A comparison between conventional and distributed acquisition induced polarization surveys for gold exploration in Nevada

Mark Goldie, Newmont Mining Corporation, Englewood, Colorado, USA

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 tradeoff between minimum target size, logistical complexity in the field, and the depth of investigation of the survey. Recent development of distributed acquisition systems (MIMDAS by M.I.M. Exploration and Titan24 by Quantec Geoscience) allow increased depth of investigation without significantly limiting minimum target size requirements. The two systems are similar in that they collect induced polarization (IP), direct current (dc) resistivity, and/or magnetotelluric (MT) data with multichannel configurations and signal-processing techniques that efficiently use nonconventional arrays and remove 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 multichannel acquisition approach consists of a large network of sensors that avoids multiplicity of cables and subsequent capacitive coupling problems, but allows quick data acquisition and offers noise cancellation benefits.

At the Brooks prospect near Newmont Mining Corporation's Lone Tree operations in northern Nevada (Figure 1), one of these distributed acquisition systems has been utilized (Titan24). The results, along with the use of inversion programs, have contributed to the generation of a new prospect and subsequent drill testing. The results of this study 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, this new approach can provide better information at greater depths in areas covered by alluvium. The cost effectiveness of this approach is related to the electrode array preparation (measurements made in one pass with the distributed system versus multiple passes and different array configurations with the conventional survey). The results at the Brooks prospect demonstrate that the distributed system produces better quality data with better resolution and twice the depth of investigation than conventional induced polarization surveys.

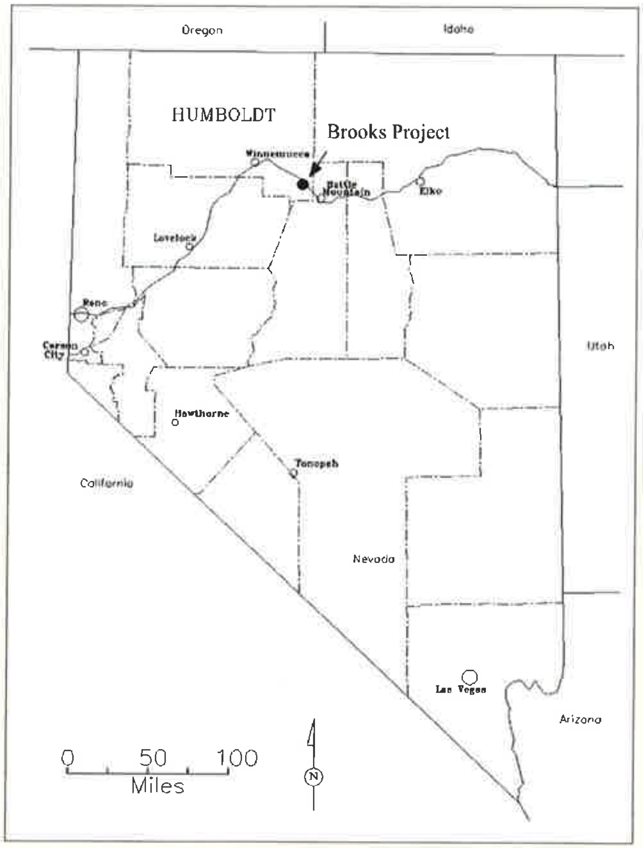

Figure 1. Location of the Brooks prospect in Nevada.

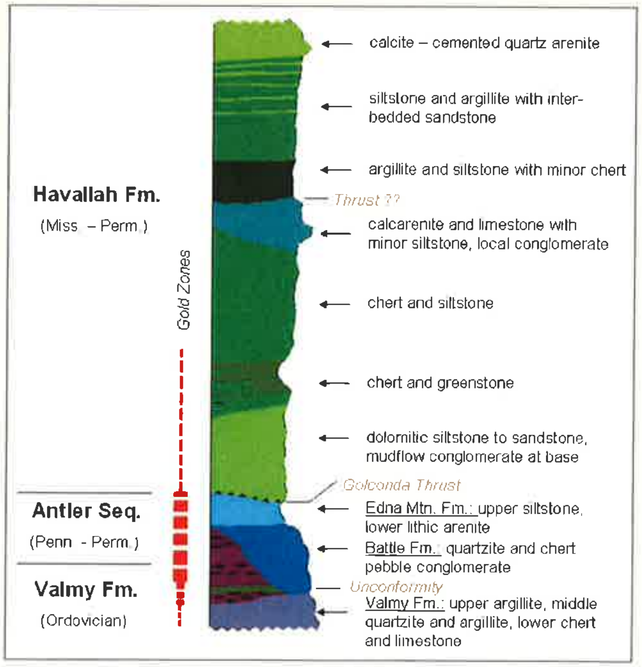

Figure 2. Stratigraphic column of the Lone Tree mine vicinity. Thickness of section is approximately 1000–1400 m.

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.

The regional geology consists of widespread postmineral cover and several Paleozoic formations. Poorly consolidated postmineral gravel including lake sediments and distal volcanic tuffs covered the Lone Tree deposit from depths of 1–125 m. This postmineral 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 Formation (Figure 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. 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 subangular chert grains and weakly bedded siltstone to sandstone. The Mississippian/Permian Havallah Formation was thrust over the Antler Sequence rocks during the Permian/ Triassic Sonoma Orogeny. The Havallah Formation consists of sandstone, siltstone, carbonaceous mudstone, and mudflow conglomerate units.

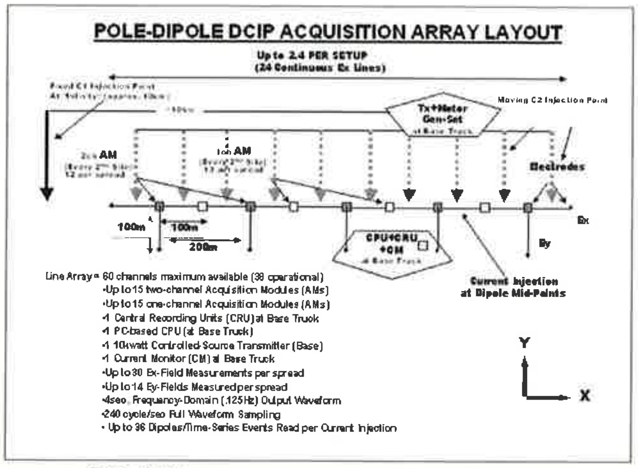

Figure 3. *Typical Titan24 distributed acquisition configuration for IP/resistivity surveys (courtesy of Quantec Geoscience).*

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.

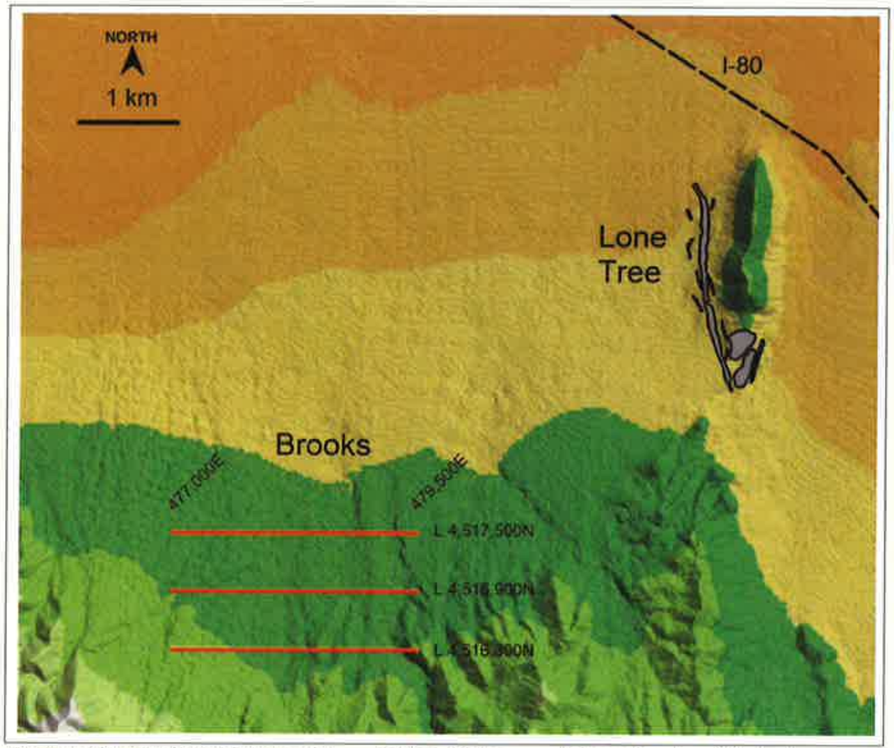

Figure 4. *Topographic relief image of the Lone Tree district with the Lone Tree deposit footprint and the location of the IP/resistivity survey at the Brooks prospect. Elevation ranges from approximately 1400 to 1900 m (brown to green).*

Distributed acquisition system. A multichannel distributed acquisition approach to collecting broadband MT, dc resistivity, and IP data was accomplished using the Titan24 DCIP and MT Distributed Deep Earth Imaging System developed by Quantec Geoscience. The MT and 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 data set.

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 depending 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 tradeoff between depth of investigation and target resolution.

Recent developments of distributed systems have attempted to improve data quality by utilizing 24-bit time series, full-waveform data that assist in data signal processing and as a way to improve field survey efficiency through greater depths of investigation.

The IP/resistivity portion of the 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 receiver dipoles with 100-m spacing laid out along a 2.5 km profile (Figure 3). The

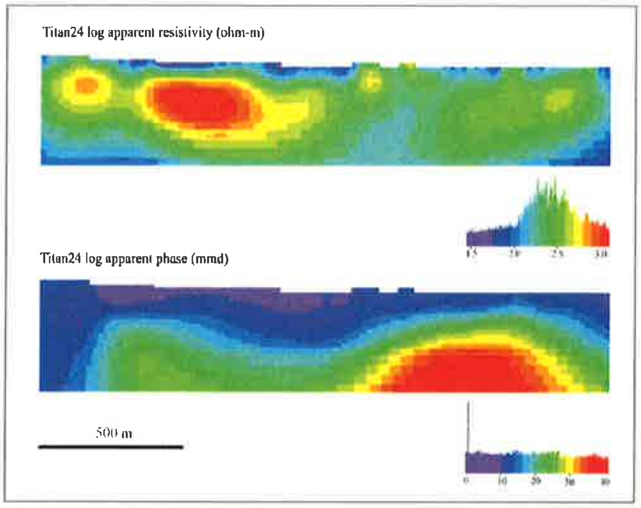

Figure 5. *Titan24 DCIP2D inversion results of resistivity and IP from line 4 516 900N at the Brooks prospect. Data ranges from 20 to 2000 ohm-m for resistivity and 5 to 40 mrad for IP (blue to red). Vertical and horizontal scales in m.*

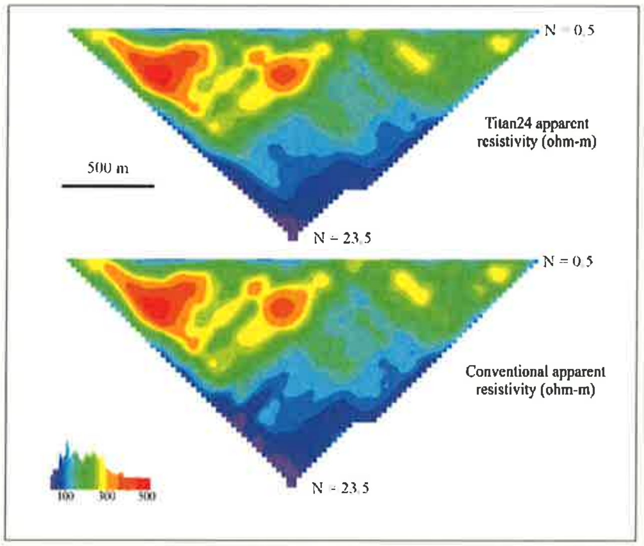

Figure 6. *Direct comparison of resistivity pseudosections from line 4 516 900N at the Brooks prospect. Resistivity data ranges from 20 to 500 ohm (blue to red). Horizontal scale in m.*

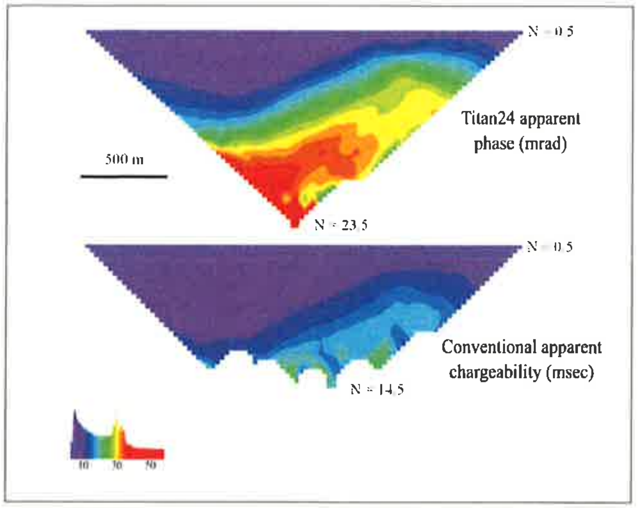

Figure 7. *Direct comparison of IP pseudosections from line 4 516 900N at the Brooks prospect. IP data ranges from 2 to 50 mrad (blue to red). Horizontal scale in m.*

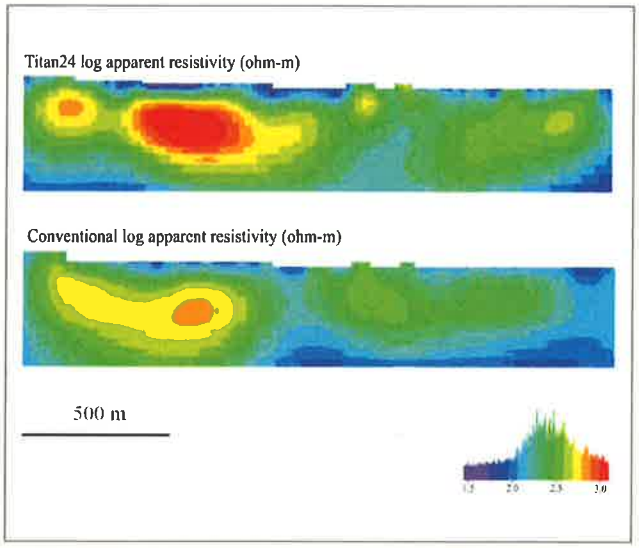

Figure 8. *Direct comparison of DCIP2D inversion results of resistivity from line 4 516 900N at the Brooks prospect. Data ranges from 50 to 2000 ohm-m (blue to red). Vertical and horizontal scales in m.*

transmitter electrode consists of a single electrode moving through the array, centered on each receiver dipole. The second transmitter electrode (infinite) is a long distance away, typically several times the array length. At each transmitter station, all receiver dipoles record data simultaneously, thus allowing complete acquisition of a 2.5-km profile in a couple of hours. Effective depth of investigation with the IP/resistivity portion of the 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 150–200 m below surface.

Inversion method. IP/resistivity profiles are usually presented as pseudosections and subsequently modeled with 2D or 3D inversion methods. The pseudosection is the traditional method of plotting the apparent resistivity from this type of survey; it is not a true geologic 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 nonuniqueness 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 geologic insights can the inherent uniqueness problem be mitigated.

The IP/resistivity inversion results 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 a geophysical inverse modeling program that estimates the distribution of resistivity and/or chargeability in the subsurface based on a numerical solution to an overparameterized, 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 geologic sense. The physical property distributions and topography are assumed to not vary in the direction that is perpendicular to the survey profile. The DCIP2D

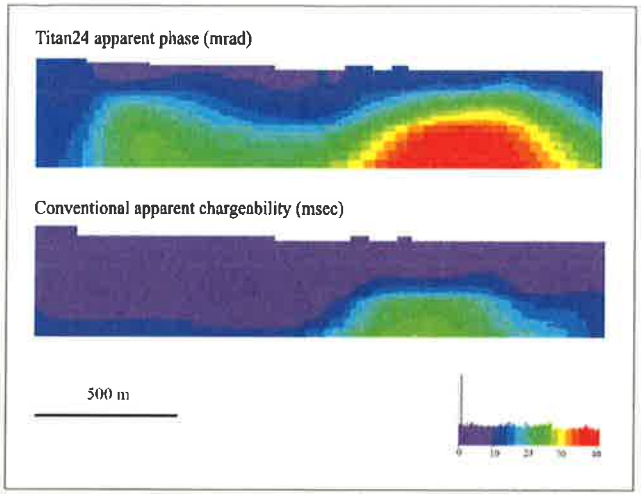

Figure 9. Direct comparison of DCIP2D inversion results of IP from line 4 516 900N at the Brooks prospect. Data ranges from 5 to 40 ms (blue to red). Vertical and horizontal scales in m.

modeling code uses finite-difference approximations to the relevant differential equations.

Discussion. At the Brooks prospect, approximately 4 km southwest of the Lone Tree gold deposit, three Titan24 survey lines were completed (Figure 4) in July 2004. The survey 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.

The 2D inversion results from the survey represented by line 4 516 900N (Figure 5) show a series of distinct moderate to high (500 to 2000 ohm-m) subsurface 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 Formation. 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.

To directly compare the distributed 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 distributed 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.

A direct comparison can be made between the distributed and conventional approach by considering the data in colored pseudosection format (Figures 6 and 7) and with the DCIP2D inversion results (Figures 8 and 9). The results as seen in the pseudosections from the conventional survey show obvious broad similarity with the distributed 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 distributed system results.

The improved data quality and subsequent depth of investigation appears to be related to the distributed data acquisition technology utilizing a 24-bit time series full waveform with enhanced data signal processing capabilities. Although the cost of using a distributed system appears high to some, the cost of doing each of the surveys at the Brooks prospect was comparable (US$4500/line km with the distributed and $5000/line km with the conventional) because of the more labor intensive field work of the conventional survey (two survey days with the distributed and four survey days with the conventional). A more simple conventional survey (100 m pole-dipole, N=1 to 6) that has been the standard approach for decades would usually cost $1500–$2000/line km in Nevada.

Conclusions. This case study at the Brooks prospect has shown that distributed acquisition technology 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.

Suggested reading. "Inversion of induced polarization data" by Oldenburg and Li (GEOPHYSICS, 1994). "2D and 3D IP/resistivity inversion for the interpretation of Isa-style targets" by Rutley et al. (ASEG 15th Geophysical Conference and Exhibition, 2001). TLE

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Corresponding author: mark.goldie@newmont.com