. The resistivity pseudo-section and log data are from Nimeck and Koch, 2008. (By permission of Areva Resources.)
The vertical and lateral resolution in the UTEM-ISR images is excellent to depths of 400 meters, and is confirmed by comparison with the resistivity log data illustrated in Figure 4: The anomaly at 500W and 400m depth correlates extremely well with responses in the resistivity and porosity logs. In addition, penetration to a depth of 2 kilometers is demonstrated, and the method correctly identifies the ~700 m thickness of the 4000+ ohm-m Athabasca sandstone overlying the crystalline basement rocks.

While the use of multi-fold ISR for resistivity imaging is recent and consists of this one test survey, the survey results strongly suggest the method has considerable potential for mapping conductive and resistive alteration. Accordingly, mineral deposits such as Carlin type gold deposits, porphyries and roll-front and Athabasca type uranium deposits are prospective targets for the method.

In this document, the application of the ISR method to locating gold deposits in Nevada is considered. Nevada is home to many large carbonate-hosted gold deposits and many of these have attributes we feel are resolvable with ISR. As an example, the gold deposit
at Cortez Hills can probably be expected to net in excess of $6 billion at current prices\(^1\) - and the Cortez Hills deposit is but one of many to be found in the state. Figure 5 presents a location map of some of these deposits. The prospect of discovering deposits of this magnitude hidden at depth is a compelling reason to consider ISR as a deep exploration tool.

This report outlines how UTEM-ISR can be used in the search for these deposits, both as an exploration tool in regional reconnaissance mode, in a more detailed brown-fields

---

\(^1\)Computed from cash costs of $300/oz and pre-production capitalization of $500 million, assuming $900/oz gold, including measured and indicated reserves. (Source: Mining Magazine, January 2009).
delineation mode, and in detailed property scale exploration mode. While the discussion presented here deals with exploration of gold deposits in Nevada, ISR should also be applicable in other situations where alteration zones related to mineralisation result in a resistivity contrast with surrounding rocks.

Because of its penetration, ISR may be particularly useful for following mineralized trends beneath cover. A particular case is exemplified by the Battle Mountain-Eureka mineralized trend in Nevada west of the Roberts Mountain thrust, where carbonates hosting gold mineralization are covered by the Roberts Mountain allochthon (Figure 6). Parts of China present a setting similar to Nevada and may be prospective for gold mineralization in the style seen in Nevada\textsuperscript{2}, as are the large Cretaceous Alaska-Yukon related gold deposits in the Selwyn Basin\textsuperscript{3}. Another example of such a mineralized trend is the Domeyko fault system - host to the Collahuasi, El Abra, Chuquicamata, La Escondida and Potrerillos porphyry deposits.

\textsuperscript{2} L. Robb, Introduction to ore-forming processes, 2008, page 192
\textsuperscript{3} Emsbo et al, 2006
The Use of EM for Gold Exploration in Nevada

Nevada is an enticing area for exploration because it is so well endowed with gold mineralization – the state hosts many of the world’s major gold deposits. While many deposits have been found, more undoubtedly remain to be located. Many deposits are hosted in carbonates that have been decalcified as a result of the ingress of ore-bearing fluids. Others are associated with silica flooding or elevated levels of sulphides. Decalcification and silica flooding often cause resistive anomalies, while sulphides may appear as conductors. Accordingly, both resistive and conductive anomalies may be of interest, depending on the nature of the mineralization.

A geophysical case-history of the Brooks prospect comparing IP/Resistivity and Titan-24 systems was published by Goldie (2007). The Brooks prospect is approximately 30 km west of Battle Mountain and is close to the large Lone Tree deposit. Gold mineralization at Lone Tree is controlled by northerly-trending faults and favourable ore-bearing lithologies in the Antler sequence which has been overthrust by the Havallah Formation. Post-mineralization cover, including poorly consolidated gravel, lake sediments and distal volcanic tuffs, can vary in thickness from 1 meter over parts of the Lone Tree deposit to 300 meters in alluvium filled basins. A similar model for mineralization was considered probable at the Brooks prospect.

Inverted IP/Resistivity and Titan-24 are shown to be capable of penetrating to 400 meters.

Figure 7: Inverted Resistivity at the Brooks Prospect, near Lone Tree, from Goldie, 2007. IP/Resistivity and Titan-24 are shown to be capable of penetrating to 400 meters.

Inverted IP/Resistivity and Titan-24 resistivity sections, over the Brooks prospect are shown in Figure 7. The Brooks prospect is overlain by pediment cover. Goldie interprets the moderate to high resistivities to be representative of the over thrust Havallah Formation, and the breaks in the resistivity to be representative of structure. It is interesting to compare the lateral resolution of the UTEM-ISR inversion for the Areva test (Figure 3) with the lateral resolution of the Titan and IP/Resistivity sections published by Goldie. In the ISR section, the anomaly at 500 W is located at approximately 400 meters depth and has lateral dimensions of approximately 200 meters.
It is difficult to imagine lateral resolution on this scale at equivalent depths in the sections presented in Figure 7. Given the overthrust geology at the Brooks prospect one would expect resistivity changes to be quite abrupt, but abrupt changes are not obvious at equivalent depths on the Titan and IP/Resistivity sections.

One possibility is that there is no such abrupt change in resistivity at depths of 400 m in the Brooks area. Another possibility is that the electrical methods used in the Brooks case history are not as sensitive to lateral resolution as is UTEM-ISR. The following section elaborates on this theme.
The Case for UTEM-ISR: What it can do and how it works

There are important differences between how UTEM-ISR and grounded source systems such as IP/Resistivity and Titan-24 detect resistivity changes. These differences explain why ISR has both a superior sensitivity to lateral resistivity changes and a superior depth of penetration.

A principal difference between grounded source systems and UTEM-ISR is that current must be injected into the ground in a grounded source system, while the UTEM-ISR method requires no such galvanic contact for the source current. When current is injected into the ground, it can be preferentially directed along conductive structures in the ground and, depending on the geometry of the conductivity distribution, some areas may remain un-energized and therefore unexplored. The Titan system deals with this problem by blanketing a survey area with electrodes, making such a possibility unlikely, but at a cost much higher than standard IP-Resistivity surveys. UTEM-ISR eliminates the problem of ground contact. The ISR primary source field geometry is determined only by the shape of the loop and is independent of ground conductivity structure. This has significant advantages for spatial coverage, because it guarantees that the volume of ground intended to be energized will in fact be energized.

Eliminating ground contact guarantees that ground contact problems will not be an obstacle to completing an ISR survey. In many places, this removes a significant variable from the cost of executing a survey. IP/Resistivity and Titan-24, in contrast, become more expensive where ground contact is difficult because additional effort is required to setup the sources to inject current into the earth.

A second important factor to understanding the sensitivity of an ISR survey in comparison with pole/pole-dipole survey is the geometric fall-off of the source field with depth. The primary electric field from a loop falls off geometrically as a logarithmic function of distance and depth, while the magnetic field of a loop and the electric fields from pole/dipole sources all fall off as power laws. At late sampling times, after diffusion effects are dissipated, the electric field from a loop is thus proportionately much more uniform with depth than are the primary fields employed in other methods.

Thus, one advantage of ISR is that the electric field from a loop falls off with depth at a slower rate than the magnetic field. From a signal strength point of view, over a good range of frequencies, electric field measurements are also generally more repeatable than magnetic field measurements because the E-field input signal is usually large compared to natural or instrumental noise.

The penetration depth expected from a UTEM-ISR survey will depend on the base frequency used and the resistivity of the ground. The more conductive the ground, the more slowly the signal will diffuse through the ground and the lower the base frequency should be to achieve a given penetration. The diffusion depth of a UTEM system is
illustrated in Figure 8. The UTEM diffusion (or penetration) depth in metres, \( d \), based on the position of the latest time channel, is given by \( d = 515(\rho/F)^{1/2} \) for a base frequency \( F \) and resistivity \( \rho \). For a detailed discussion on how the diffusion depth is computed, please refer to Macnae and Lamontagne, (1987). Their paper discusses how magnetic-field based conductivity-depth images are calculated.

At the Exploration 87 conference, Macnae and Spies (1987) and McMullan et al. (1987) show three examples of UTEM conductivity imaging surveys to depths of 2000m in routine surveys and to 10km in a special large scale crustal study survey.

![ISR Penetration Depth](image)

**Figure 8:** UTEM-ISR penetration depth as a function of resistivity and base frequency.

The penetration (or diffusion) depth and the detectability depth of a structure are related, but different, concepts. For a target to be detectable, it must lie within the diffusion depth (as per Figure 8), and it must fall within the target sensitivity guidelines summarized in the Appendix. In the case of UTEM-ISR, 4-fold loop coverage with 20-channel sampling creates an 80-fold primary field coverage from which the ground structure can be inverted. With 80-fold coverage, together with the high repeatability of the e-field signal, anomalies of 1-2% can be resolved into meaningful structure. This level of resolution is much higher than can be achieved in conventional EM and magnetotelluric surveys.

Because ISR is based on measurements of the electric field, it is also more sensitive to deep structures with lateral resistivity contrasts than are magnetic field measurements. In such cases, the induced currents in the host rocks may be too small to produce any
detectable magnetic field EM anomaly, but could still affect the electric field quite strongly. ISR seems particularly well suited to areas with resistive cover and complex non-layered structure. These attributes make ISR a promising exploration method in areas where large deposits in favourable geology may be overlain by resistive gravels and/or overthrust.

Cost and penetration depth comparisons of IP/Resistivity, Titan-24 and UTEM-ISR surveys are summarized in Table 1. The IP/Resistivity and Titan-24 depths are taken from Goldie (2007). The UTEM-ISR cost levels assume conservative production rates for UTEM crews. UTEM is less expensive than Titan-24 because the survey logistics are simpler and the equipment is easily transportable. UTEM-ISR penetration depths were computed assuming a 4 Hz base frequency in a 250 ohm-m background (see Figure 8).

**Table 1: Cost comparison of IP/Resistivity, Titan-24 and UTEM-ISR**

<table>
<thead>
<tr>
<th>Method</th>
<th>Rate / line-km</th>
<th>Penetration Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP/Resistivity (standard pole-dipole n=1,6)</td>
<td>Low</td>
<td>150-200</td>
</tr>
<tr>
<td>IP/Resistivity (n =1,23)</td>
<td>High</td>
<td>&gt; 400</td>
</tr>
<tr>
<td>Titan-24 IP/Res</td>
<td>High</td>
<td>&gt;400 (500m⁴)</td>
</tr>
<tr>
<td>UTEM-ISR (1 receiver, 4Hz, 4-fold stacks)</td>
<td>Medium</td>
<td>3000</td>
</tr>
</tbody>
</table>

It is clear from Table 1 that UTEM-ISR is attractive in comparison with standard electrical methods, both on the basis of penetration depth and on the basis of cost. In addition, 80-fold coverage and low noise provides superior lateral resolution.

---

⁴ Irvine and Thomas, pers. comm.
Characteristics of Gold Mineralization in Nevada & the Relevance of UTEM-ISR

Much of the gold mineralization in Nevada occurs along trends that are thought to be controlled by deep-seated structures associated with basin and range faulting. Although several theories exist to explain the source of the gold mineralization and the association with these basement faults, there is no doubt that the majority of economic mineralization occurs in belts. Figure 5 shows the locations of Nevada’s gold belts. The most important these belts are the Battle Mountain-Eureka trend (containing the Cortez trend), the Getchell and Carlin trends, and the Independence and Alligator Ridge groups. Another important mineralized trend is the Walker trend, in the southwest of the state, parallel to the California border. Historic gold production and reserves exceed 6000 tons\(^5\) (~$150 billion), making Nevada a compelling place to explore for gold.

The prospective returns from gold exploration in Nevada are exemplified by the Cortez Hills deposit, currently being developed by Barrick Gold. Cortez Hills is located 120 km southwest of Elko, Nevada. The deposit has proven/probable resources of 3.5 Moz, and measured and indicated resources of 11.5 Moz, with expected cash costs of under $300/oz and an expected cap-ex of approximately $500 million\(^6\).

The Cortez-Hills deposit lies on the Battle Mountain-Eureka trend in a basin and range setting. Precious metals are hosted in the Silurian-Devonian lower-plate carbonate sequences. Ores are hosted in the Roberts formation, a 600m thick silty limestone, and in the overlying Denban Limestone. The deposits are overlain by Quaternary alluvium. The pit will be approximately 1100 feet deep, with a breccia zone lying beneath the pit to be mined with underground methods. In parts of the state, post-mineral cover, including poorly consolidated gravel and distal volcanic tuffs, can be up to 100m thick, and can exceed 300m\(^7\) in alluvium filled basins. In this environment a 300-400 meter depth of exploration is mandatory. Even deeper penetrating methods are required where one must contend with an overthrust and/or deep alluvial gravels.

Gold is typically contained in arsenopyrite, sulphidation, host rock decalcification, and silicification. The first two modes of emplacement may be manifested by conductivity and polarization anomalies, while the second two may appear as resistors. There are several models for gold deposition in Nevada, and Figures 9 and 10 illustrate two of these. Gold can be found in a number of different deposit styles, including sedex, porphyry, Carlin-type, epithermal and hot spring deposits.

For deposits following the model illustrated in Figure 9, ISR would be expected to be sensitive to the resistivity highs typically associated with the jasperoid formed in the fracture systems that is associated with fluid flow. A model for Carlin type deposits is illustrated in Figure 10. It is thought that ISR would be effective in mapping the base of

---

\(^5\) Emsbo et al, 2006
\(^6\) Mining Magazine, Jan/Feb 2009
\(^7\) Goldie, The Leading Edge, Feb 2007
the Roberts Mountain allochthon and the underlying carbonates, since the rocks comprising the allochthon are more resistive than the underlying carbonates (refer, for example, to the green trajectory plotted in Figure 6). Additionally, UTEM-ISR surveys are expected to be sensitive to the resistivity changes associated with gold mineralization in the rocks at the base of the allochthon. Such mineralization is often associated with the presence of small fault-propagated anticlines, at locations where basin and range faults intersect shale-limestone contacts.

Clearly, if the basin and range faults could be seen with ISR, the ability to trace these faults along strike until prospective conductivity or resistivity anomalies were located would provide exploration companies with a formidable tool. It is clear both from the Athabasca Basin case study (Figure 4) and from the calculations presented in Figure 8 that UTEM-ISR can penetrate several kilometers in depth given the resistivities expected in Nevada. Whether the faults are resistive or conductive enough on their own to be detected directly is a question that needs further study. However, given UTEM-ISR’s potential depth of penetration, it may be possible to map the faults by mapping lateral changes in lithology caused by the faulting, rather than by directly detecting the subtle resistivity variations associated with the faults themselves. Again, we refer to the deep contact feature mapped in Figure 4 as evidence that this might be possible. The next section presents further evidence that such a strategy may be feasible.

Figure 9: A model for the formation of Carlin type deposits (modified from Sawkins, 1984). Both the jasperoid alteration associated with Carlin type deposits and the deep structures thought to control the deposits are targets for the ISR method. ISR could detect resistive alteration associated with the jasperoid (stippled blue) and conductive or resistive alteration (stippled red) caused by fluid flow along structural features.
**Figure 10:** A model for gold emplacement in Nevada and ISR targets (modified from Robb, p192) showing early thrusting in red, followed by later basin and range extensional faulting in blue. The associated fluid circulation during this later phase of the faulting is considered to have led to ore formation along these structures, particularly where they intersect the permeable carbonates and the less permeable overlaying siliciclastics. Gold deposit locations are shown in yellow. The Twin Creeks deposit lies approximately 24 km northwest of Golconda. ISR targets would be alteration (stippled) associated with mineralization in the carbonates and siliciclastics, alteration associated with fluid flow on the basin and range faults, the conductivity contrast between the resistive “®” overthrust rocks of the Roberts Mountain allochthon and the underlying conductive “©” carbonates, or the resistivity contrast between the lithologies bordering the basin and range faults.
Mapping Deep Electrical Structure with UTEM-ISR

Here, we examine data from a magnetotelluric transect near the Carlin mine for evidence to support our hypothesis that UTEM-ISR can be used to detect deep structure. The transect, shown in Figure 11, was conducted by Williams and Rodriguez, across the Carlin trend in Nevada. The transect runs southwest/northeast, approximately perpendicular to the trend. Data are published in USGS open file report 00-419, and consist of apparent resistivity, phase and skew plots for the approximately 25 stations surveyed. A brief analysis of those data is presented.

![MT Transect over the Carlin trend](image1.png)

A detailed view of the transect near the Carlin mine is illustrated in Figure 12, together with apparent resistivity plots acquired at several sites near the mine. All plots show dual-valued apparent resistivities at lower frequencies (greater depth) - indicating a departure from 1-dimensional near surface structure to 2-D structure at depth. It is quite likely this two-dimensional structure is related to the basin and range faulting illustrated in Figure 10, and if so, it would represent an important control on mineralization. Simple skin-depth calculations have been used to infer depths to the two dimensional structure and the inferred basin and range faults. Since the natural field involves both downward
and upward propagation of the field, the skin depth is likely to be an overestimate to the depth of the 2-dimensional structure.

On the westernmost part of the detailed segment, the near-surface apparent resistivity is \(~300\ \text{ohm-m}\) and the 2-D structure appears to begin at a depth of 2.5 km. Moving northeast across the transect, the near surface apparent resistivity decreases to \(~10\ \text{ohm-m}\). Toward the centre of the profile, the 2-D structure is inferred to be as shallow as a few hundred meters, while to the east of the profile, the 2-D structure appears to revert to a depth of \(~2\ \text{km}\).

On the basis of diffusion depths (plotted in Figure 8 as a function of resistivity), UTEM_ISR should be capable of penetrating to approximately 4 kilometers in 300 ohm-m material and to approximately 800 meters in 10 ohm-m material at 3.872 Hz. Given these penetration depths UTEM_ISR should easily map both the near-surface conductivity structure shown in Goldie’s work in Figure 7, and the 2-D structures associated with stations 6 and 7 in Figure 12 that may be associated with the Carlin mineralization.

For the cases examined, UTEM_ISR should be effective in mapping the upper 400 meters using a base frequency of 3.872 Hz. Based on diffusion depths, ISR should also be effective in penetrating the more resistive rocks in the Golconda thrust and mapping the surface of the underlying carbonates where the potential for finding gold deposits is high. With the right choice of base frequency to obtain optimal diffusion depths, we expect the ISR method should be able to map to depths of 3-4 km in the more conductive sequences seen to the east of the Carlin deposit. On this basis, and with the potential to map deep structure that is thought to control mineralization, UTEM_ISR has the potential for re-writing the manual for gold exploration in Nevada.

The potential for new discoveries is clear, but requires developing the knowledge on how to effectively use UTEM_ISR in areas such as Nevada. ISR has the potential to change exploration strategies by mapping the locations of the basin and range faults that are thought to play a controlling role in the locations of Carlin type, sedex, porphyry and hot-spring type deposits. It may also be used in more conventional exploration strategies, for example by detecting alteration in the carbonates underlying the over-thrusts and within the siliciclastic sequences. In some applications, ISR may improve on existing strategies that employ Titan-24 or deep penetrating IP-Resistivity surveys, at a lower cost than those methods.
Figure 12: Detailed MT data over a profile near the Carlin Mine. From Williams & Rodriguez, 2000. Plan map and apparent resistivity plots courtesy of the U.S. Geological Survey. On the apparent resistivity plots, the vertical bars indicate locations on the plot where 1-D surficial structure splits into 2-D. Numbers in the lower right corner indicate the station number where the data were collected. The labeled depths are estimates of the skin depths where the 2-dimensional structure is seen. These depths are sketched in red just above the traverse line, with the ordinate ("y") axis labeled in kilometers.
The Current State of the Art

All indications point to the effectiveness of UTEM-ISR surveys for detecting alteration associated with gold deposits of the type commonly found in Nevada, and to its potential for detecting geophysical anomalies associated with porphyry, uranium roll-front and Athabasca-type uranium deposits.

Current UTEM systems are capable of collecting electric field data to approximately 1Hz base frequency. Further development will interface the electric field sensors to receivers with new noise rejection features capable of high-precision sampling to base frequencies below 1Hz. The new UTEM transmitters have no low frequency limit. As the technology currently stands, all indications are that, with a base frequency of 2Hz, the ISR method is capable of mapping the upper 1000 meters in 10 ohm-m rock, and to approximately 3000 meters in 300 ohm-m rock.

Further development of the UTEM system will be required to facilitate deep mapping in highly conductive (< 10 ohm-m) rock.

Electric fields can be acquired either through grounded metal stakes or with capacitively coupled electrodes. Metal stakes are quite acceptable where conditions permit. Capacitively coupled electrodes are useful in deep snow or in rocky conditions where metal stakes cannot make contact with the ground.

Data can be processed with custom software written at Lamontagne Geophysics. The software uses a one-dimensional approximation to estimate the background conductivity from the diffusion of the electric fields, and a 2-D approximation to simulate scattering within that background. The software was developed and successfully tested to process the data acquired in the test at Shea Creek for Areva Canada Resources Inc. Strongly three-dimensional structures are not imaged accurately.

Doug Oldenburg, at the University of British Columbia, is undertaking further examination of the Shea Creek ISR data and the application of inverse methods to it. For the immediate future the plan is to use the Lamontagne software for initial imaging, with any follow-up processing to be arranged between the client and Doug Oldenburg’s group or any available processing alternatives.

Currently, the processing at Lamontagne Geophysics does not fully take into account lateral conductivity variations on the surface, which would include large variations in topography. These effects are manifested as near-surface geological noise. This noise is currently being mitigated with geometrical stacking and by field normalization methods.

The present processing software is suitable for areas where the structure is not overly 3-dimensional and where topography is not overly severe. In common with all electrical methods, it may be difficult or impossible with ISR to resolve deep structures overlain by highly conductive cover. However, we expect ISR to be less affected by conductive cover than other electrical methods.
Conclusions

According to Smee (1997), the majority of the gold deposits that have been found in Nevada have had some surficial indications of their presence. Many of these deposits are located in the ranges where mineralization or alteration has been exposed by erosion. As the ranges become increasingly explored, exploration is shifting to the basins where alluvial cover makes such direct detection difficult. ISR has many characteristics that are compatible with exploration below alluvial cover and overthrusts.

ISR is a relatively inexpensive, deep penetrating method with good lateral resolution. While the method is still in its infancy, all indications are that it has the characteristics required for successful gold exploration in Nevada, and in exploration for porphyry, sedex and epithermal deposits in general. ISR also has the potential for mapping the deep structures, such as basin and range faults, that control the locations of these deposits.

The mining industry in Nevada is facing new challenges as exploration moves from exposed ranges into the alluvium filled basins and under the overthrusts. ISR addresses these challenges by offering an increased depth of exploration and resolution, and at a lower cost than comparable geophysical methods.
References


Goldie, Mark, A comparison between conventional and distributed acquisition induced polarization surveys for gold exploration in Nevada, The Leading Edge, February, 2007

Lamontagne Geophysics Ltd.: Windjammer brochure; ISR brochure

Macnae, J.C., Geophysical prospecting with electric fields from an inductive source, PhD thesis, University of Toronto.


Macnae J.C. and Y. Lamontagne, 1987, Imaging quasi-layered conductivity structures by simple processing of transient electromagnetic data, Geophysics vol. 52, No 4, p 545


Nimeck, G. and R. Koch, A progressive geophysical exploration strategy at the Shea Creek uranium deposit, The Leading Edge, January 2008


Robb, L, 2008, Introduction to ore forming processes, Blackwell Publishing

Sawkins, 1984, Metal deposits in relation to plate tectonics, Springer-Verlag, Berlin

Williams and Rodriguez, 2000, USGS Open File Report, 00-419

* Exploration ’87 Proceedings are downloadable from: http://www.exploration07.com/events/default.asp#proceedings

24
Appendix

**ISR Target Sensitivity Guidelines**

1) 3-D Resistive Barrier (Depth < 2s)
2) 2-D Resistive Barrier (Depth < 4s)
3) Thick Conductive Zone (Depth < T/2)
4) 3-D High Contrast Conductor or Resistor (Depth < 2s)
5) 2-D High Contrast Conductor or Resistor (Depth < 4s)
6) 3-D Conductive Lense (Horizontal, Depth < 2s)
7) 2-D Conductive Lense (Horizontal, Depth < 4s)
8) Thick flat-lying resistivity (Depth < 2T)
9) Vertical Conductive Lense (Depth < 2s)