mdru Mineral Deposit Research Unit

DMEC Decennial Mineral Exploration Conferences

Practical uses for ground-based MT surveys – Regional terrain studies, Porphyry and Minesite applications

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Summary

The magnetotelluric (MT) method is a proven technology established in the 1950’s to provide resistivity information about the subsurface. Commercial near surface applications for mine exploration started to be more common place in the early 2000’s and the technology has benefited greatly in the last 10 years, thanks to advances in electronic technology and computing power.

Detailed resistivity information collected with the MT method provides a flexible exploration tool to help investigate the earth on many scales from very deep crustal studies of tens of kms to near surface. Explorers today are interested in deep controlling features surrounding the potential emplacement of orebodies. In addition, roots and/or extensions of potential mineralisation to depth can be mapped if the surveys are detailed and that may contribute to new discoveries earlier, or better focus them when it comes to delineation programs.

We will look at the method applied to scenarios; Regional terrain studies, porphyry applications and minesite studies.

Introduction

MT measures the natural magnetic and electric (EM) fields at the surface of the earth. Sources of these EM fields are initiated by solar winds and lightning strikes activities. Systems typically measure in a very broad frequency range (10,000 Hz down to <.0001 Hz). By comparison, airborne systems that measure some components of these naturally occurring fields collect data in the range of 20-30 Hz to 720 Hz. By simultaneously measuring the Magnetic and Electric fields across a wide range of frequencies, we are able to provide a resistivity value of the subsurface for a range of depths, nominally from a few tens of meters to a few hundred kms.

Figure 1 shows a typical MT site deployment. A site may take an hour or so to set up and then the system is left to measure the electric and magnetic fields over a period of time. This can range from several hours to several days depending on the quality of data desired as well as the depth of investigation. The magnetic coils are buried in the ground in order to protect them from environmental and ambient disturbances.

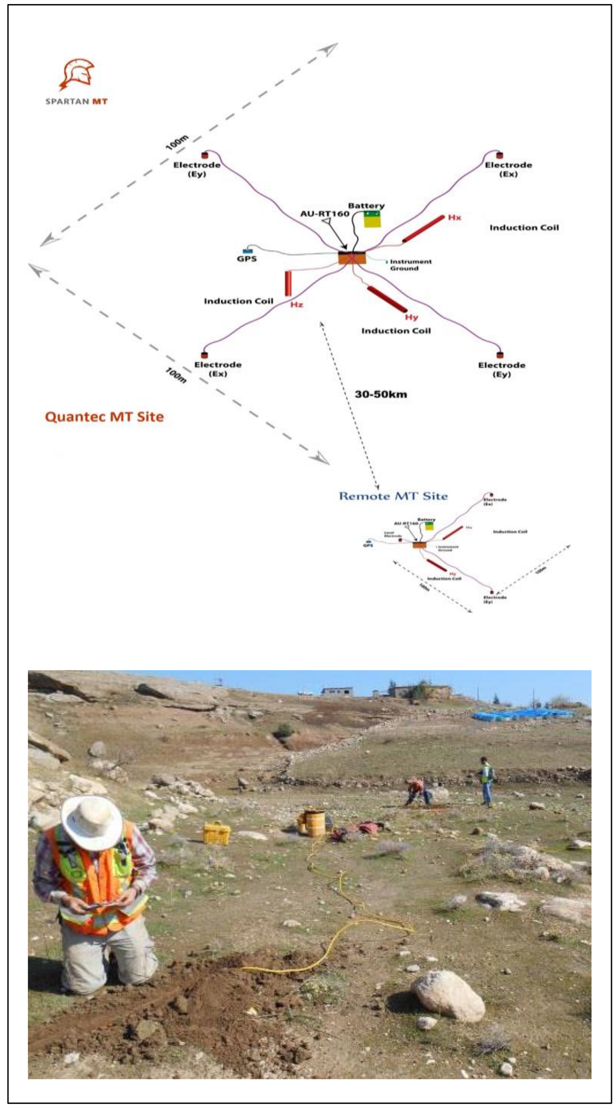

Figure 1. A typical MT site deployment showing layout (above) and field footprint (below).

Data is then collected from the site and post-processed while the site equipment is re-deployed. Each site is an individual resistivity sounding. When sites are collected in lines, 2D profiles can be made of the resistivity cross-section. Grids of data can be processed and inverted in 3D to provide 3D models of the subsurface. (**Figure 2**)

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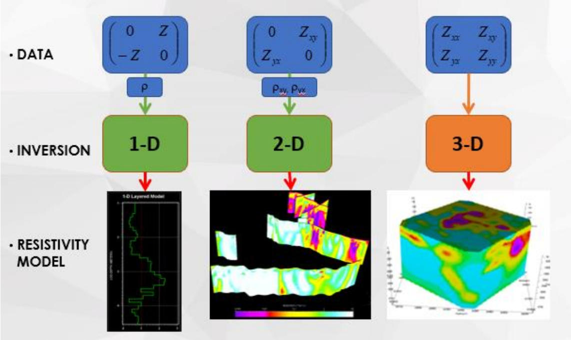
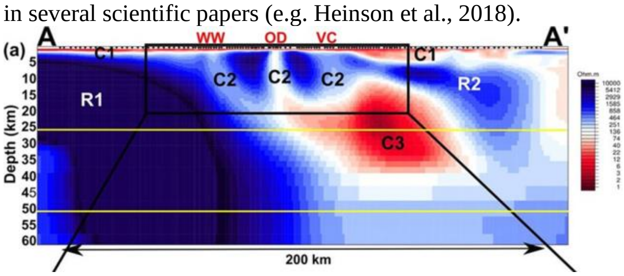


Figure 2. Various data properties and dimensional presentations and applications for MT resistivity.

Case Study – Regional studies

Geophysical exploration for mineral deposits has typically searched directly for ore bodies by looking for a region with anomalous physical properties such as 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 researches. These studies use 3-D exploration methods that image down to crustal and upper mantle depths. One of the most promising technologies for these deep investigations has been magnetotellurics (MT).

Perhaps the most famous of these studies was carried out in Australia across Olympic Dam (**Figure 3**), as a large scale deep MT survey, where the results have been communicated in several scientific papers (e.g. Heinson et al., 2018).



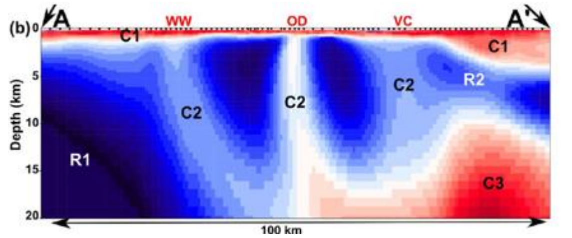


Figure 3. Fingers of God, new edition. Heinson et al., 2018, SciReports. partial resistivity section shown down to 20km. Olympic Dam (OD), Wirda Wells (WW) and Vulcan VC) deposits are shown on the surface.

More recently in Canada, MT has been applied by the Government of Yukon for terrain analysis in the search of Geothermal deposits. In addition, the Metal Earth program from Laurentian University (The Mineral Exploration Research Centre - MERC) has been studying the crustal information below mineral endowed gold camps such as Timmins , Kirkland lake and Red Lake.(**Figure 4**)

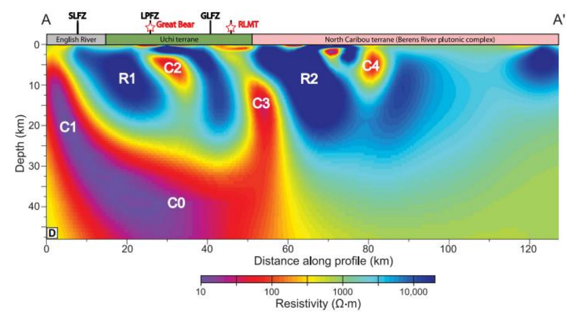


Figure 4. Cross section extracted from the three-dimensional model R1–R2 and C0–C4 are resistive and conductive features, respectively (from Crustal conductivity footprint of the orogenic gold district in the Red Lake greenstone belt, western Superior craton, Canada. Ademola Q. Adetunji et al., 2023)

These studies show significant promise for regional exploration initiatives to identify priority exploration areas.

Case Study – Porphyry exploration

Porphyry exploration has traditionally followed on after the discovery of geologic indicators such as stockwork, dyke swarms, alteration mapping for phyletic and potassic zones associated with our knowledge of a “typical porphyry”.(**Figure 5**) Geophysical indicators may be represented by sulphide halos detected by IP methods. However, in deeper terrains, many of the potential indicators are buried to the human eye and in very deep cases beyond the detection of even the deepest looking IP systems (such as TITAN DCIP).

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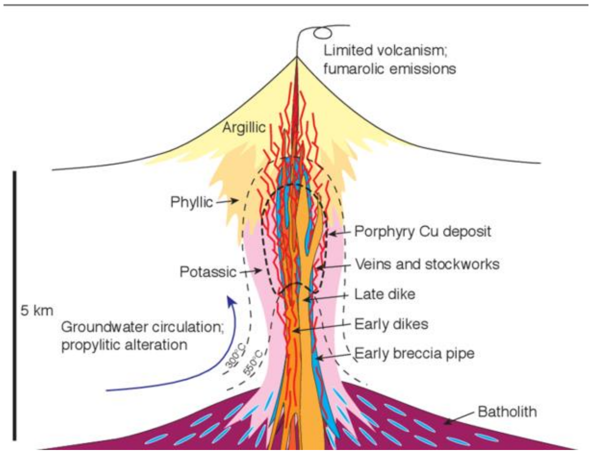
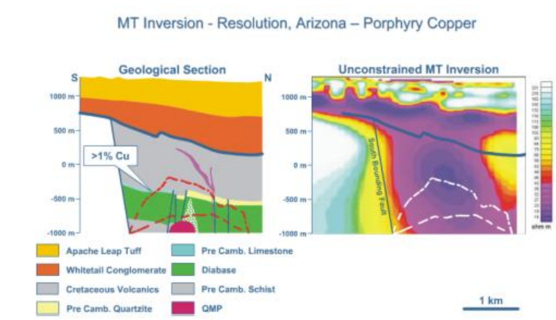
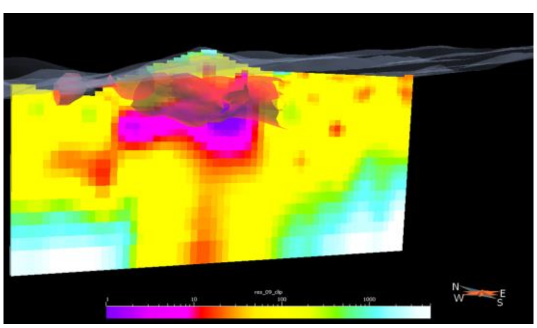


Figure 5. Crustal magmatic controls on the formation of porphyry copper deposits. From; Park, JW., Campbell, I.H., Chiaradia, M. et al. Nat Rev Earth Environ 2, 542–557 (2021). https://doi.org/10.1038/s43017-021-00182-8.

Deep geophysical methods like MT have been tested on deeply buried deposits such as the Resolution deposit in Arizona. Often typical to porphyry deposits is the remaining deep fluid pathway associated to the development of the porphyry. In many cases the root is characterized by a significant rise in the background conductivity. Several examples of these deep conductive roots are seen at Resolution, Santa Cecelia and more recently below the Kemess deposit in Northern B.C.





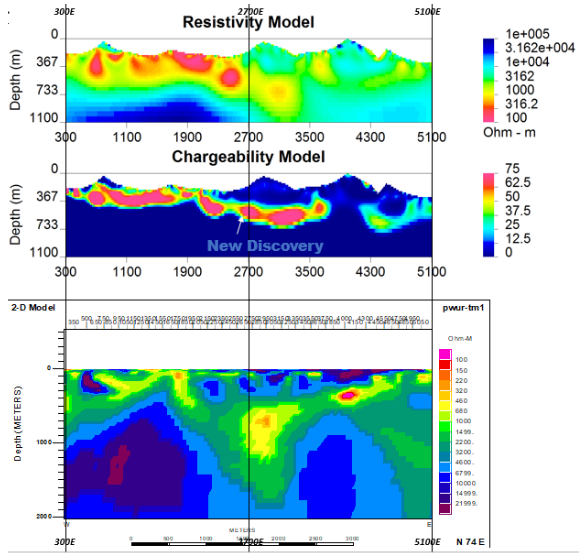


Figure 6. Deep conductive roots below known porphyry discoveries. Top: Resolution, AZ USA, Middle: Santa Cecelia, Chile, Bottom: Kemess, BC.

Case Study - Minesite

The example presented is from the Yauricocha Mine in central Peru. The mine is at an average altitude of 4,600 masl. Until very recently mineralization at the Yauricocha Mine has been represented 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.

For this survey an array-based MT survey was applied. With the advent of distributed technology in the early 2000's very detailed MT surveys could be executed in relatively short time frames (Kingman et al. 2007). **Figure 7** shows the set up for a distributed MT survey. Many inline and orthogonal electric field measurements are made along with sparse magnetic field measurements. Resistivities are calculated along a line of 2.5 – 3.5 km at 50m or 100m centers. By collecting the data in this manner typically over 24 sites can be collected in a 12-hour period. Advantages of array-based surveys are they can also be configured to collect deep DCIP data as well.

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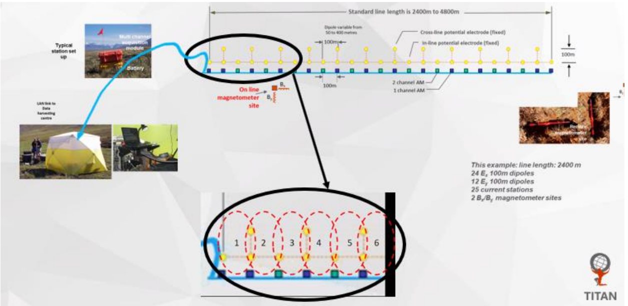

Figure 7. Distributed MT survey layout.

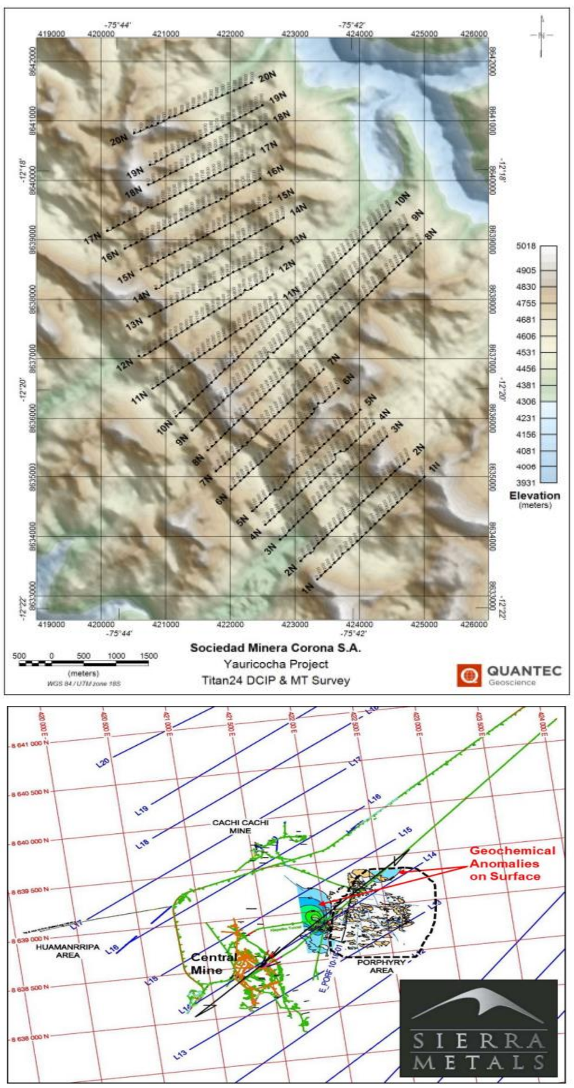

Figure 8. Minesite survey directly over current workings.

At Yauricocha a deep multiparameter survey was commissioned to cover the active mine and surrounds. The geophysical surveys, including MT, at the mine site provided the impetus to investigate deep below the current workings.

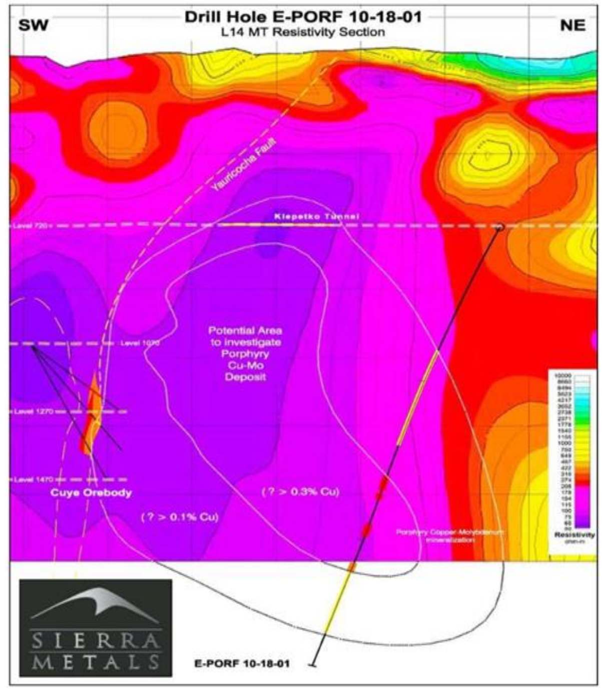

Figure 9. Distributed MT resistivity (Line 14) section shown to 1500m depth.

Drilling in late 2018 confirmed the presence of an underlying new porphyry (copper-molybdenum porphyry) system. In October 2018 Sierra Metals confirmed the discovery of a new style of mineralization based on testing of the geophysical anomalies, in the quartz monzonite intrusive, in the eastern part of the mineralized area. Discovery drilling at over 1,300 m was based on deep electrical resistivity imaging made possible by the TITAN system.

Conclusions

Deep imaging surveys have practical applications for mapping structure, alteration, and mineralization. Increased use of MT within the mining sector over the last 10 to 15 years has contributed to a new level of knowledge about the subsurface and to discovery. Mining companies are starting to realise the significant impact deep accurate imaging can have on exploration programs, and the use of these surveys for near-mine activities continues to grow as applications include condemnation studies as well as pre tailings planning and near-mine exploration.

The ability to accurately plan expensive drilling programs is now possible; mining companies and explorationists alike simply need to incorporate the imaging phase into annual drilling budgets as a pre-emptive measure, rather than an afterthought.

Acknowledgements

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