A Comparison Between Conventional and Titan24 Induced Polarization Surveys for Gold Exploration in Nevada

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Abstract

Electrical geophysical survey methods have been applied successfully in world-wide mineral exploration programs for many years. The interpretation of data generated from these surveys improved during the 1990s due to the development of 2-D and 3-D inversion algorithms that provided relevant quantitative results. Recent advances in computer technology, in particular the practical application of time-series data processing and noise cancellation techniques in electrical geophysical data acquisition, have spawned the development of distributed acquisition technology that have resulted in improved spatial resolution and depth of investigation. This paper will compare the traditional electrical geophysical approach with distributed acquisition technology at the Brooks mineral prospect in Humboldt County, Nevada. The results show that for a comparable cost, improved data quality and depth of investigation can be achieved with distributed acquisition systems.

Introduction

Electrical geophysical methods, when applied to mineral exploration, have traditionally consisted of electrode array configurations such as pole-dipole, dipole-dipole, gradient array, etc. in which survey design usually results in a trade-off between minimum target size, logistical complexity in the field, and the depth of investigation of the survey. The recent development of the MIMDAS (M.I.M. Exploration) and Titan24 (Quantec Geoscience) distributed acquisition systems have allowed increased depth of investigation without necessarily significantly limiting minimum target size requirements (Rutley et al., 2001, http://www.quantecgeoscience.com/projectShowcase.html). These two systems are similar in that they collect induced polarization (IP), direct current (DC) resistivity, and/or magneto-telluric (MT) data with multi-channel configurations and signal processing techniques that allow for the efficient use of non-conventional arrays and the removal of natural and cultural noise. This can be particularly effective in near-mine environments where traditional systems are challenged to produce interpretable information, particularly at depth.

The distributed acquisition approach to geophysical data collection has been commonplace with seismic methods for some time. This multi-channel acquisition approach consists of large network of sensors that avoids multiplicity of cables and subsequent capacitive coupling problems, but allows for quick data acquisition and offers noise cancellation benefits.

At the Brooks prospect, near Newmont Mining Corporations’ Lone Tree operations in northern Nevada (Fig. 1), the Titan24 distributed acquisition system has been utilized. The results, along with the use of inversion programs, have contributed to the generation of a new prospect and subsequent drill testing. The Titan24 results have been directly compared with results based on the use of a traditional pole-dipole IP/resistivity survey and show that, for a similar cost, these new systems can provide better information at greater depths in areas covered by alluvium. The cost effectiveness of the Titan24 approach is related to the electrode array preparation (measurements made in one pass with the Titan24 vs. multiple passes with different array configurations with the conventional survey). The results at the Brooks prospect demonstrate that the Titan24 system produces better quality data with better resolution and twice the depth of investigation than conventional induced polarization surveys.

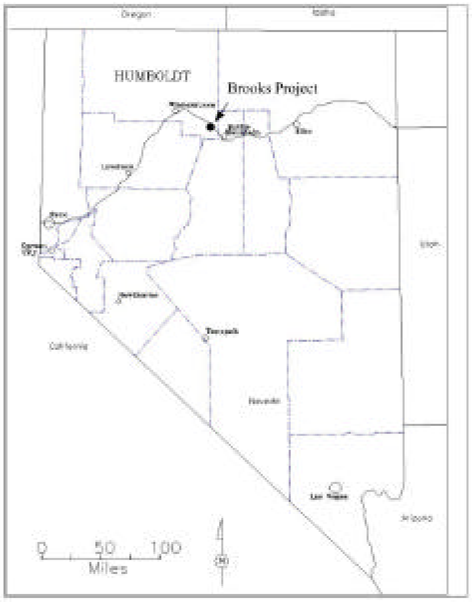


Figure 1: Location of the Brooks prospect in Nevada.

Geologic Background

The 5.5 million ounce Lone Tree deposit was discovered by Rayrock and Santa Fe Pacific Mining in 1989. The deposit is hosted in Paleozoic sedimentary rocks and is structurally focused along an approximately north-striking series of faults and fractures and is covered by up to 125 m of alluvium. The deposit has been described as a quartz-adularia-sericite low-sulfidation type based on the hydrothermal alteration and mineral chemistry where deep oxidation occurs along structures (Saderholm and Johnston, 2004).

The regional geology consists of widespread post-mineral cover and several Paleozoic formations. Poorly consolidated post-mineral gravel including lake sediments and distal volcanic tuffs covered the Lone Tree deposit from depths of 1 to 125 m. This post-mineral cover extends to the Brooks prospect area and beyond where alluvium-filled basins occur to depths exceeding 300 m.

Three Paleozoic rock sequences are present. The sequences from oldest to youngest are the Valmy Formation, the Antler Sequence, and the Havallah Sequence (Fig. 2). The Ordovician Valmy Formation is part of the Roberts Mountain Allochthon associated with the Devono-Mississippian Antler Orogeny. The Valmy Formation consists of an upper argillite/chert unit, a middle quartzite unit, and a lower chert/argillite unit containing lesser quartzite, minor volcaniclastic siltstone and greenstone. The Valmy Formation is unconformably overlain by the overlap assemblage of Pennsylvanian/Permian Antler Sequence rocks which includes the Battle and Edna Mountain Formations. The Battle Formation consists of poorly sorted Valmy-derived chert/quartzite cobble conglomerate, while the Edna Mountain Formation consists of massive lithic arenite with pronounced sub-angular chert grains and weakly bedded siltstone to sandstone. The Mississippian/Permian Havallah Sequence was thrust over the Antler Sequence rocks during the Permian/Triassic Sonoma Orogeny. The Havallah Sequence consists of sandstone, siltstone, carbonaceous mudstone, and mudflow conglomerate units (Saderholm and Johnston, 2004).

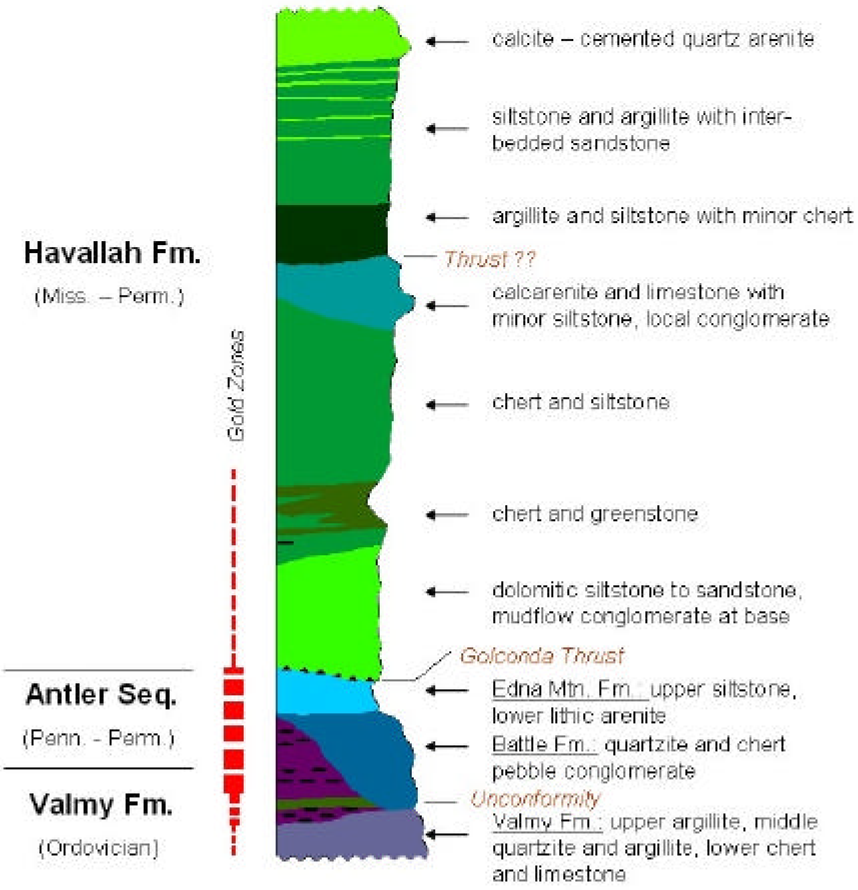


Figure 2: Stratigraphic column of the Lone Tree mine vicinity. Thickness of section is approximately 1000 to 1400 m.

Gold mineralization at Lone Tree is primarily controlled by NNW to NNE striking faults and, to a lesser extent, the favorable host lithologies of the Antler Sequence. The Edna Mountain rocks within the Antler Sequence are preferentially mineralized distal to the feeder faults (Panhorst, 1996).

Titan24 Distributed Acquisition System

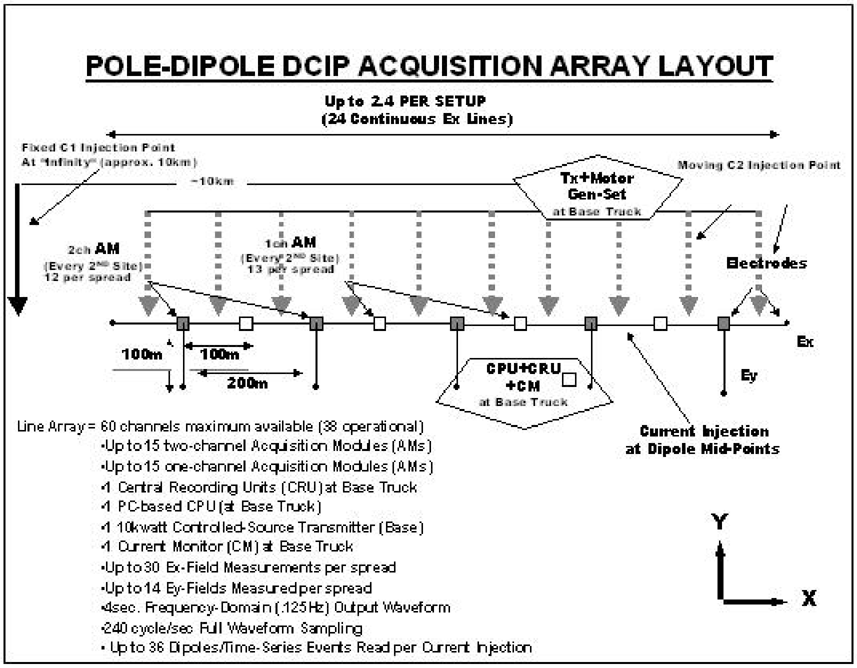
The Titan24 DCIP and MT Distributed Deep Earth Imaging System, developed by Quantec Geoscience, is a multi-channel distributed acquisition approach to collecting broadband MT, DC resistivity, and IP data. The MT and the DC measure the physical property of resistivity, while the IP portion of the survey may indicate the presence of sulfide mineralization (but can also respond to clay or graphite). This paper will focus on the IP/resistivity portion of the system.

Common arrays for profile surveys at the surface in mineral exploration include dipole-dipole, pole-dipole, and gradient. The dipole-dipole array has both good horizontal and vertical resolution capabilities and the best resolution characteristics for narrow, vertical bodies. It has the disadvantage of low signal levels compared to the pole-dipole or gradient arrays. The pole-dipole array has the advantage of increased signal strengths over the dipole-dipole array. This array does not have the vertical resolution of dipole-dipole or the same level of resolution for narrow vertical anomalies. The gradient array is a common reconnaissance configuration that utilizes a single stationary current bipole in which the electrodes are placed outside of the designated survey area. While it has good signal strength, it has poor resolution of narrow vertical targets, does not give any information about the depth to a target, and yields resistivity maps that depend to some extent on the location and orientation of the current bipole. With dipole-dipole or pole-dipole configurations, electrode spacing can vary dependant on the available power and external noise levels, as well as target size and location. The larger the separation, the deeper the penetration, however, the usual result is a trade-off between depth of investigation and target resolution.

The recent development of the Titan24 system has been an attempt to improve data quality by utilizing 24-bit time series full waveform data that assists in data signal processing, and as a way to improve field survey efficiency with greater depth of investigation.

The IP/resistivity portion of the Titan24 system is effectively a combination of a pole-dipole and dipole-pole survey (i.e. simultaneously taking measurements on either side of the single transmitter electrode along the survey section) that collect data with transmitter and receiver electrode separations from N = 0.5 to

23.5. A typical array consists of 100-m spaced receiver dipoles laid out along a 2.5 km long profile (Fig. 3). The transmitter electrode consists of a single electrode moving through the array, centered on each receiver dipole. The second transmitter electrode (infinite) is located a long distance away, typically several times the array length. At each transmitter station, all of the receiver dipoles record data simultaneously thus allowing for a complete acquisition to be completed over the 2.5 km length in a couple of hours. Effective depth of investigation with the IP/resistivity portion of the Titan24 system is at least 400 m, based on field experience in northern Nevada, compared to a traditional 100-m spaced survey (N = 1 to 6) that will typically investigate to depths of 150 to 200 m below surface.



Line Array = 60 channels maximum available (38 operational)
- Up to 15 two-channel Acquisition Modules (AMs)
- Up to 15 one-channel Acquisition Modules (AMs)
- 1 Central Recording Units (CRU) at Base Truck
- 1 PC-based CPU (at Base Truck)
- 1 10kwatt Controlled-Source Transmitter (Base)
- 1 Current Monitor (CM) at Base Truck
- Up to 30 Ex-Field Measurements per spread
- Up to 14 Ey-Fields Measured per spread
- 4sec. Frequency-Domain (.125 Hz) Output Waveform
- 240 cycle/sec Full Waveform Sampling
- Up to 36 Dipoles/Time-Series Events Read per Current Injection

Figure 3: Typical Titan24 distributed acquisition configuration for IP/resistivity surveys (courtesy of Quantec Geoscience).

Inversion Method

IP/resistivity profiles are usually presented as pseudo-sections and subsequently modeled with 2D or 3D inversion methods. The pseudo-section is the traditional method of plotting the apparent resistivity from this type of survey; it is not a true geological cross-section. The vertical axis is based upon electrode separation rather than depth. A formal inversion is increasingly being used to quantify IP/resistivity data. The non-uniqueness of applying an inversion to geophysical data must be appreciated; i.e. a single data set may yield multiple interpretations. Only by applying some independent constraints derived from other surveys or from geological insights, can the inherent uniqueness problem be mitigated.

The IP/resistivity inversion results referred to in the following examples were performed with the DCIP2D inversion software developed by the University of British Colombia Geophysical Inversion Facility (Oldenburg and Li, 1994). DCIP2D is an example of a geophysical inverse modeling program that estimates the distribution of resistivity and/or chargeability in the subsurface based on a numerical solution to an over-parameterized, constrained optimization problem. Such problems are intrinsically nonlinear and require iterative solutions, as well as some form of regularization to stabilize the solution and yield models that are realistic in a geological sense. The physical property distributions and topography are assumed to not vary in the direction that is perpendicular to the survey profile. The DCIP2D modeling code uses finite difference approximations to the relevant differential equations.

Discussion and Conclusions

At the Brooks prospect, located approximately 4 km south-west of the Lone Tree gold deposit, three Titan24 survey lines were completed (Fig. 4) in July, 2004. The surveys lines were 2.5 km in length, consisted of 100 m receiver dipole separations, and were 600 m apart with an east-west orientation. The area of interest is dominated by pediment cover. The design of the survey was based on a target concept related to the Lone Tree geologic model and refined from the interpretation of previous geophysical surveys (ground gravity and dipole-dipole and gradient IP/resistivity) and regional structural analysis.

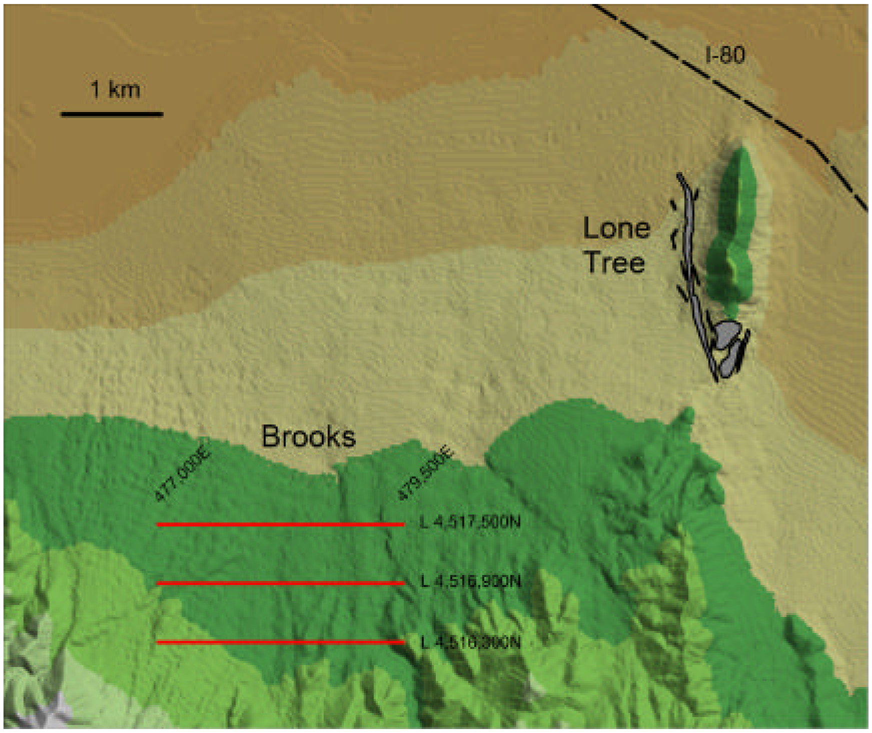


Figure 4: Topographic relief image of the Lone Tree district with the Lone Tree deposit footprint and the location of the IP/resistivity survey at the Brooks prospect. Elevation ranges from approximately 1400 to 1900 m (brown to green).

The 2D inversion results from the Titan24 survey represented by Line 4,516,900N (Fig. 5) show a series of distinct moderate to high (500 to 2000 ohm-m) sub-surface resistivity anomalies with an irregular horizon of elevated IP response (20 to 40 mrad) occurring in the bottom portion of the section. The distinct resistivity breaks are interpreted to represent structure while the moderate to high resistivity response represents the Havallah Sequence. The deeper IP response is interpreted to represent the potentially favorable sulfide and/or carbon rich Edna Mountain formation associated with the higher grade mineralization at the Lone Tree deposit. Similar IP and resistivity characteristics were delineated on the parallel survey lines.

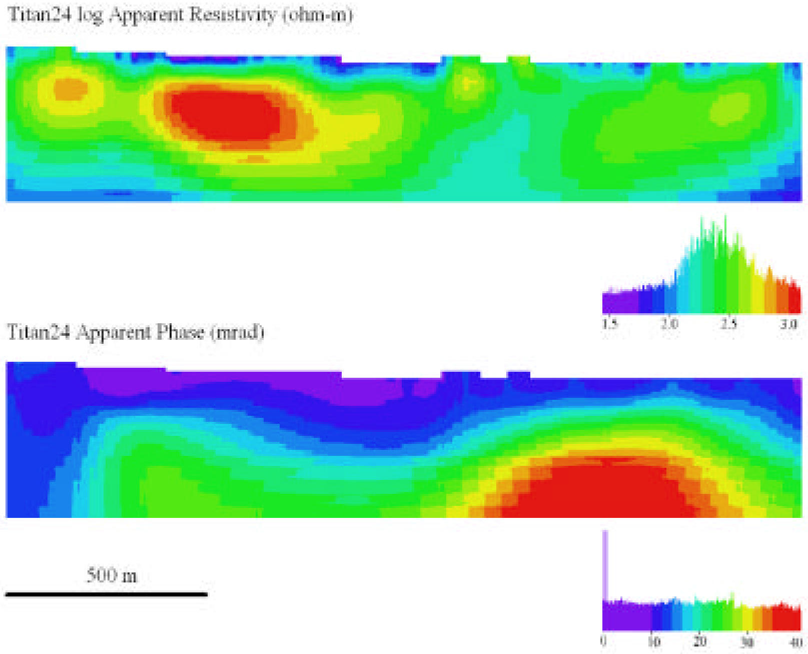


Figure 5: Titan24 DCIP2D inversion results of resistivity and IP from Line 4,516,900N at the Brooks prospect. Data ranges from 20 to 2000 ohm-m for resistivity and 5 to 40 mrad for IP (blue to red). Vertical and horizontal scales in meters.

In order to directly compare the Titan24 results with a more traditional approach, we collected IP/resistivity data along Line 4,516,900N with identical survey parameters, but utilized the IRIS Instruments Elrec-6 receiver and time-domain transmit waveform, instead of the 24-bit time series full waveform approach of the Titan24 system. The identical survey parameters included: the same transmitter (including infinite) and receiver electrode sites (N = 0.5 to 23.5), the same transmitter (Zonge GGT-30) that produced similar output current levels at each site, and the same crew and operators. We noted an evident increase in observed noise levels during the conventional survey, particularly in regards to the long offset IP data.

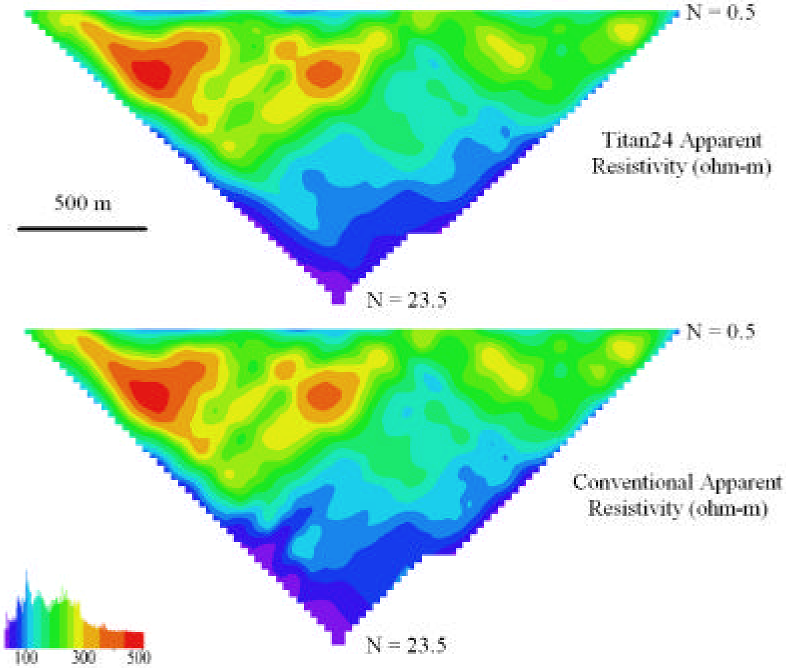


Figure 6: Direct comparison of resistivity pseudo-sections from Line 4,516,900N at the Brooks prospect. Resistivity data ranges from 20 to 500 ohm (blue to red). Horizontal scale in meters.

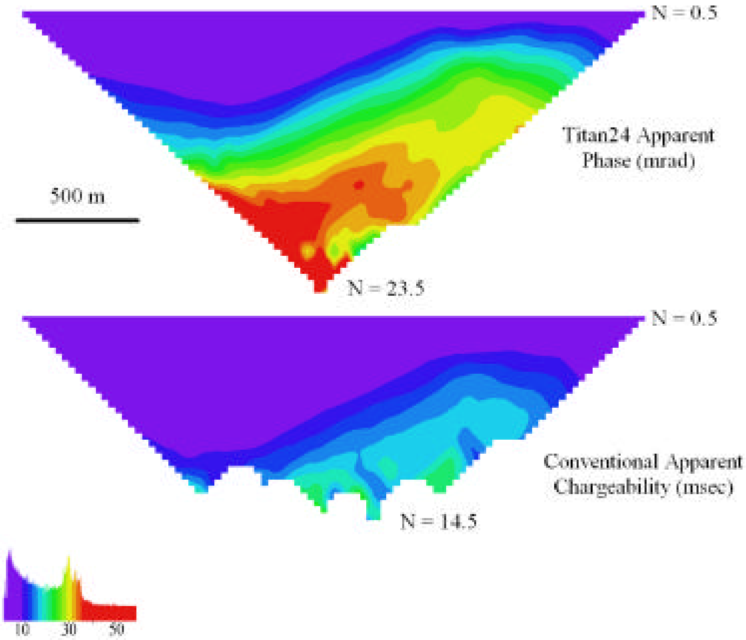


Figure 7: Direct comparison of IP pseudo-sections from Line 4,516,900N at the Brooks prospect. IP data ranges from 2 to 50 mrad (blue to red). Horizontal scale in meters.

A direct comparison can be made between the Titan24 and conventional approach by considering the data in colored pseudo-section format (Figs. 6 and 7) and with the DCIP2D inversion results (Figs. 8 and 9). The results as seen in the pseudo-sections from the conventional survey show obvious broad similarity with the Titan24 data, in particular with the resistivity data, but the IP response at the deeper N levels (below N = 14) could not be included with any confidence. The 2D inversion results show less detail in the resistivity and poorer depth of investigation and resolution with the IP (i.e. magnitude of the response) when compared with the Titan24 results.

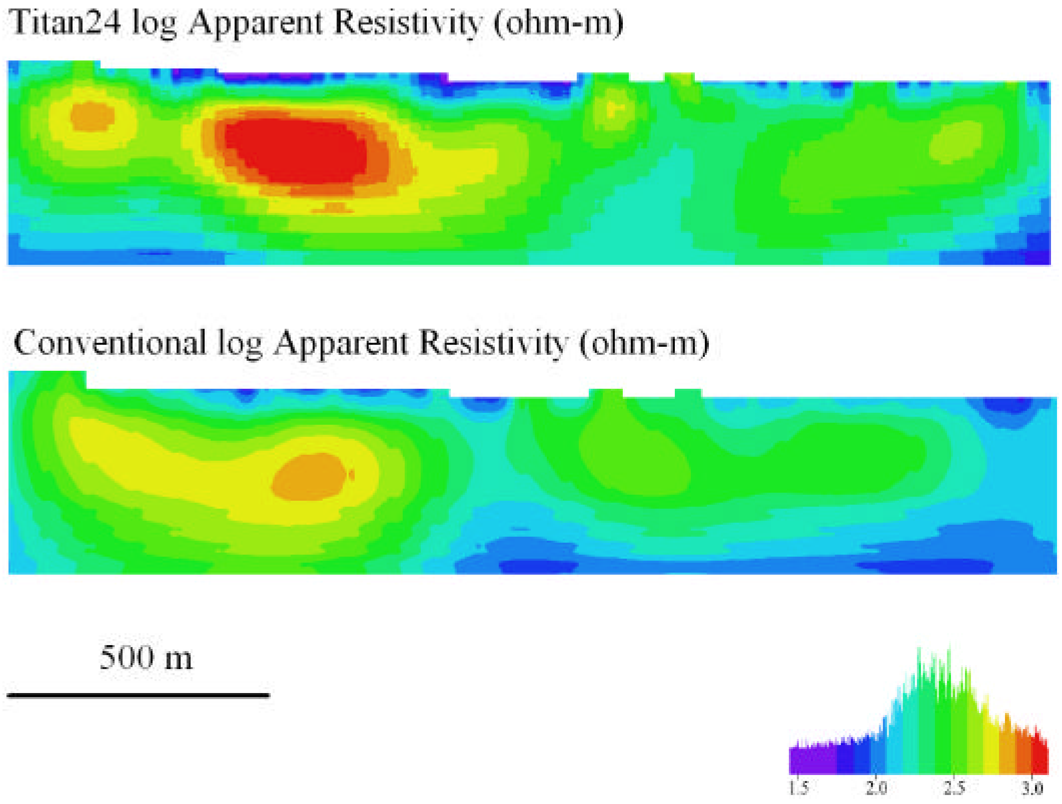


Figure 8: Direct comparison of DCIP2D inversion results of resistivity from Line 4,516,900N at the Brooks prospect. Data ranges from 50 to 2000 ohm-m (blue to red). Vertical and horizontal scales in meters.

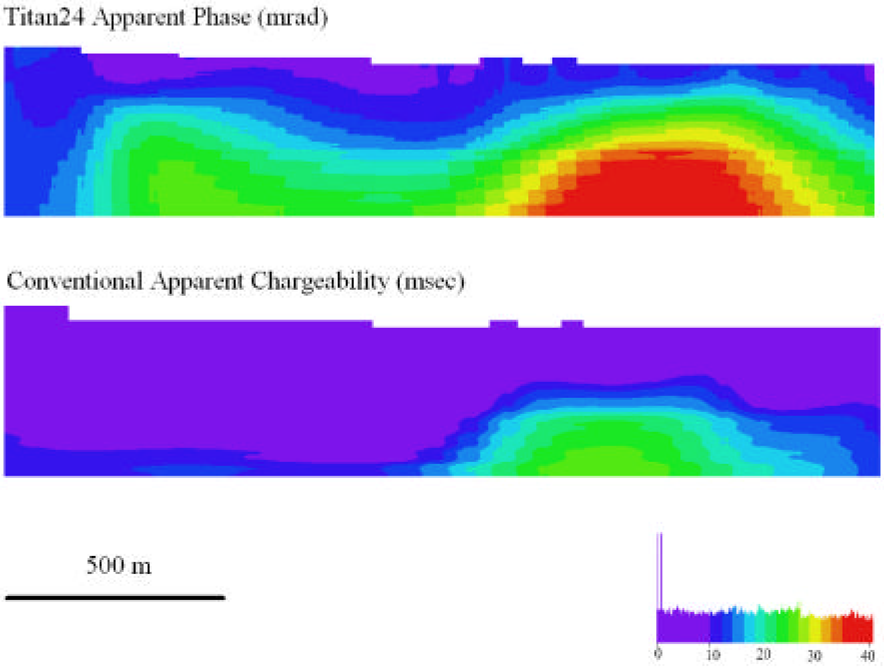


Figure 9: Direct comparison of DCIP2D inversion results of IP from Line 4,516,900N at the Brooks prospect. Data ranges from 5 to 40 msec (blue to red). Vertical and horizontal scales in meters.

The improved data quality and subsequent depth of investigation appears to be related to the Titan24 data acquisition technology that utilizes a 24-bit time series full waveform with enhanced data signal processing capabilities. Although the cost of contracting a Titan24 survey appears high to some, the cost of doing each of the surveys at the Brooks prospect was comparable ($4,500/line km with the Titan24 and $5,000/line km with the Elrec-6) because of the more labor intensive field work of the conventional survey (2 survey days with the Titan24 and 4 survey days with the Elrec-6). A more simple conventional survey (100 m pole-dipole, N = 1 to 6), that has been the standard approach for decades, would usually cost $1,500 to $2,000/line km in Nevada.

It has been shown in this case study at the Brooks prospect, the use of distributed acquisition technology offered with the development of the Titan 24 system can enhance the usefulness of electrical geophysical data in exploring for structurally-controlled deposits in northern Nevada. In this particular case, the depth of investigation of IP/resistivity surveys of at least 400 m can be achieved without sacrificing the spatial resolution typically only achievable in the past with small dipole spacing. The cost benefit and speed of acquiring a higher density of data points in a given area makes distributed acquisition surveys a useful tool for mineral exploration.

Acknowledgments

Thanks to Eric Saderholm and Ivan Johnston for providing the geologic support, Perry Eaton for his constructive comments, and Newmont Mining Corporation for allowing the publication of the data.

References

Oldenburg, D.W., and Li, Y., Inversion of induced polarization data: Geophysics, **59**, 1327-1341, 1994.

Panhorst, T.L., Structural control and mineralization at the Lone Tree Mine, Humboldt County, Nevada with implications of sampling protocol, Lone Tree Mine internal report, August, 1996.

Quantec Geoscience, Geophysical Survey Logistic Report, Project QCT-390, August 2004.

Rutley, A., Oldenburg, D.W., and Shekhtman, R., 2-D and 3-D IP/resistivity inversion for the interpretation of Isa-style targets, ASEG 15th Geophysical Conference and Exhibition, August 2001.

Saderholm, E. and Johnston, I., Lone Tree Mine internal report, November 2004.