EarthProbe: Meeting the Challenges of Gold Exploration through High Resolution Borehole and Surface IP

Julie Palich and Wei Qian, Caracle Creek International Consulting Inc.
jpalich@cciconline.ca

INTRODUCTION

Geophysical exploration for gold is known to be challenging. Traditionally, induced polarization (IP) surveys have had to make compromises between target size, horizontal resolution, and depth of investigation to accommodate for logistical survey limitations. These surveys tend to result in large scale structural IP targets masking what is often a narrow zone of gold mineralization contained within. The consequence - the geologist drills, often misses, and moves on, each time a bit more cynical about the capability of geophysics to assist in identifying a relevant gold target.

Recently, some of the limitations of traditional IP have been addressed by drawing upon smaller-scale technologies developed for geotechnical and hydrogeologic applications. The University of Toronto, through CAMIRO funding, progressed initial studies to adapt a geotechnical resistivity system developed by Geoserve in Germany for mining applications (Qian et al, 2007). Caracle Creek has further developed Geoserve's resistivity system, with the assistance of IRAP funding, to incorporate induced polarization measurements for mining applications. The resultant EarthProbe DCIP system is successfully enabling geophysicists to adjust their scale of surveying to the scale of geologic features applicable to gold exploration. EarthProbe's narrow electrode spacing and ability to operate in multiple surface and borehole configurations facilitates both improved target delineation and characterization of host rock and mineralization signatures. This is demonstrated through presentation of data from three DCIP surveys undertaken in Ontario, Canada. The data collected during these surveys using a combination of surface and borehole arrays was interpreted using multiple processing techniques to provide enhanced anomaly resolution, correlate resistivity and chargeability signatures to mineralized and non-mineralized sulfide-zones and host-rock lithologies, identify off-hole drilling targets, and delineate the off-hole extent of intersected mineralized zones.

THE EARTHPROBE TECHNOLOGY

The EarthProbe DCIP system deploys tightly spaced electrodes connected to a centralized data acquisition system that enables arbitrary selection of current and potential electrodes through relays. Rapid data collection (approximately 1000 readings per hour) and advanced signal processing allow for efficient use of conventional and novel arrays and the removal of natural and cultural noise. What is unique about the system is its electrode and borehole cable design, which allows seamless integration of borehole and surface measurements. EarthProbe operates in four configurations – surface, borehole, borehole-to-borehole, and surface-to-borehole (a variant of the borehole-to-borehole configuration).

Surface IP

EarthProbe surface DCIP surveys employ electrodes spaced at 4.4 m. The length of the array can vary up to 630 m (144 electrodes) providing intermediate depth imaging and detailed lateral and vertical resolution. Data collection may be undertaken by a number of dipole-dipole and pole-dipole array geometries, but is typically undertaken using a Wenner-alpha array. Use of the Wenner-alpha array with closely spaced electrodes provides the effective horizontal and vertical resolution capabilities that are necessary for the resolution of narrow, vertical features (Dahlin and Loke, 1998). Figure 1 depicts the additional depth information and vertical and lateral resolution obtained by EarthProbe compared to a traditional pole-dipole IP survey array over the same distance.

Borehole

EarthProbe uses borehole cables with up to 24 electrodes spaced at either 4 m or 16 m with the capacity to profile boreholes up to 172 m or 400 m. Data are collected with the electrode array in a single borehole in which the current and potential electrode setup is the same as for a surface Schlumberger survey.

Vertical profiles provide information regarding both in-hole features and can detect off-hole features up to 100 m from the borehole. The resistivity and chargeability information collected at the borehole can also be used to provide realistic bulk rock properties of the host rock and mineralized zones for more improved characterization.

Borehole-to-Borehole/Surface-to-Borehole

Borehole-to-borehole tomography, in which both current electrodes and potential electrodes are placed in two boreholes, can provide detailed information about resistivity distribution between the boreholes (Daniels 1977; Daniels and Dyck 1984; Shima 1992). Daniels and Dyck (1984) demonstrated a variety of applications of borehole resistivity measurements to mineral exploration.

The configuration we employ for cross borehole resistivity tomography was successfully proposed and demonstrated by Zhou and Greenhalgh (2000). In this configuration, the current electrodes and potential electrodes straddle the two boreholes.

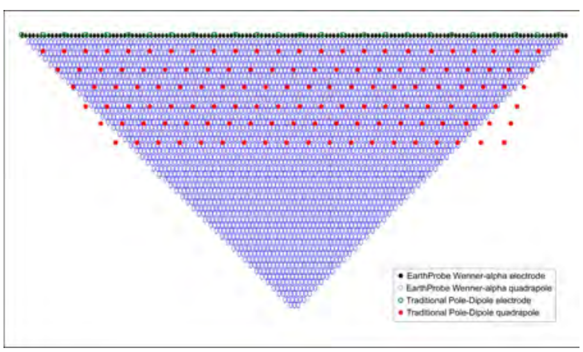


Figure 1: Comparison of the data density and depth of investigation obtained using the EarthProbe Wenner-alpha surface array with 144 electrodes (3384 unique quadrapoles) versus a traditional pole-dipole survey over the same distance (a=25 and n=6 resulting in 147 unique quadrapoles).

FIELD EXAMPLES

Since 2010, several surface, borehole and tomography surveys have been undertaken in prolific Canadian gold camps using the EarthProbe system that demonstrate its capabilities in addressing common issues faced in the geophysical delineation of narrow vein gold deposits. Select results from three surveys in Kirkland Lake, Dryden and Sudbury, Ontario, Canada are presented.

Kirkland Lake, Ontario

Vertical borehole profiling and borehole-to-borehole tomographic imaging was collected for six boreholes in the Bidgood Property near Kirkland Lake, Ontario, Canada. The survey aimed to test the ability of the system to image high grade, narrow (less than 2 m) gold intersections.

The Bidgood Property lies within the southern Abitibi greenstone belt located within the Timiskaming assemblage, a 50 km east-west trending linear belt adjacent to the Larder-Cadillac Deformation Zone (LCDZ) consisting of a 3 to 5 km thick sequence of mainly interbedded alkalic volcanics and clastic sediments. Most rock units have been impacted by hydrothermal alteration including carbonitization, sericitization, chloritization and silicification of varying intensity. Gold mineralization is spatially associated with high strain and brittle fractured zones, commonly as splays off of the LCDZ.

Figure 2 presents the vertical profiling and borehole-to-borehole tomographic imaging results collected from two boreholes with a separation of 125 m. Vertical profiling identifies a low resistivity, high chargeability in-hole response in Borehole 1 associated with known gold mineralization and a predominantly off-hole response in association with narrow, low grade mineralization in Borehole 2. The "bullseye" response in the tomography suggests electrical and chargeable connectivity between the mineralized zones.

Dryden, Ontario

We collected borehole profiles, and borehole-to-borehole imaging from sixty boreholes associated with the Goliath Gold Deposit located in Dryden, Ontario, Canada. A key objective of the survey was to characterize the resistivity and chargeability signatures associated with the mineralized zone to determine the on-going suitability of using borehole DCIP as an exploration tool at the site.

Rapid deployment of the system allowed roughly eight (8) boreholes per day to a depth of 170 m.

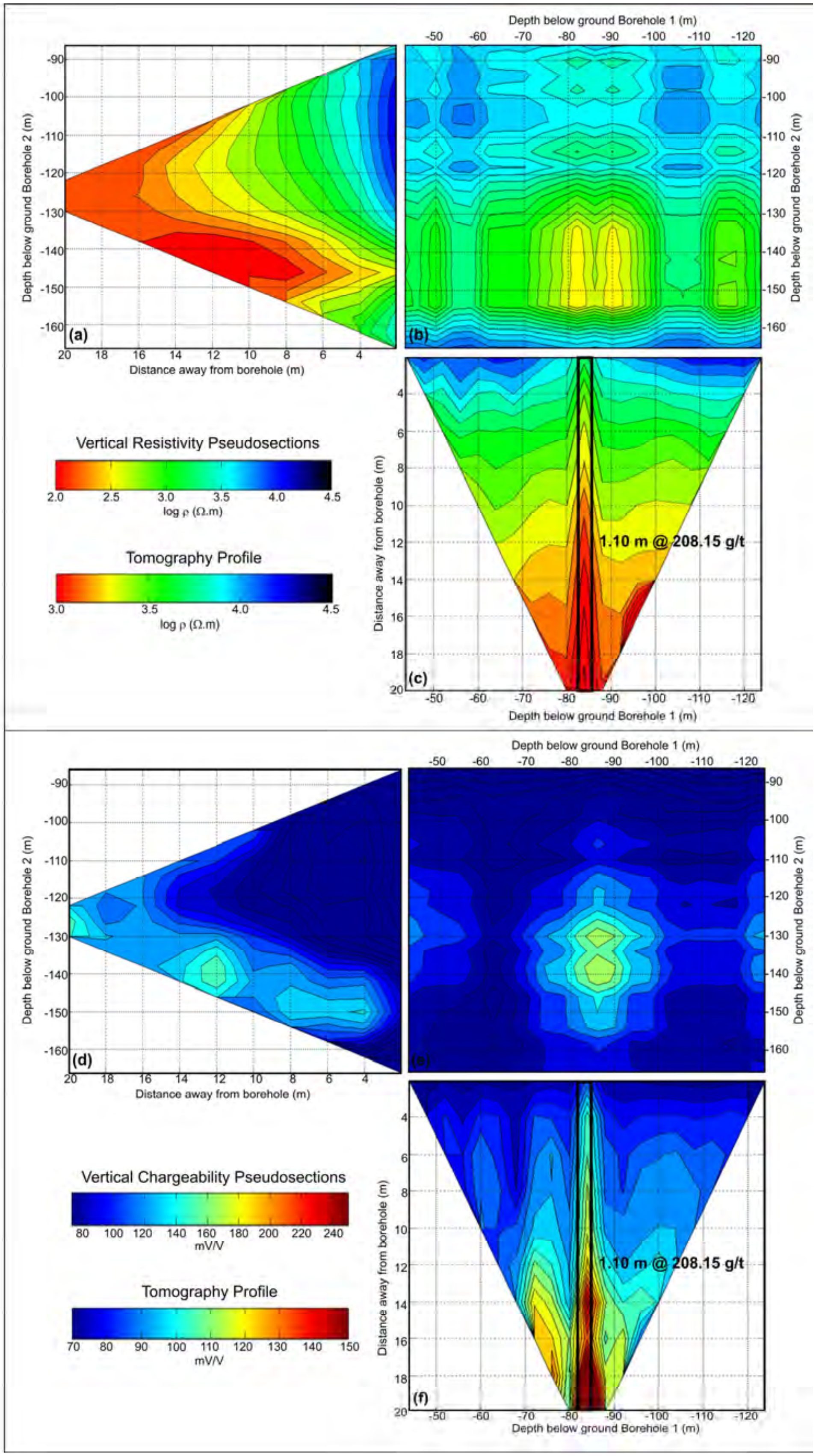


Figure 2: Comparison of vertical profiling and tomographic results between two boreholes for a) vertical resistivity profile of Borehole 2, b) resistivity tomography between Borehole 1 and Borehole 2, c) vertical resistivity profile of Borehole 1, d) vertical chargeability profile of Borehole 2, b) chargeability tomography between Borehole 1 and Borehole 2, and c) vertical chargeability profile of Borehole 1.

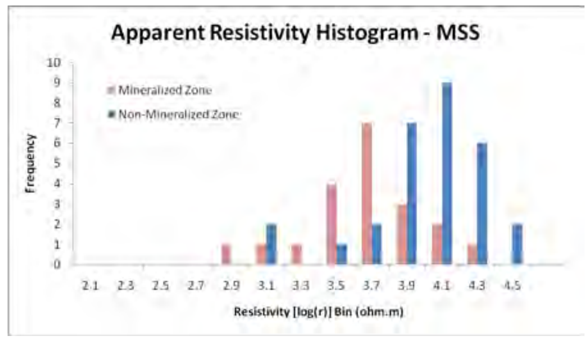
The project area is located within the northern domain of the Wabigoon Subprovince. Three major rock groupings are consistently recognized within the project area (Page, 1994): a hanging wall unit of quartz and feldspar-porphyry intrusive rocks and meta-sedimentary rocks, a central unit, which hosts the most significant gold concentrations comprising intensely deformed and variably altered felsic, quartz-feldspar-sericite and biotite-quartz-feldspar-sericite schist with minor metasedimentary rocks, and a footwall unit of predominantly meta-sedimentary rocks. Mineralized zones within the Goliath Gold Deposit typically exhibit thicknesses less than 5 m.

The in-hole resistivity and chargeability data collected from the vertical profiling was correlated against the three main lithologies (biotite-muscovite-schist (BMS), metasediments (MSED), and muscovite-sericite-schist (MSS)). Independent assessment was conducted with respect to mineralized versus non-mineralized zones in the lithology, whereby the mineralized zone was defined as having greater than 1 m thickness with a gold concentration greater than 0.5 ppm. Figure 3 depicts the histogrammatic distribution of resistivity and chargeability for the muscovite-sericite-schist (MSS) lithology.

Results of the statistical assessment identified a bimodal distribution of resistivity and chargeability for this site that indicated:

- Resistivity responses greater than 7,900 Ω.m (3.9 logρ Ω.m) typically reflect non-mineralized zones
- Resistivity responses less than 5,000 Ω.m (3.7 log logρ Ω.m) may reflect mineralized zones;
- Chargeability responses less than 30 mV/V reflect non-mineralized zones
- Chargeability responses greater than 50 mV/V typically reflect mineralized zones.
- There is a notable overlap of resistivity and chargeability response between the mineralized and non-mineralized zones suggesting that the occurrence of gold may be controlled by multiple factors (e.g. several alteration types) each having a unique IP signature.

Additional comparison of the in-hole anomalous responses obtained from the vertical profiling to gold concentration indicated that 95% of the low resistivity anomalies correlated to zones of mineralization. Anomalous resistivity responses consistently occurred in association with mineralized zones greater than 4 m thick exhibiting gold concentrations greater than 2 ppm, and in mineralized zones less than 4 m thick with gold concentration greater than 2 ppm and zinc concentration greater than 2000 ppm. These results suggest that borehole DCIP will be a reliable tool for ore zone delineation at this site.



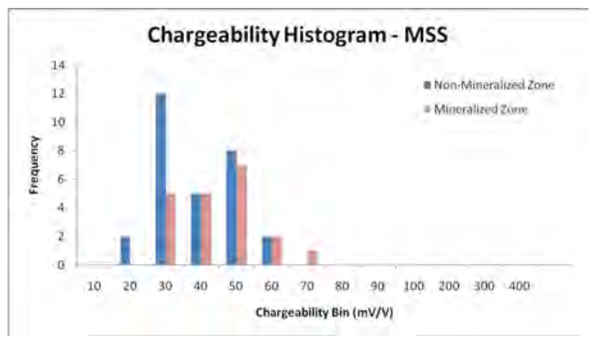


Figure 3: Histograms of the distribution of bulk resistivity (above) and chargeability (below) values measured from in-hole vertical profiling using the EarthProbe borehole cables with 4 m electrode spacing.

Sudbury, Ontario

Vertical resistivity profiles and tomography data were collected from six historic boreholes associated with the Long Lake Gold Project near Sudbury, Ontario, Canada to determine if mineralized intersections in the boreholes represented a continuous mineralized zone, and to assist with targeting for future drilling programs.

The Long Lake Mine Project is located in the Southern Province of the Canadian Shield, south of the Sudbury impact crater and the Sudbury Intrusive Complex. The dominant rock types in the area are metasedimentary rocks (mainly Mississagi quartzite) of the Huronian Supergroup (Jones, 1982). Gold mineralization has been observed in association with sulfide assemblages comprising arsenopyrite, pyrrhotite, pyrite and chalchopyrite. The investigation area reported historical mineralized intersections less than 3 m thick.

Results of the vertical profiling identified several in-hole low resistivity and moderately chargeable features that correlated to interfaces where gold mineralization had been intersected. Borehole-to-borehole tomography suggested connectivity of these narrow electrical and chargeability anomalies between four of the boreholes.

3D inversions of the borehole data were undertaken using ERTLab, a finite element inversion program, to determine the spatial relationship between the in-hole, off-hole and tomographic responses. Inversion was undertaken in three-stages to test the integrity and robustness of the model: 1) inversion of the vertical profiling data, 2) inversion of the tomography data, and 3) joint inversion of the vertical profiling and tomography data. The results of the inversion stages are presented in Figure 4.

The process demonstrates the complimentary characteristics of the vertical profiling and tomography information, providing confidence and enhancing the geologists understanding of the regions of uncertainty presented the integrated inversion.

CONCLUSIONS

EarthProbe's integration of high-resolution surface and borehole IP survey techniques is helping to address many of the challenges faced by geologists when trying to interpret geophysical results. This is attributed to the system's ability to:

- rapidly collect integrated surface, borehole, borehole-to-borehole and surface-to-borehole data;
- image smaller features and disturbances often related to narrow vein type systems of disparate mineralization due to the use of tight electrode spacings;
- provide a range of information to the geologist regarding near surface and mid-depth features

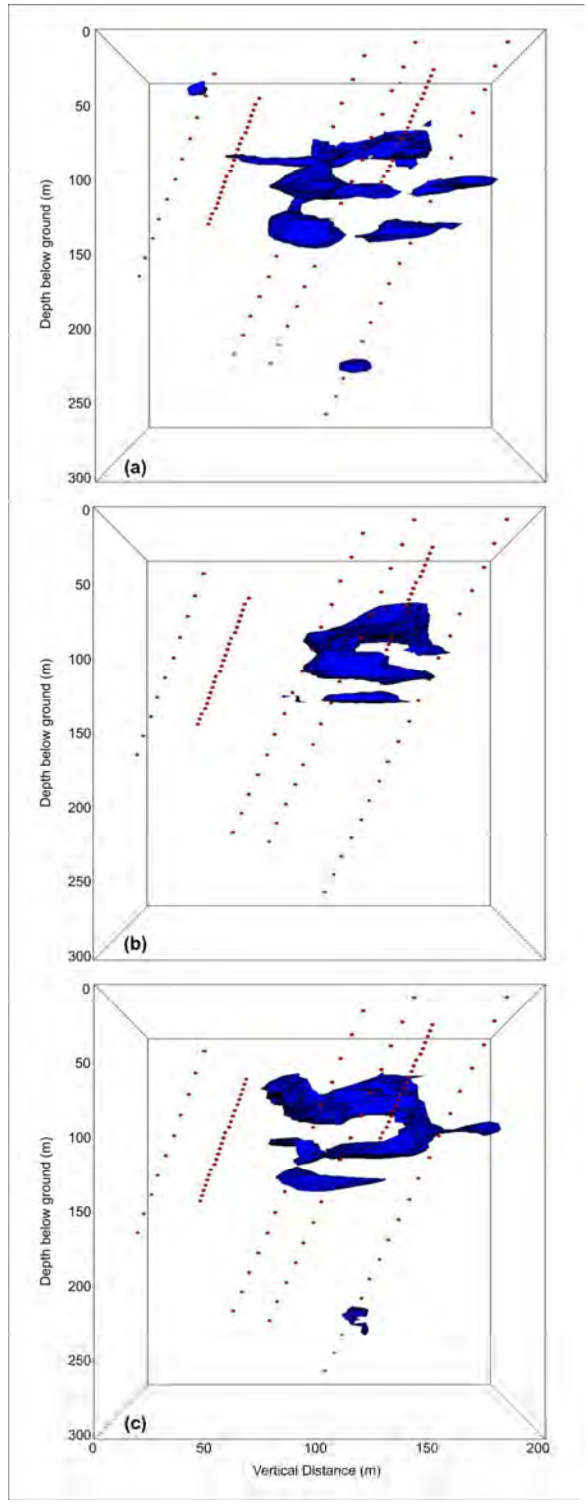


Figure 4: Results of the three-stage resistivity inversion of borehole data collected from six boreholes, showing a) inversion of the vertical profiling data, b) inversion of the tomography data, and c) joint inversion of the vertical profiling and tomography data. Vertical profiles are depicted looking north.

- identify in-hole and off-hole features and between hole connectivity of electrical/ chargeable features, and
- characterize bulk resistivity/chargeability of key lithologies and alteration/mineralized zones.

On-going challenges in the geophysical search for gold remain, but the advancement of IP technologies, such as EarthProbe, which are appropriately scaled to the geology they are trying to map, can reduce the hurdles and hopefully improve geophysical success rates into the future.

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REFERENCES

Dahlin,T. and Loke, M.H. 1998. Resolution of 2D Wenner resistivity imaging as assessed by numerical modelling, *Journal of Applied Geophysics*, 38, 237-249.

Daniels, J.J. 1997. Three dimensional resistivity and induced-polarization modeling using buried electrodes, *Geophysics*, 42, 1006-1019.

Daniels, J.J. and Dyck, A. 1984. Borehole resistivity and electromagnetic methods applied to mineral exploration. *IEEE Transactions on Geoscience and Remote Sensing*, GE-22, 80-87, 1984.

Jones, M.I. 1982. *Geology and Mineralogy of the Long Lake Gold Mine, Eden Township, south-central Ontario*. Unpubl. BSc. Hons. Thesis, University of British Columbia, 67 p.

Page, R. 1995. *Report on the 1994 Exploration Program, Thunder Lake West Project, Zealand Township, Ontario, Part 1* (NTS 52 F/15), Report No. 1263NB, Teck Exploration Ltd., 41p.

Qian, W., Milkereit, B., and Graber, M. 2007. Borehole resistivity tomography for mineral exploration, *EAGE 69th Conference and Exhibition*, London, UK, 11-14 June 2007.

Shima, H. 1992. 2D and 3D resistivity imaging reconstruction using cross-hole data, *Geophysics*, 55, 682-694.

Zhou, B. and Greenhalgh S. A. 2000. Cross-hole resistivity tomography using different electrode configuration, *Geophysical Prospecting*, 48 (5), 887-912.