ISR - Induced Source Resistivity - Sierra Gorda Project: ISR across a development-stage copper-molybdenum project, Atacama Desert, northern Chile.

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Summary

The ISR (Induced Source Resistivity) technique produces a resistivity-depth section from a suite of electric-field measurements collected using an induced source. Sierra Gorda (Figure 1) is considered an excellent location for a test of the applicability of electric-field measurements/ISR to the detection/delineation of porphyry mineralization.

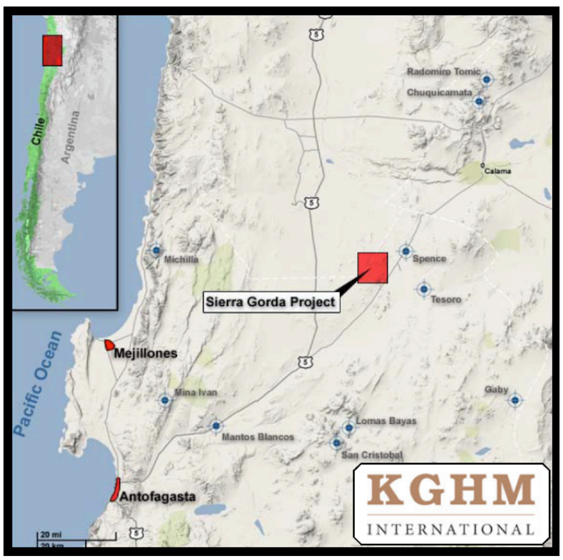

Figure 1: Sierra Gorda Location map.

The ISR survey technique and the UTEM3 (West et al, 1984) equipment used to collect all measurements were modified to work in the Atacama field conditions. The principle field issue in collecting the electric-field measurements is electrostatic noise due to contact electrification (triboelectricity). The conditions found in the Atacama are considered an analogue for conditions on the planet Mars.

The Sierra Gorda target is clearly detected by the ISR survey. Current ISR processing software has limitations - it is a 2D inversion and tolerates but does not fully render IP effects. When the geology is more ~3D and when IP effects are present - likely both the case at Sierra Gorda - these limitations will influence the final ISR Sections. Work on a 3D solution is ongoing. Overall we are still well within the learning process with ISR surveying and processing, however, the results of the Sierra Gorda ISR Test are very encouraging.

Introduction

The ISR (Induced Source Resistivity) technique produces a resistivity-depth section from a suite of electric-field profiles collected using an induced source. The source (transmitter loop) is offset a greater distance for each successive electric-field profile. In this survey a suite of four electric-field profiles was collected with transmitter loops offset 200/600/1000/1400m from the survey line (Figure 2). The use of an induced source circumvents the difficulty involved in getting current into the ground inherent in traditional IP/resistivity surveys. In addition the depth penetration of the electric field is less dependent on the conductivity structure present.

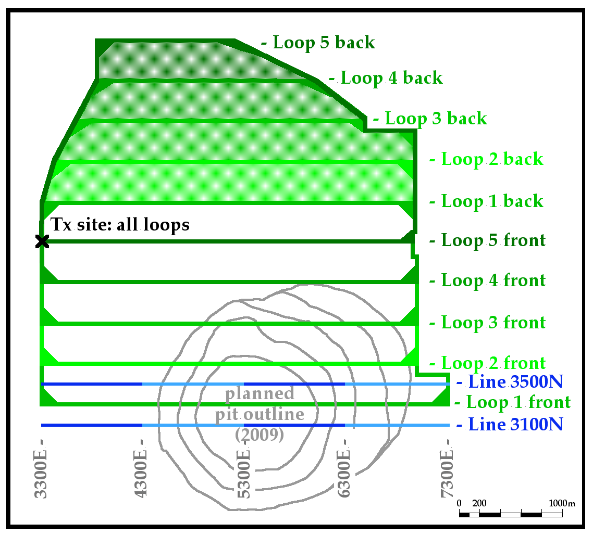

Figure 2: ISR Survey Layout: Loops/Lines 31/35N Survey Line 31N is east-west (UTM) and ~bisects the planned pit (2009) outline. Loop shape conforms to the property shape – all wire was deployed on the Sierra Gorda property.

Sierra Gorda is considered an excellent location for a test of the applicability of electric-field measurements/ISR to the detection/ delineation of porphyry mineralization. The Sierra Gorda Project (KGHM International) is a development-stage copper-molybdenum-gold project in the Atacama Desert, Region II of northern Chile. Sierra Gorda has

MDA 2010 updated resource estimates :total 2 billion tonnes of Measured and Indicated Resources in sulphides mineralization, and 237 million tonnes in oxides mineralization (Technical Report for the Sierra Gorda Project,Chile, 2011).

The ISR survey technique and the UTEM equipment were modified for work in the field conditions encountered in the Atacama. The principle field issue in collecting the electric-field measurements is electrostatic noise due to contact electrification (triboelectricity) resulting from the combination of wind, arid conditions, dust and to a lesser extent the daytime rise in temperature. The conditions found in the Atacama are considered an analogue for conditions on the planet Mars. (Delory et al, 2006)

Field Method

Figure 2 shows the Loop and Line layout used for the Sierra Gorda ISR Survey. The in-line component of the electric field - Ex - was measured along two 4000m east-west survey lines from a total of five ~4000x2000m ungrounded Tx loops. Each of the survey lines – Line 31N and Line 35N - was surveyed using UTEM3 equipment from 4 transmitter loops offset to the north of the line by 200/600/1000/1400 m respectively.

E-field measurements were collected using 50m electrode dipoles and capacitive electrodes. The capacitive electrodes consisted of a heavy copper mesh over a wooden frame and measure 0.9x1.8m. Ground proximity (capacitance) was improved by shoveling available material onto the electrodes. Once a line is surveyed, all the electrode sites are prepared and in each successive surveying the identical electrode sites are occupied.

Surveying was carried out at a base frequency of 2Hz with 20 receiver sampling times increasing in a square root two progression from 293µs to 213ms. For each station the number of electric-field data collected is the number of channels (20) multiplied by the number of transmitter loops (4).

One of the four Line 31N Ex profiles is shown in Figure 3. The field data shows the characteristic mirroring of the later channels in the early channels that results from the use of a periodic waveform. The profile is also shown Step-Corrected - deconvolved into a step response for processing.

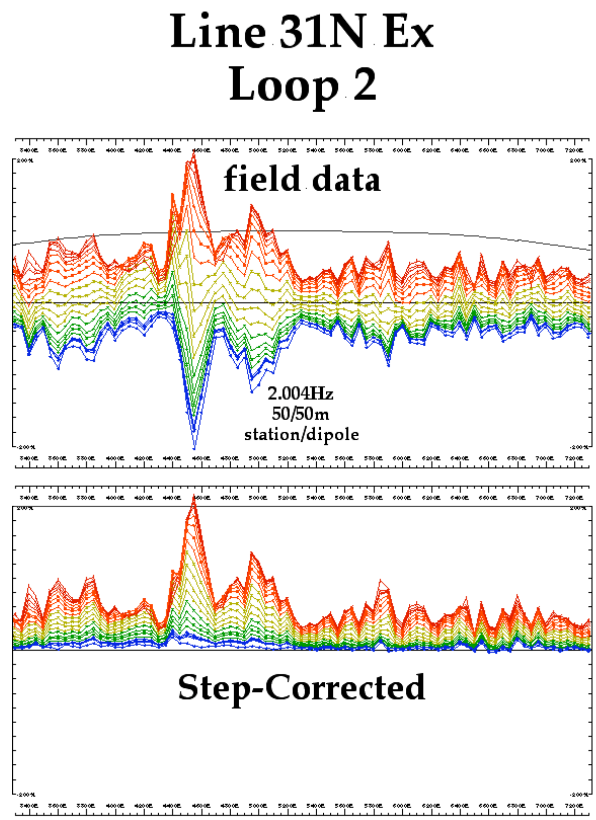

Figure 3: ISR Survey Layout: Loops/Lines 31/35N Survey Line 31N is east-west (UTM) and ~bisects the planned pit (2009) outline. Loop shape conforms to the property shape – all wire was deployed on the Sierra Gorda property.

Processing Method

The E-field data collected during this test was processed with the goal of producing an ISR - Induced Source Resistivity - resistivity-depth section for two lines surveyed over the - Lines 31N and 35N. The ISR processing software employed has been developed by Lamontagne Geophysics and upgraded as required, The result is an ISR processing package capable of handling more complex geological environments, dealing with local cultural features, better able do handle end-of-line effects and tolerant of IP effects

The method used to obtain the resistivity-depth section involves two processes:

1) ECDI E-field Conductivity Depth Imaging
2) ISR E-field Imaging.

The ECDI process is CDI (Macnae,1987) with electric field measurements. The field data is Step Corrected (Figure 3), normalized to the Late-Time limit and then laterally averaged. The averaged data are then fit to apparent diffusion time as a function of depth, creating a laterally-smooth conductivity distribution.

E-field imaging is done on stacked, Step-Corrected data which are not late-time normalized. E-field imaging is simply a DC resistivity inversion process where the source E-field is inferred as a function of time from the ECDI results.

The ISR inversion is a 2-step process. At each outer (main) iteration (MITER) the Step-Corrected E-field data and the diffusion time data are jointly fitting using a trade-off parameter subject to smoothing conditions. The updated synthetic response and residuals in both data and diffusion times are recalculated after each MITER. The number of anomaly profiles fitted is the number of channels (20) multiplied by the number of loops (4).

This process is repeated until the RMS (Root Mean Square) residuals no longer appreciably decrease - the generally accepted practice. The number of main iterations (MITER) required to reach this point varies with the data set. Further iterations beyond this tend to lower the residuals marginally but generally result in increasing complexity in the model that is not supported by the structure of the data .

Sierra Gorda

Figure 4 shows the Line 31N ISR resistivity-depth section after MITER 7 - the main iteration at which the overall RMS residuals no longer appreciably decrease. As a test different combinations of 2 or 3 profiles were processed in addition to the full 4 profile suite. The features outlined in the ISR Section (Figure 4) are present in these other sections. Overall the ISR section produces a simpler resistivity model that agrees reasonably well with geology/grades near Line 31N. The ISR section is interpreted in Figure 5 and Figure 6 shows a more detailed comparison with Cu values.

The primary Sierra Gorda target is a resistive target (Catalina sulphide) from ~4600-6100E on Line 31N with depth-to-top of ~150-400m - shallowest expression at the western edge on Line 31N. The overlying unit is more conductive (Catalina oxide). The contact between these two correlates well with the top of sulphide - the boundary marking the top of the sulphide zone/base of the oxide zone (Figure 6).

No lower contact is interpreted for the resistive target (Catalina sulphide) as we know from the planned pit footprint that the causative body is not really 2D.

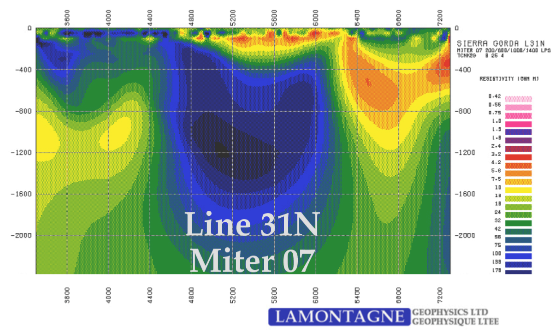

Figure 4: ISR resistivity-depth section for ISR survey Line 31N shown to a depth of 2500m. Note that Miter 7 refers to the number of Main iterations of the processing software.

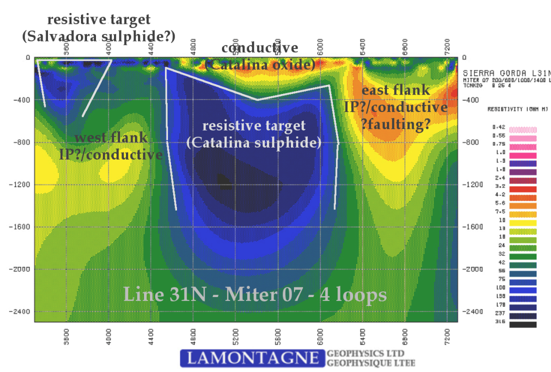

Figure 5: Interpreted ISR resistivity-depth section for ISR survey Line 31N showing the contrast between the sulphide and oxide ores.

The resistive target (Catalina sulphide) resistivity is about 10x more resistive than the background with the sharper contrast on the east edge. The ~10:1 contrast probably underestimates the true contrast, however it is clear that there is a systematic resistivity contrast between the mineralized rocks and the host.

A second Sierra Gorda target is a smaller, shallower resistive target (Salvadora sulphide?) at the western end of the ISR Sections from ~3300-3700E. This target is more extensive on Line 35N where it is closer to the projected Salvadora pit outline. On Line 31N it more likely reflects a feature related to the Salvadora pit target.

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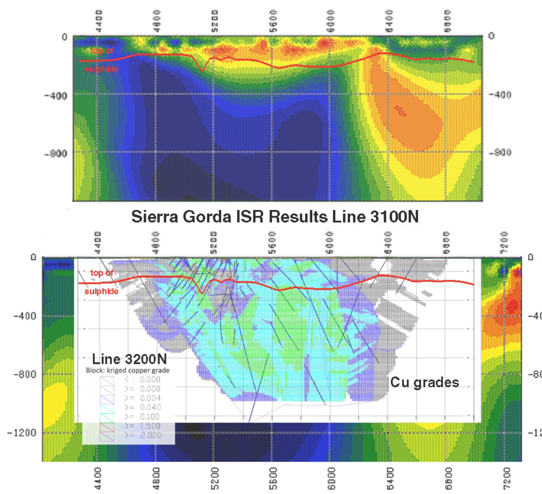

Figure 6: Detail of ISR resistivity-depth section for ISR survey Line 31N(shown to ~1400m) compared to Cu grades(source:Scoping Study for the Sierra Gorda Project, 2009). The top of the sulphides/base of the oxides is shown as a red line on both the ISR section and the kriged Cu values.

Current Work

Work with the Sierra Gorda ISR data set and other available ISR data sets is heading towards 3D processing. Currently sections found through the inversion are sent to a routine for assembly as a volume. A 3D finite difference routine solves for a forward model of the E and H fields to be plotted.

Figure 7 shows a comparison of this model data and Ex field data profiles for Line 31N Loop3. The model profile is influenced by all of the data collected on both lines so unless the geology was truly 2D an exact match would not be expected.

Conclusions

The ISR processing software has limitations - it is a 2D inversion and tolerates but does not fully render IP effects. When the geology is more ~3D and when IP effects are present - likely both the case at Sierra Gorda - these limitations will influence the final ISR Sections and these influences should be considered during interpretation. Overall we are still well within the learning process with ISR surveying and processing, however, the results of the Sierra Gorda ISR Test are very encouraging. The Sierra Gorda target was clearly detected by the ISR survey.

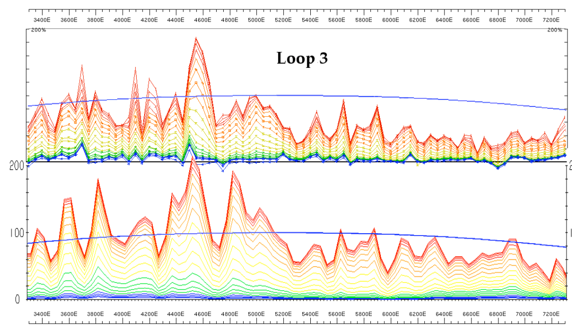

Figure 7: Comparison of Step-Corrected Line 31N Loop 3 Ex field data profile (upper) with equivalent model data generated for a ~3D model produced from the ISR Line 31N and Line 35N resistivity-depth sections. Note the poorer match in amplitude over the eastern section. The residuals are highest over this section indicating some difficulty in fitting the field data, probably reflecting IP effects.

Acknowledgments

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