Emerging Technology and Processes Utilising Deep Magnetotelluric Resistivity Imaging for Regional and Local Exploration, Brownfields and Mine Planning

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EXTENDED ABSTRACT SUMMARY

This paper reviews the application of the magnetotellurics method for deep earth imaging, specifically its recent use to better understand original mineral emplacement processes. Resistivity information from newer innovative applications of the technology for nearer surface imaging also provides valuable insights into near surface structure, which in some cases has led directly to new discoveries.

Key Words: Magnetotellurics, Resistivity, Imaging, Emerging Technology, Exploration, Mine Planning

INTRODUCTION

Geophysical exploration for mineral deposits has typically relied on detecting ore bodies on the basis of their anomalous properties e.g. density, resistivity, magnetic susceptibility or chargeability. Many ore bodies are formed by processes that occur in convergent plate boundaries such as subduction zones. Studying these processes can give insights into the formation and distribution of deposits. The mineral systems approach expands the exploration scope by looking for the entire system that formed the ore body, including regions where fluids originated, flow pathways and structures that caused mineral deposition. The value of this approach is being investigated by a number of recent initiatives in both governmental and university research. These studies use 3-D exploration methods that image to crustal and upper mantle depths.

MAGNETOTELLURICS

A range of electromagnetic methods can be used to image subsurface conductivity/resistivity. For depths exceeding a few kilometers, natural source techniques are the most effective methods. One of the most promising electromagnetic technologies for these deep investigations has been magnetotellurics (MT). This method measures natural magnetic and electric fields at the surface of the earth across a wide range of frequencies. The depth of investigation depends on the signal frequency, allowing the same instrument to measure resistivity from a few hundred metres to hundreds of kilometers. From MT measurements at a number of points a 3-D model of the subsurface resistivity can be obtained. The time-varying electromagnetic fields are generated by a variety of natural phenomena such as solar storms and lightning strikes. Broadband MT measures these fields over a very broad frequency spectrum, typically 1000–0.001 Hz, giving information to mid and lower crustal depths. Audiomagnetotellurics (AMT) only measures the audio frequencies, which image the upper 1–2 km only. CSAMT was developed to work when the natural source EM signals were too weak and a Controlled Source or generator is used to create the electromagnetic fields. This type of survey is typically used for resistivity mapping in the top few hundred meters.

The MT method was invented and introduced independently in Japan in the 1940s (Hatakeyama and Hirayama, 1934; Rikitake, 1948) and later in Russia and France in the 1950s.

The use of MT in mineral exploration was limited through the 1990s, but since 2000 its use in deposit scale exploration has increased, although until recently wide scale use across the mining industry was limited. With the recent use of the mineral systems concept, there is now significant interest in using MT to look even deeper and define the structures associated with deposit formation on a crustal and upper mantle scale. This trend has followed from a number of studies that show that major resistivity anomalies are present beneath a number of major deposits, e.g., the discovery of a set of low resistivity fingers be-

neath the world class Iron Oxide Copper Gold (IOCG) Deposit at Olympic Dam in South Australia (Heinson *et al.*, 2006).

This paper will present examples of how MT can be used on a range of depth scales and will include (1) regional scale government funded initiatives from Western Australia and examples from several parts of the Andes, (2) regional scale exploration in Northern Canada, (3) local scale surveys in Ontario and British Columbia, and (4) a mine site scale survey in Peru, where the geophysical study contributed directly to the discovery of a new porphyry system below the mine.

DEEP EARTH IMAGING

Exploration initiatives in Australia have embarked on large regional scale MT programs to image the resistivity structure of the entire Australian continent and understand the mechanisms that control ore emplacement on a crustal scale. MT data have been acquired at nearly 5000 stations across Australia through a national MT survey program and regional MT surveys with data collected on both profiles and grids (Figure 1). Dramatic evidence for a direct correlation of crustal scale anomalies with ore deposits has been shown by a number of studies, including that at Olympic Dam. Results to date highlight a number of very deep conductive features which indicate where conduits may have existed in the past as mineral emplacement occurred though deep fluid flow. Resistivity images have highlighted features that extend from upper mantle depths and approach or are connected to the surface (Figure 2). This approach is also being applied in Canada, with some initial studies being made through university research that includes the Metal Earth initiative.

Insights into mineral formation in volcanic arcs can be obtained by studying presently active magmatic processes. In Southern Bolivia, a recently published deep exploration initiative crossed the Central Andes. MT stations were deployed with a 1–5 km spacing, and low frequencies were recorded with deployments lasting 1–2 days (Figure 3).
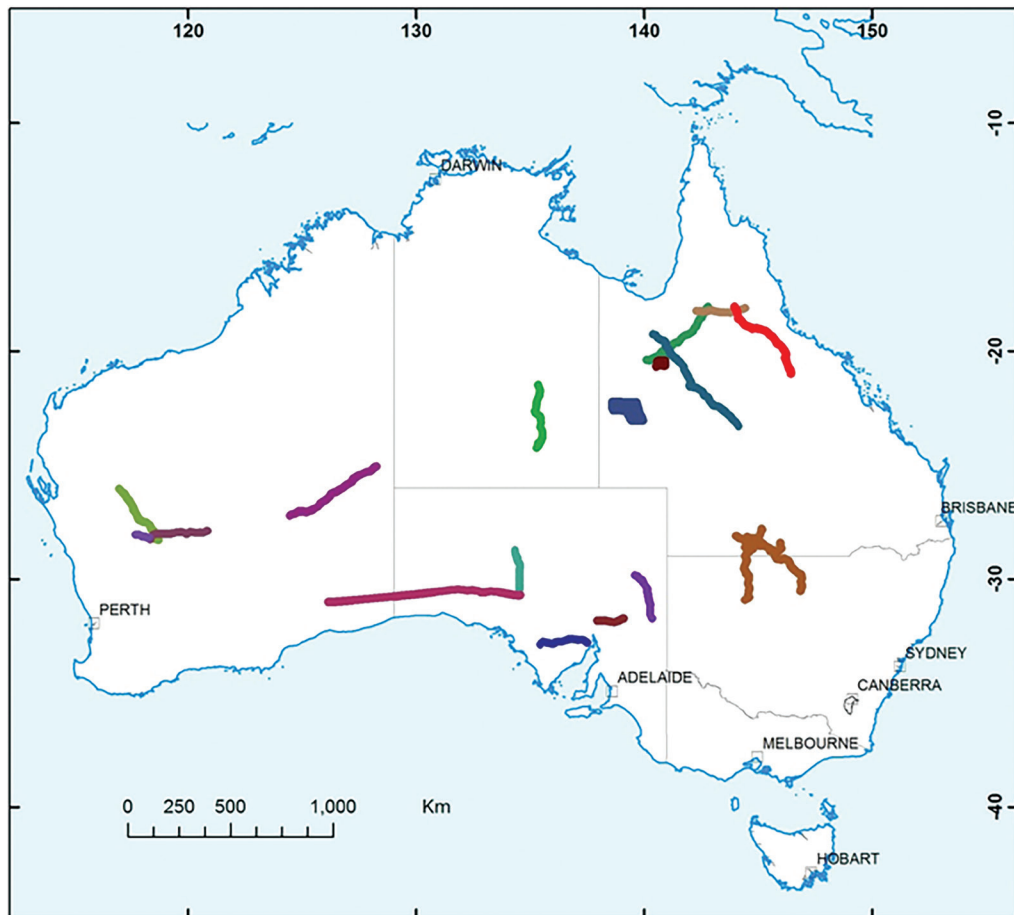

Figure 1. Map of Australia showing recent regional MT surveys from Australian Gov't website (Geoscience Australia[1]).

[1]https://www.ga.gov.au/about/projects/resources/regional-mt-program
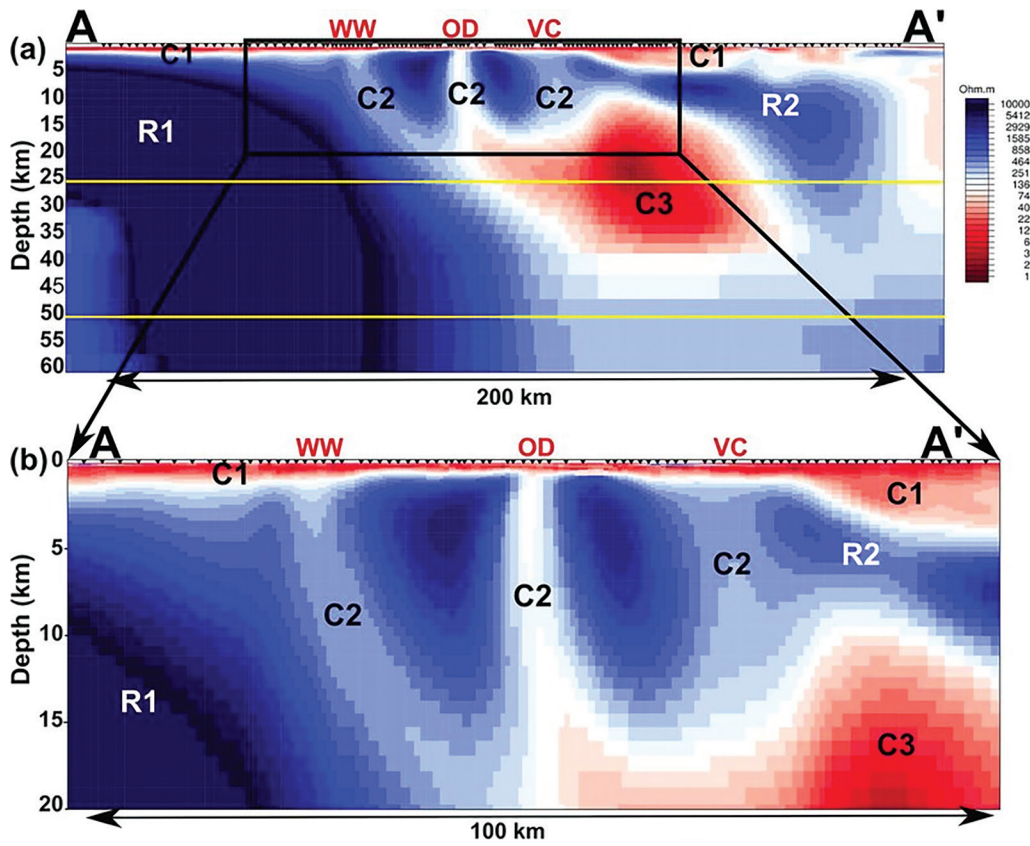
Figure 2. MT resistivity section shown to 60 km highlighting deep conductive trends. Note C2 conductor lies directly below Olympic Dam, a giant IOCG deposit. (Heinson and others, 2006).
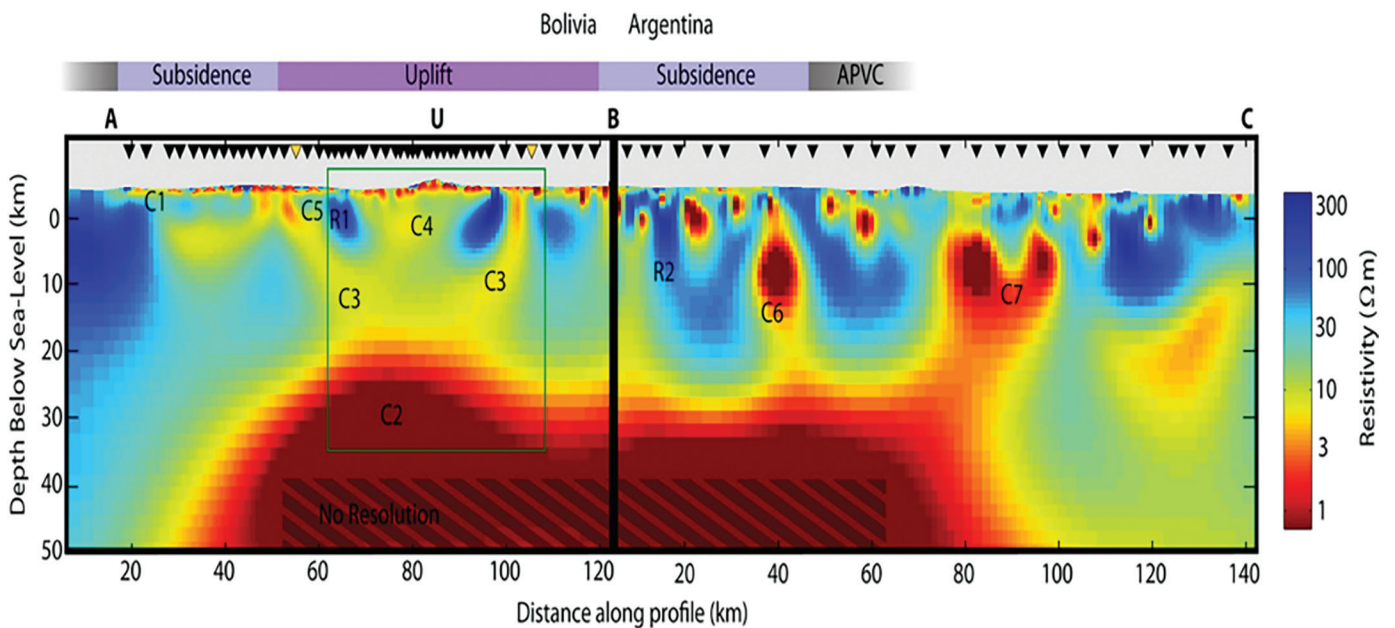

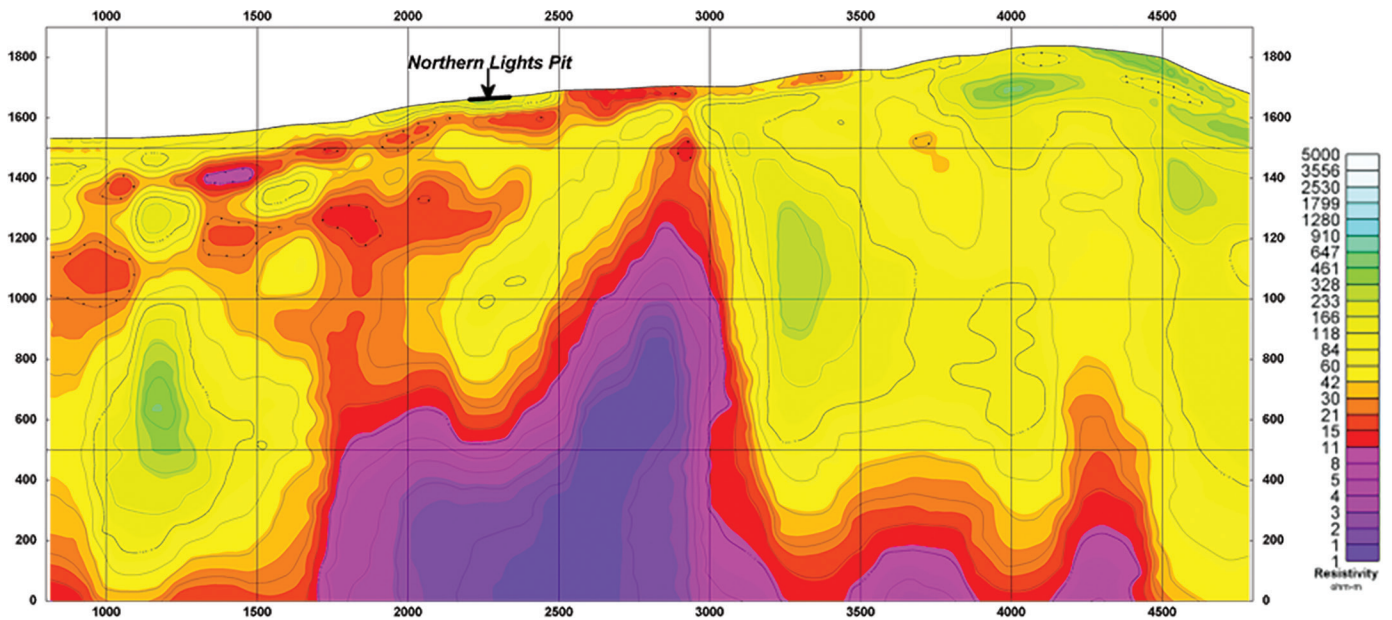Figure 3. Andes Centrales (22°S): Volcan Uturuncu,Bolivia. (Comeau and others, 2015).

Figure 4. 2D MT resistivity survey results from a distributed multiparameter acquisition array system which provides detailed high-resolution information below an existing mine operation in Nevada. (TITAN MT Data collected for Newmont for comparison to their new system (Eaton, P., 2010)).
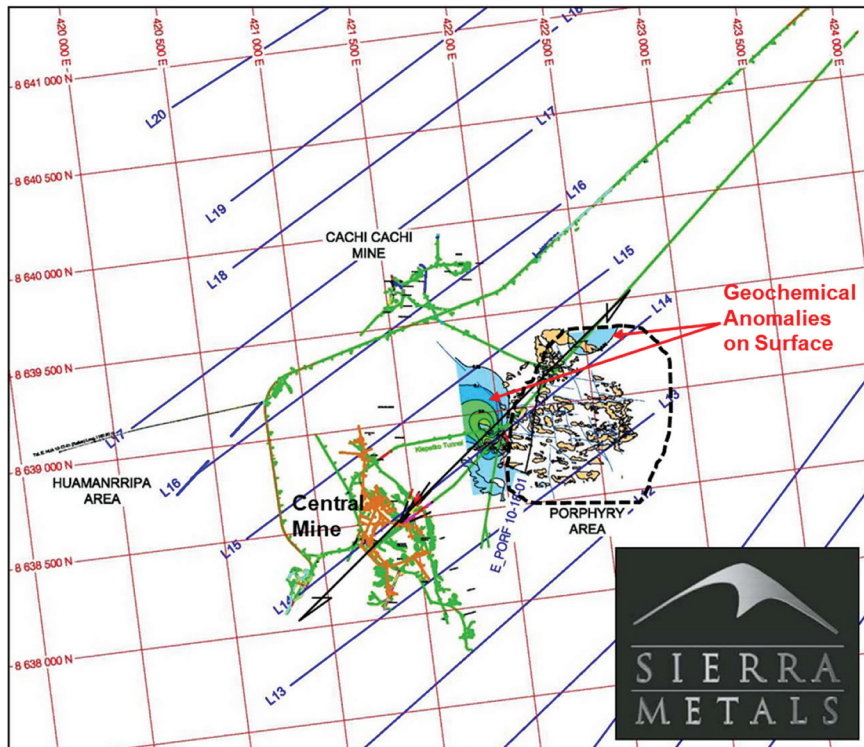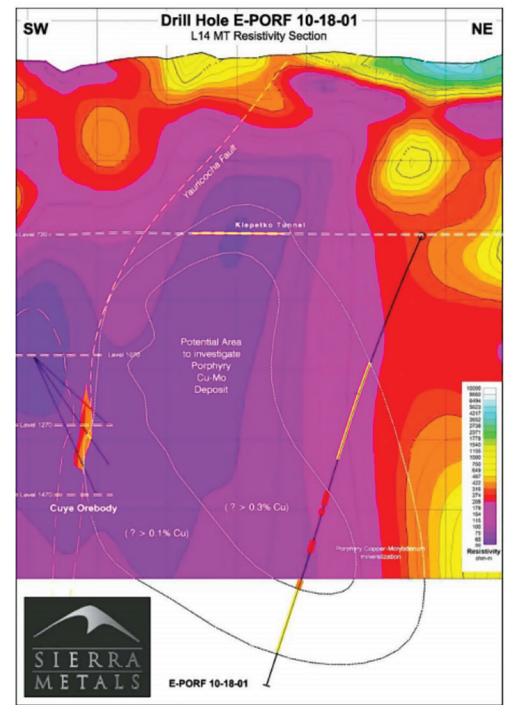

Figures 5a (L) and 5b (R). Distributed MT survey plan at mine site and one image of the deep conductive system (Sierra Metals[2]).

[2]https://www.sierrametals.com/investors/news-releases/news-release-details/2018/Sierra-Metals-Confirms-Porphyry-Mineralization-at-Its-Yauricocha-Mine-in-Peru-Positive-Results-Include-22-Meters-Of-046-Copper-and-134-Ppm-Molybdenum-and-1073-PPM-Cobalt/default.aspx

NEARER SURFACE APPLICATIONS OF MT RESISTIVITY MAPPING

In 2000, the first commercially available multi-parameter distributed array technologies were introduced to the industry. This capability was first derived from earlier studies by John Kingman for applications with induced polarization (IP) (Kingman, 1994). The increase in computer capability at the time allowed for the deployment of distributed computers along a survey line. The introduction of measuring tightly spaced magnetotellurics (100 m) along a standard profile of 2400 m was a novel new way to explore (White and Gordon, 2003). This new application provided explorers with very deep, highly detailed resistivity images for the first time. The frequencies measured in these systems are higher than those required for deep imaging but still sufficiently low enough to provide to a depth of a few kilometres (Gordon). Recording time is typically in the order of 4–8 hours to obtain images to depths of 1500 m (Figure 4).

In 2018, a new zone of deep mineralization was discovered at the Yauricocha mine in Peru. Yauricocha is located 150 km ESE of Lima in the Yauricocha Mining District (Cordillera Occidental). Until very recently mineralization at the Yauricocha Mine has been characterized by variably oxidized portions of a multiple-phase polymetallic system with at least two stages of mineralization, demonstrated by sulfide veins cutting brecciated polymetallic sulfide mineralized bodies.

MT resistivity was used to target areas 700 m below the current workings at depths greater than 1000 m. In this case 23 lines, each 2.4 km long and spaced 200 m apart, were surveyed in two weeks (Figure 5a).

A new copper-molybdenum mineralized porphyry deposit was discovered, associated with large deep conductive zones identified by the survey in the quartz monzonite intrusive, in the eastern part of the mineralized area. A hole was targeted and drilled from the Klepetko Tunnel located on the 720 level to a depth of 1,394.6 m. Subsequent sampling and results indicated an average of > 0.1% copper (Figure 5b).

REFERENCES

Comeau M. J., Unsworth M. J., Ticona F., *et al.*, 2015, Magnetotelluric images of magma distribution beneath Volcan Uturuncu, Bolivia: Implications for magma dynamics, Geology, vol. 43, no. 3, pp. 243–246.

Eaton P., Anderson, R., Queen, S., Mackenzie, I., & Wynn, D., 2010, NEWDAS—the Newmont Distributed IP Data Acquisition System, Society of Economic Geologists Technical Program Expanded Abstracts, pp. 1768–1772.

Gordon R, 2006, New technology approach needed for mining industry. First Break, Vol 24, July 2006.

Hatakeyama, H.& M. Hirayama, 1934, On the phase difference between the pulsation of terrestrial magnetism and of earth current. J Meteorol. Soc. Japan, 12, 449–459.

Heinson, G., Direen, N., & Gill, R., 2006, Magnetotelluric evidence for a deep-crustal mineralizing system beneath the Olympic Dam iron oxide copper-gold deposit, Southern Australia. Geology (2006) 34 (7) pp. 537–576.

Kingman J, 1994, Digital signal processing approaches to interpreting induced polarization data: John S. Sumner memorial international workshop on IP in mining and the Environment, Tucson AZ.

Rikitake, T., 1948, Note on the electromagnetic induction within the earth. Bull. Earthquake Res. Inst. Univ. Tokyo, no. 24, pp. 1–9.

Sharpe, R, Gordon, R, Zhurba, A., Data, E., 2017, A decade of technological advances in distributed IP & Resistivity. DMEC 2017 Exploration workshop.

White, M., and R. Gordon, 2003, Deep imaging: New technology lowers cost of discovery: Canadian Mining Journal, no. 4, pp. 27–28.