Introduction

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. The ORION3D DCIP & MT system provides large scale 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 and a copper-gold porphyry system. Case studies show increased depth of penetration and increased resolution and the advantage of true 3D vs 2D exploration.

The ORION3D DCIP & MT technology

The ORION 3D technology was built 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. ORION3D was the first ever distributed acquisition system (DAS) - based on full 3D data acquisition system that includes both DC resistivity, IP and MT.(Sharpe 2017)

There are several unique features of the system 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 ostensibly equal number of in-line and cross-line receiver dipoles that maximizes coupling with any target. Figure 1.

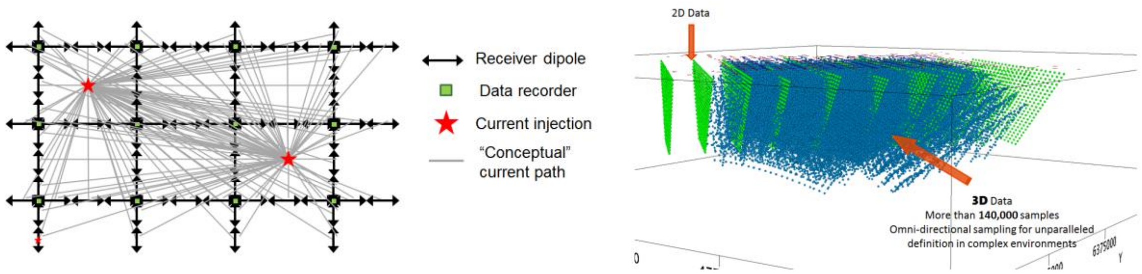

Figure 1 *(left) An example of a 3D deployment of receivers with conceptual current paths for 2 injection points. (Right) Typically over 250 injection points are made on a grid. 3D data plot points are shown in blue and compared to data plot points from a 2D survey shown in green.*

True 3D is defined to mean acquisition where receiver electrodes sample the current in orthogonal directions and a large number of receivers (300) are deployed (using a DAS) to optimize the footprint geometry. 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.

Background - Distributed Array Systems

John Kingman (1994) introduced digital signal processing (DSP) concepts that would require a paradigm-shift in instrumentation. 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 development of the ORION system was the evolution of the 2D multi-parameter TITAN 24 distributed acquisition system which was introduced in 2002. (Gordon 2006).

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 coupled use of MT being run simultaneously and on very tight centres (100m) provides corroborative information in the top 700 metres but extends the imaging of resistivity down to useful depths of 1500 to 2000 meters and more.

DC Resistivity and IP

These hybrid systems combined the best aspects of the three main technologies of the time, time-domain chargeability, complex resistivity phase (CR) and frequency domain signal comparison (percent frequency effect or PFE). Time-series acquisition means the modern receivers are configured as loggers which fundamentally monitor, by recording a signal sampled at some regular rate, the response of a sensor located at some particular and interesting location within an area of interest. A sampling rate is chosen that is pertinent to the geophysical parameter being measured. For IP signals that are pertinent to the mining community (Macnae 2016) the sampling rate must provide a focus on the band from 'DC' (typically 0.1 Hz) to 50 Hz. (Sharpe 2017)

MT

For a DAS capable of MT, the sampling rate and sensors should cover a broad-band of perhaps 100 seconds to 10 kHz, although systems limited to 250 Hz upper end may practically be coupled with a deep-search DC system. Robust, referenced processing (Egbert and Booker, 1986) is necessary and often extremely helpful in a near mine or culturally noisy environment. Using robust processing methods, MT resistivity can outperform DC resistivity even at shallow depths.

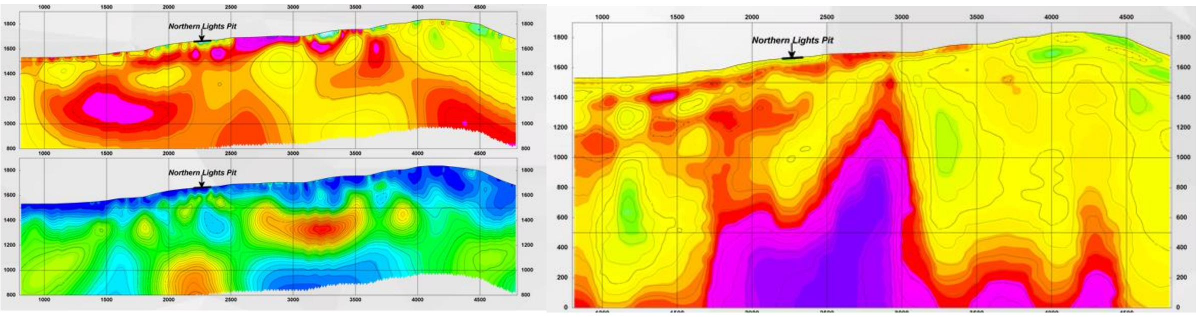

Figure 2 *(left-top) DC resistivity inversion model from 2D TITAN24 distributed array survey. (left-bottom) IP Inversion model from TITAN24 survey. Note how the DC model sees a near surface horizontal layer, senses a second deeper feature and also senses something at the bottom of the section.(Right) 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.*

3D vs 2D

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

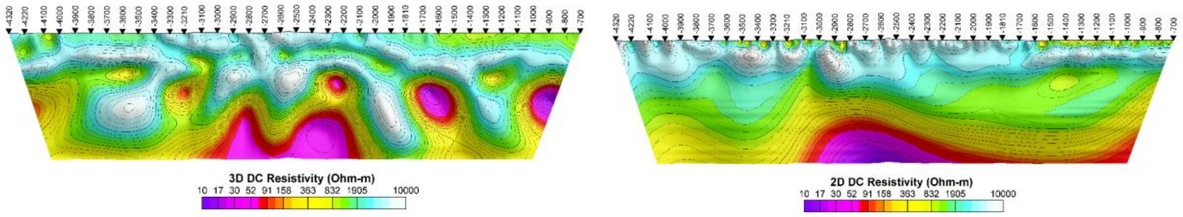

***Figure 3** Resistivity inversion models (sections) from the Athabasca Basin in Northern Saskatchewan Canada. Depth of the section is roughly 800 meters.(Left) 2D section sliced from a 3D inversion model of 3D data. (Right) 2D resistivity section from 2D inversion of single line of receivers.(2D data)*

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 4. The MT successfully confirmed and mapped the root of the system to depths well over 2 km. The survey was completed in 4 weeks and cost roughly $400,000 dollars.

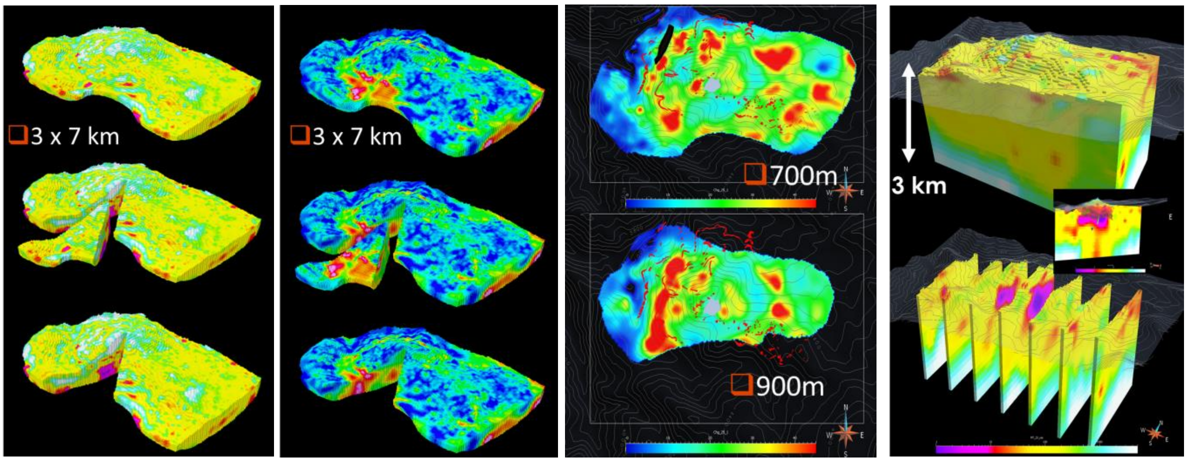

***Figure 4** Santa Cecilia ORION3D survey results. DC resistivity left, Chargeability 2nd from left. Chargeability slices at 700 and 900 meters depth shown third from left. 3D MT Inversion model shown at right to a depth of 3 km.*

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.

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. Figure 5.

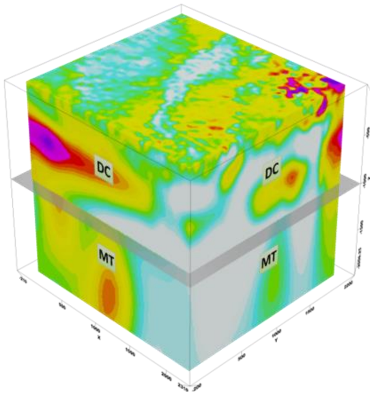

Figure 5 *Combined DC resistivity and MT resistivity data cube. Approximate size is 2 x 2 x 2 km.*

Acknowledgements

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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