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Deep Exploration Imaging

Meeting the challenges of decreasing discovery rates through improved drill targeting

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1. Introduction

Challenges in the exploration world include several large issues which have associated high costs. Discovery rates are down in part to the fact ore deposits are deeper, there is more cover on top of them, the earth is complicated and drilling budgets are not limitless. Companies work against time to provide positive results to shareholders. Until recently, the drill was the fastest way to explore deep, highly prospective terrains. But drilling is expensive, and faced with more and more blind drilling to investigate the subsurface, the industry has been forcing the geophysical world to smarten up.

Advanced imaging in the medical world developed in the 1950's through the 1970's thanks to new applications of physics to measure key parameters related to internal aspects of the human body. This involved imaging methodologies, and sophisticated software and data manipulation. Damadian was the first to perform a full body scan of a human being in 1977 to diagnose cancer with Magnetic Resonance Imaging (MRI) technology. Today, MRI's are used routinely by doctors to perform investigations and diagnoses prior to any invasive further steps, including surgery.

Advances in the geophysical world have followed a similar timeline. Recently, advances in large scale deep multi-parameter 3D earth imaging technologies are coming close to providing the geoscientist with the equivalent of an MRI. Today systems can provides large scale accurate 3D deep imaging to depths of 800 m for IP and 2000 meters for MT. Large, detailed cubes of information are now available for interrogation and planning prior to drilling.

A brief discussion of the evolution of deep electrical imaging systems and survey results will be shown from a number of exploration situations globally including epithermal gold, IOCG , Zinc in Peru and a copper-gold porphyry system in Chile. Case studies show increased depth of penetration and increased resolution and the advantage of true 3D vs 2D exploration.

2. Distributed Array Systems

2.1. Background

John Kingman (1994) introduced digital signal processing (DSP) concepts that would require a paradigm-shift in instrumentation for Resistivity and IP survey methods. These changes enabled the creation of super large arrays of computers which immediately contributed to deeper search capabilities. In a (1998) presentation, Sheard et al. introduced the distributed acquisition system (DAS) with time-series acquisition, current-monitoring, available MT and telluric cancelation. In 1999, John Kingman began working with EMI and Quantec to produce the MT-24 acquisition system and the first survey work was performed in August 2000.

The coupled use of the MT technology for deeper resistivity imaging being run simultaneously as the

IP survey was novel and contributed further to our ability to image deeper with greater accuracy. Now multiparameter images were provided from surface to 750 metres for IP and to depths of 1500 to 2000 meters and more for MT.

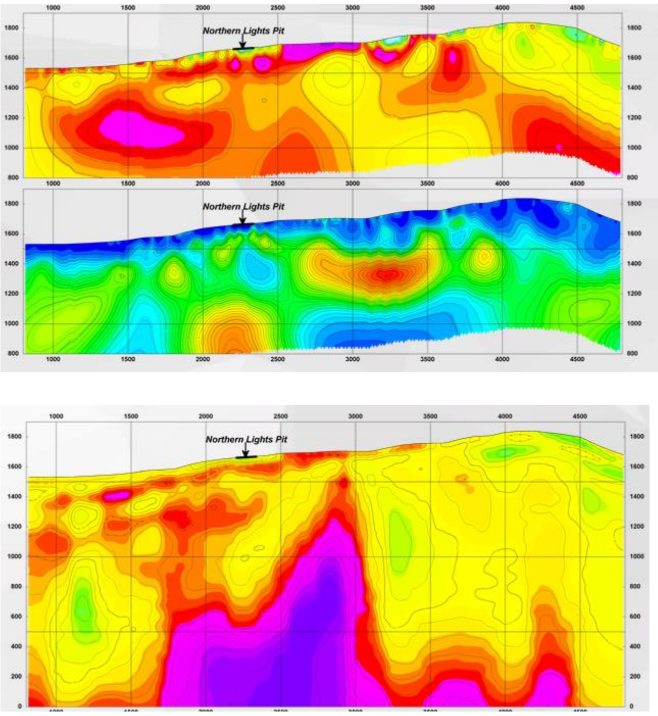

Figure 1. (top) DC resistivity inversion model from 2D TITAN24 distributed array survey. (middle) IP Inversion model. Note how the DC model sees a near surface horizontal layer, senses a second deeper feature and also senses something at the bottom of the section. (Bottom) The MT corroborates the DC in the near surface but pulls out more definition on a sub parallel layer and also highlights the deeper structure central to the area. Data courtesy Newmont, Nevada USA.

2.2. Deep 2D imaging success

Deep 2D imaging has proven to be extremely successful over the last 15 years. Goldie showed the superiority of the methodology for deep IP in 2007. (Goldie 2007).

The use of these deep 2D surveys was particularly useful in near mine environments where noise rejection allowed acquisition of data in areas never possible before. *Figure 2*.

3. 3D systems

3.1. Innovative data acquisition

Challenges with interpretation of 2D data in complex environments still existed through 2010.

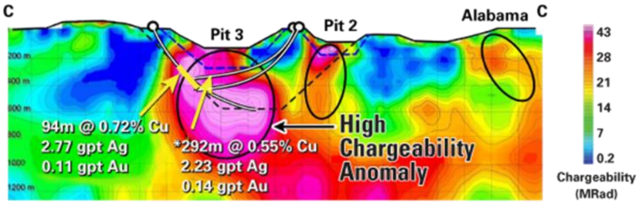

Figure 2. An example of a 2D chargeability section. The section is 750 metres deep and highlighted new discoveries directly below existing open pits. Data courtesy Copper Mountain mining, Canada.

3D technology was developed to address limitations in 2D data acquisition techniques. With the advances in 3D data inversion techniques in the early 2000's for single point data collection techniques such as Mag, Gravity and MT, the natural progression was to develop methodologies for collecting full 3D DCIP data.

There are several unique features of these systems including a large footprint of 2 x 2 km and more to optimize DC and IP depth of investigation in the 600 m to 900 m depth range; and an large numbers of in-line and cross-line receiver dipoles that maximizes coupling with any target. *Figure 3*.

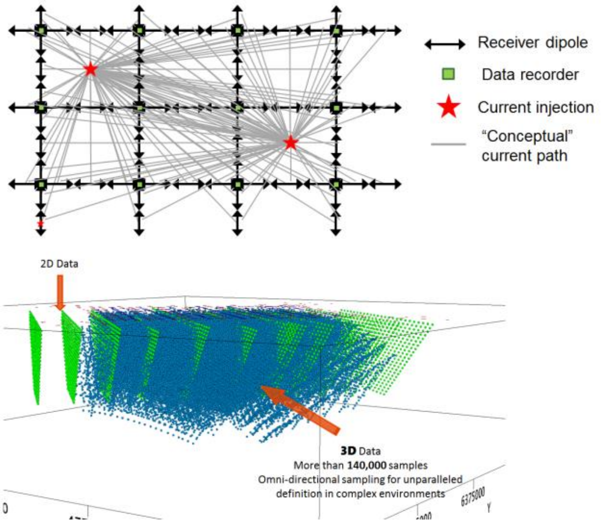

Figure 3. (top) An example of a 3D deployment of receivers with conceptual current paths for 2 injection points. (bottom) Typically over 250 injection points are made on a grid. 3D data plot points are shown in blue and compared to data plot points from a 2D survey shown in green.

For every current injection, all receivers are active. This results in a true omnidirectional coverage for each current injection and gives multiple intersecting current paths over the entire survey with a very large number data points acquired. The result is greater volumes of data and better coupling with complicated 3D geology and structure which enhances resolution and target detection at both shallow and deep depths. The omnidirectional coverage provides a better 3D inversion result because there is no acquisition directional bias and each cell in the inversion volume is sensitive to multiple omnidirectional current paths.

3.1.1. 3D vs 2D

The increase in data volume coupled with the omnidirectional sampling provides the basis for highly data constrained 3D inversions. In *Figure 4* we see significantly more detail extracted from the full "3D" survey.

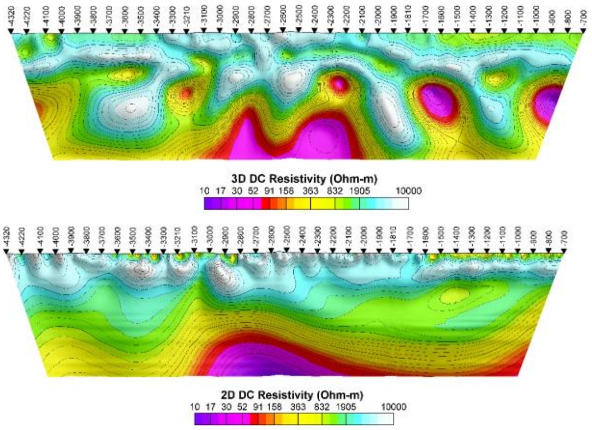

Figure 4. Resistivity inversion models (sections) from the Athabasca Basin in Northern Saskatchewan Canada. Depth of the section is roughly 800 meters.(Top) 2D section sliced from a 3D inversion model of 3D data. (Bottom) 2D resistivity section from 2D inversion of single line of receivers.(2D data).

3.2. Porphyry Example

A deep comprehensive 3D survey was carried out over the Santa Cecilia Cu, Au, deposit in Chile South America. In this case a broad area was covered (3km x 7km) using 150m dipoles for the IP survey and 300m centres for the MT survey. The survey used 50 Data loggers, 300 receiver dipoles and 559 current injections. The final products for the survey are shown in *Figure 5,6* and *7*. The survey was completed in 4 weeks and cost roughly $500,000 dollars.

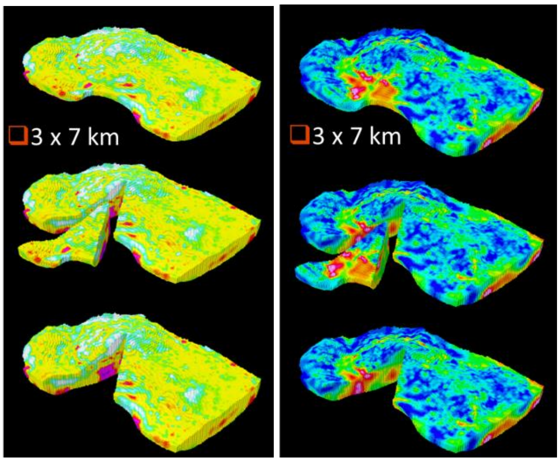

Figure 5. Santa Cecilia 3D survey results. DC resistivity left, Chargeability.

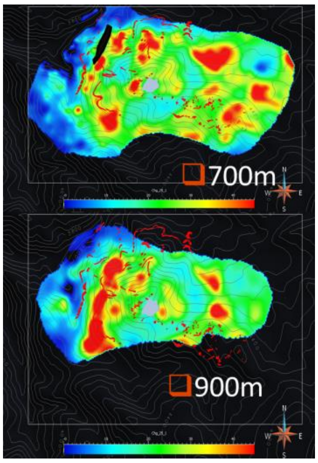

Figure 6. Chargeability depth slices shown at 700m (top) and 900m (bottom.

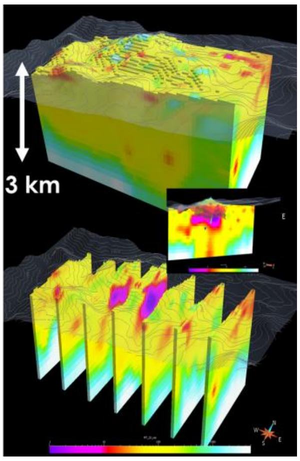

Figure 7. The MT successfully confirmed and mapped the root of the system to depths well over 2 km.3D inversion modelling shown.

The scope of the survey is huge and provides a completely new way in which to deploy funds for near-regional exploration. The property can be systematically tested through enhanced targeting vs. more traditional methods of drilling on conjecture. A comprehensive exploration approach is achieved through “imaging before drilling”.

4. Conclusions

The oil industry has utilized an image before drilling exploration process for years, with huge success rates, thanks in part to seismic deep imaging capability in sedimentary units. The mineral industry, faced with significantly more complex formations is starting to realize the benefits of advances in data acquisition and data processing and inversion routines that have just evolved over the last 20 years.

The recent advances in deep electrical earth imaging are starting to have a profound impact on our ability to investigate the subsurface prior to drilling. Deep imaging surveys have practical applications for mapping deep structure, alteration and mineralization. In addition the use of these surveys for near mine exploration continues to grow. Mining applications include planning and condemnation studies as well as pre-tailings planning. *Figure 8.*

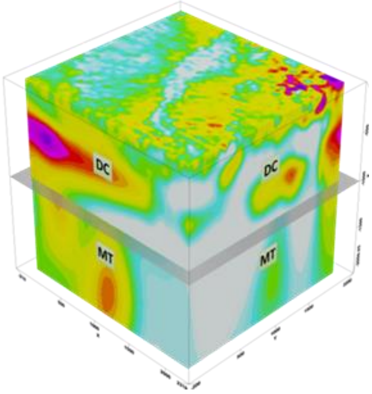

Figure 8. Combined DC resistivity and MT resistivity data cube. Approximate size is 2 x 2 x 2 km.

Other advances in technology such as machine learning promise to advance the industry even further in the coming years. We can now imagine that large multi-parameter data sets will be acquired and the data cubes will be thoroughly interrogated for probabilistic occurrences prior to any drilling, in a growing number of exploration programs.

Thanks

The author wishes to acknowledge the vast array of people that are involved in the data acquisition and processing portions of these surveys. They have contributed significantly over the last 17 years to continuously improve survey logistics, QA/QC, processing routines and suggestions, all of which have contributed greatly to the overall accuracy and quality of the information.

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