

Synthetic model testing and Titan-24 DC resistivity results over an Athabasca-type unconformity Uranium target at Wheeler River, Athabasca Basin, Northwestern Saskatchewan

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Summary

Two-dimensional forward modeling and synthetic inversions were used to optimize the DC resistivity array type and survey parameters prior to investigating a 400m deep Athabasca type unconformity uranium target in northern Saskatchewan, using the Titan-24 distributed acquisition system. The model testing determined that the pole-dipole array, using 100m dipoles, could possibly provide the best combination of lateral and vertical resolution in the 300-400m unconformity depth range for these particular graphitic targets. In an actual field test over a target on the Wheeler River property, known as M-zone, pldp was compared directly against dipole-dipole array results as well as pole-pole which is the most popular resistivity array currently used in the Athabasca Basin. Tensor audio-magnetotellurics were also acquired. The field tests appeared to corroborate the synthetic model testing results but also demonstrated improved signal-to-noise over the other two arrays. The DC resistivity surveys over the Wheeler River property define a consistent depth, location and dip for the known “M”-zone graphitic conductor along its >2 km surveyed strike length. They also identify a more weakly conductive response lying directly overtop that potentially represents its structurally controlled clay-alteration zone. Of note, a nearby major powerline has no significant effect of the DC data quality or survey results. In addition, the IP results, although of a lesser quality, also appear to map increased bulk chargeability both as layers within the Athabasca sandstone, as well as basement highs that are directly correlated with the graphitic units, making it a potentially useful corroborative and geologic mapping tool to complement DC resistivity. Three dimensional DC and IP inversions appear to provide more consistent mapping of resistivity and chargeability variations along strike, including the basement conductor and upper clay-alteration zone.

Introduction

From April 12 to 29, 2007, Quantec (QGL) undertook a Titan distributed acquisition system (DAS; Sheard, 1998) survey over the M zone grid on the Wheeler River Property, situated in the southeastern Athabasca Basin, approximately 35 km northeast of Key Lake, in northern Saskatchewan (Figure 1). The “M”-zone is a uranium occurrence that lies at the unconformity, under approximately 400m of Athabasca sandstone, and is associated with a conductive graphitic metasedimentary unit in the basement rocks. Originally discovered in the 1980’s, little exploration had been undertaken since then, however the increasing value of uranium ore has renewed

interest in the property. In addition to the recent presence of a nearby major 3-phase power line (Figure 2) which limits more conventional ground EM follow-up on the property, the DC resistivity technique has been favoured due to its ability to map structurally controlled alteration zones in the sandstones that often accompany unconformity uranium targets (Bingham et al., 2006). In fact, the DC resistivity method has become a preferred reconnaissance mapping tool for target selection prior to diamond drillhole (DDH) testing, in the Athabasca Basin. The Titan-24 multi-parameter survey system was chosen as a deep resistivity imaging tool and for its noise rejection capabilities.

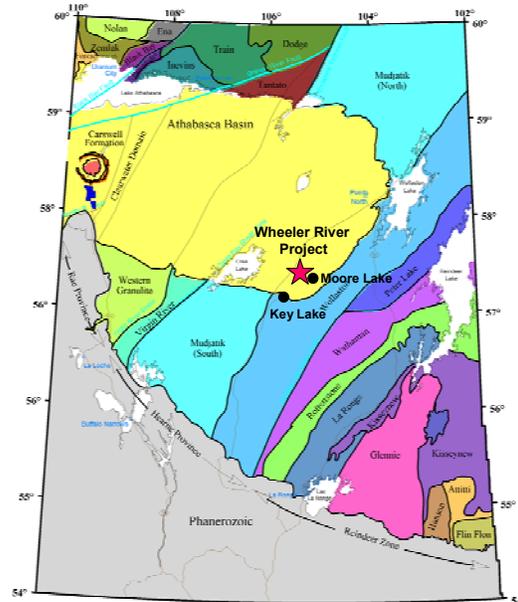


Figure 1: Wheeler River property location and regional geology.

Titan-24 (White and Gordon, 2005) is a multi-channel, multi-parameter, distributed acquisition system, recording broad band Tensor Audio Magnetotelluric resistivity (AMT/MT; Vozoff, 1972; Strangway, et al., 1973; Orange, 1989), D.C. Resistivity and Induced Polarization (DC/IP; Siegel, 1959; Pelton, et al., 1978; Halverson, et al., 1981; Johnson, 1984) data. It uses a large multi-channel, fixed receiver array in combination with a wide variety of possible current injection arrays and highly accurate 24-bit sampling to achieve great depth of penetration, data quality and detectability. First used in mineral exploration applications in 2000, it has been applied for Athabasca-type uranium exploration since 2005 (Legault, 2006). In addition to its field acquisition system, the Titan-24 is

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complemented by its full-waveform, digital signal processing platform and its 2D-3D forward modeling and inversion capability.

The Titan surveys were preceded by a 2D synthetic modeling study that tested for the optimal array parameters and to compare the responses from the various arrays, including pole-pole (plpl), pole-dipole (pldp) and dipole-dipole (dpdp). The Titan survey at Wheeler River included a single test line of joint DC resistivity & IP acquisition directly over the M zone, using multiple array configurations, in combination with a tensor MT audio-magnetotelluric survey line. The survey was then completed over an additional 10 adjacent survey lines using pole-dipole DC resistivity and induced polarization.

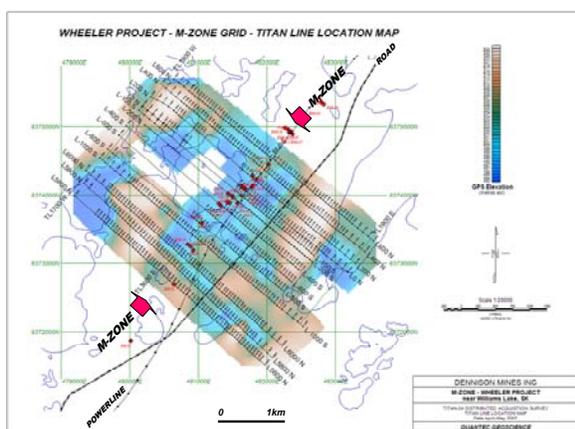


Figure 2: Wheeler River Property, M-zone Titan line location map, showing gps elevation contour, location of lakes, road, powerline and drill-holes that define the basement graphitic conductor that hosts the known mineralization, situated at the unconformity, near L100S-BL0E.

Geological setting

The Wheeler River property is regionally underlain by 300-400m thick Athabasca sandstones and conglomerates of upper paleo-Proterozoic age (1540-1740 Ma). Sandstones of the Manitou Falls Formation host most of the uranium deposits in the eastern part of the basin and are composed of orthoquartzite sandstones and conglomerates. Below the unconformity (UC), the crystalline basement comprises the 2.5-2.6 Ga Wollaston Group that is a mixture of graphitic, pelitic, metasedimentary units and metaquartzite units (Tuncer, et al, 2006).

Unconformity uranium mineralization in the Athabasca basin is structurally controlled by the paleo-Proterozoic unconformity and faults. Oxidizing basin fluids carried uranium from the sandstone while reducing fluids from graphitic faults in the basement also carry other minerals such as silica from the basement rocks to the unconformity. Uranium is deposited at the top of the fault around the

unconformity and alteration occurs above the unconformity due to the fluid flow (IBID).

On the Wheeler River property the “M”-zone geology is poorly known outside the narrow DDH drilling corridors. The “M” zone, which is situated at the eastern edge of the Wheeler River property, consists of uraniumiferous intersections along a graphitic pelite conductor, centered around L100S and BL0E, as well as elevation changes in the basement topography, lying at roughly 380-400m depth. The M-zone conductor has been traced for >1 km strike length, however very little is known geologically beyond this trend, including the exact geologic dip direction for the basement, which is presumed to be steep southeast, conformable to the granite contact. The Archean granitic gneiss unit in the basement is indicated in the southeast half of the grid, based on the magnetic results (Figure 3).

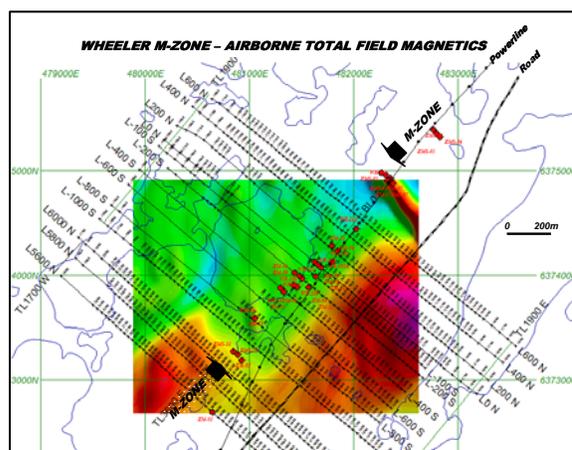


Figure 3: M-zone grid airborne total field magnetics showing relationship between magnetic lows to the northwest that correlate with the basement metasediments and the M-zone mineralized trend, as well as the magnetic high that correlates with the granite unit that lies to the east.

The Wheeler River M-zone mineralized conductor was originally discovered in the mid 1980's using ground transient EM follow-up of airborne survey targets (Figure 3), but has remain unexplored in the years since then. However, the presence of a major powerline on the grid, built during this interim period, to extend power from Key Lake mine to McLean Lake, has complicated additional ground geophysical follow-up (D. Carriere, pers. comm., 07-2007). In fact, it is well established that transient EM surveys, locally, are heavily impacted within a several hundred metre vicinity of these powerlines due to unusually high levels of cultural noise (W. Coulson, QGL, pers. comm., 07-2007).

Recent drilling at M-zone has detected and confirmed anomalous uraniumiferous intersections in the sandstone over the M-zone. The Titan DC resistivity surveys were planned over the M-zone area in spring 2007 to: a) define the M-

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zone conductor, b) detect the granite to the south-east, and c) detect an alteration chimney associated with the mineralization, in the MT/DC resistivity and IP results.

Two dimensional synthetic modeling & inversions

In an effort to optimize the DC resistivity survey results at Wheeler River, the surveys were preceded by a 2D synthetic modeling study that tested the array parameters, such as dipole size (a-spacing) for the typical Titan array (24 continuous dipoles) configuration as well as comparing the responses from the various electrode arrays, including pole-pole, pole-dipole and dipole-dipole. Of these array types, pole-pole is currently favoured in the Athabasca Basin due to its high signal levels, its deep penetration and its anomaly resolution, having proven effective to >600m (Bingham et al., 2006). However, for shallower UC depths, it was felt that either dipole-dipole or pole-dipole methods might provide higher resolution than pole-pole, as suggested in previous array studies (Roy and Apparao, 1971; Coggon, 1973). Although the normal Titan-24 acquisition mode utilizes the pole-dipole array, the final choice of array configuration for the Wheeler River survey were to be based on the results of the synthetic modeling and the eventual field testing.

A series of 2D synthetic models were created that simulate the expected Titan DC resistivity results over a typical 300m deep, Athabasca graphitic target, using a 50m, 100m and 150m dipole, 24-channel Titan array that might typically be used, in the pole-pole, pole-dipole and dipole-dipole configurations. The geologic model and physical properties were drawn from the geophysical model proposed by Witherly (2005) and shown in Figure 4. It includes a thick (300m) resistive sandstone caprock (3k Ω -m), less resistive half-space basement (1k Ω -m) and a thin (100m) graphitic conductor (5 Ω -m), as shown in Figure 5.

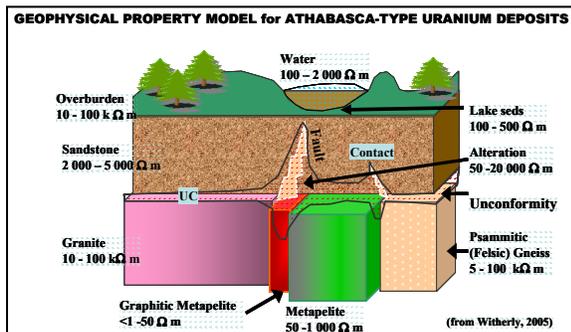


Figure 4: Geophysical property model for Athabasca-type uranium deposits (from Witherly, 2005)

The procedure for the synthetic modeling study was as follows: A common geologic model was used to calculate the 2D forward responses for the DC resistivity, utilizing the UBC *Deipf2d* code of Oldenburg and Li (1994), using a simulated Titan array geometry with a variety of array

configurations. These synthetic forward responses were then input into 2D inversions, with parameters identical to those typically used for Titan DC surveys. The final 2D inversion results were then directly compared to the original geologic model for assessment.

The 2D forward DC resistivity results over a 300m deep tabular conductor are presented in Figure 5. They were calculated for a standard Titan pole-dipole DAS array, with current injections between the receiver dipoles and also extending beyond each end (n=0.5-33.5) and whose fixed 24-channel receiver set-up combines both pdp-right & pdp-left voltage measurements at each injection point. The synthetic 2D results demonstrate the progressive changes in the expected measured Titan DC response when using dipole sizes varying incrementally from 50m, 100m and 150m. Similar comparisons were obtained for Titan dpdp and plpl arrays. The results qualitatively indicate that the 50m dipole data provides insufficient penetration in the 300-400m UC depth range, particularly for the dpdp array, and that the 100m dipole might provide better anomaly resolution, over the 150m spacing, in spite of its improved penetration, particularly for pole-pole array. These predictions were subsequently tested in the following 2d inversion stage.

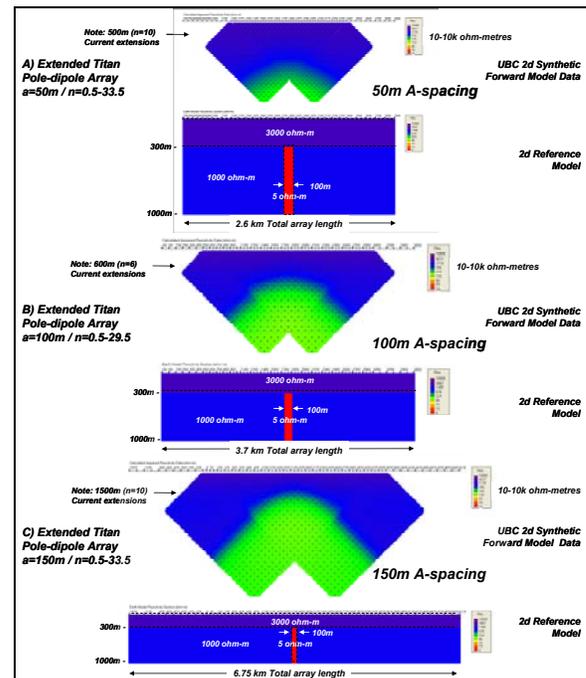


Figure 5: Two-dimensional synthetic forward DC resistivity models, calculated for A) 50m, B) 100m and C) 150m dipole Titan DC pole-dipole array, from 100m width graphitic conductor model, buried below 300m sandstone.

Figure 6 presents the 2D synthetic DC resistivity inversion results using the 100m spaced dipole-dipole, pole-dipole

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and pole-pole forward model data, over a 300m deep tabular conductor, obtained previously. They were calculated using the *Res2dinv* code of Loke and Barker (1996a). As expected, the dipole-dipole results appear to provide the best resolution at the UC depth but perhaps lack sufficient penetration needed to adequately resolve the basement geology. As was also predicted, in addition to showing remarkably similar resolution at the UC, the pole-pole results provide the greatest depth of investigation, although its wide anomaly pattern might limit its deep geologic mapping capability. Overall, however, of the arrays tested, the 100m pole-dipole results appear to feature the best combination of depth penetration and shallow-to-deep anomaly resolution for the UC target in the 300-400m target range, albeit closely followed by pole-pole. Similar results from the 50m and 150m dipole inversion studies also support these conclusions. As a proof of concept, all three arrays would nevertheless be tested in the field, using the 100m dipole spacing.

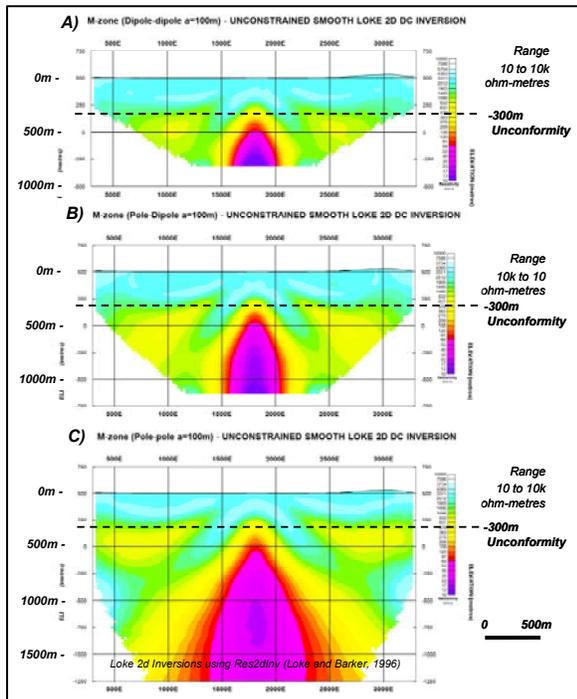


Figure 6: Two-dimensional synthetic inversions, calculated from A) dipole-dipole, B) pole-dipole and C) pole-pole array 2D forward DC model results, for 300m deep UC target, using typical Titan DC resistivity survey configuration with 100m dipoles. Notice similarity in responses at UC, but also relative differences in depth penetration versus lateral resolution & anomaly width, particularly between dpdp and plpl.

A Titan-24 test survey line was acquired directly over the center of the M-zone, on the Wheeler River property, in April 2007. Along line 100S, the M-zone uranium mineralization occurs at 0+00E at the UC, directly over a graphitic metapelitic conductor that lies in the basement

beneath approximately 380-400m of Athabasca sandstone. The Titan DAS array was 3 km in length and consisted of 30 continuous, 100m spaced receiver electrodes centered over the deposit. For the DC resistivity and IP surveys the survey procedure consisted of current injections at 100m intervals at the mid-points of the receiver dipoles and then extending 450m beyond each end of the receiver array. The DC/IP survey data were initially acquired in the pole-dipole array mode, and the Titan system was then reconfigured to sequentially acquire pole-pole and dipole-dipole data at identical sites on the same survey line. Tensor audio magnetotelluric data were also obtained in the 0.1. to 10k Hz frequency bandwidth for direct comparison.

Two-dimensional DCIP inversion

Two dimensional inversions of the: A) dipole-dipole, B) pole-dipole, and C) pole-pole array DC resistivity data acquired over M-zone line 100S are presented in Figure 7. The results are remarkably similar to those predicted in the synthetic inversions shown in Figure 6. This includes the relative differences in vertical depth penetration, with dipole-dipole having the least penetration (<600m), followed by pole-dipole (>1 km) and, as expected, pole-pole has the greatest (>1.5 km). Other contributing factors, not shown, were the relative noise levels in the raw data, which were greatest for the dpdp and the least for pldp, closely followed by plpl, which further diminished the DC/IP penetration and arise from inherent primary voltage signal and telluric noise levels in each of the arrays.

Another more important similarity to the synthetic models was the superior shallow lateral resolution of the dpdp results to the M-zone conductor which is however offset by its insensitivity to the apparent west dip, that is clearly borne out in the plpl as well as the pldp inversions, and is also shown in the remaining survey lines at Wheeler River (Figure 8cde). All three array inversions appear to highlight a similar, weak resistivity low directly above the M-zone UC that is consistent with the clay-alteration zone normally associated with Athabasca type uranium deposits. On the other hand, at greater depths, below the UC, in spite of its greater strength, the unusually broad width of the M-zone conductive anomaly clearly might lessen the ability of the plpl array to accurately map resistivity distributions in the basement. On the basis of these results that showed that, compared to pole-pole, pldp provided the best combination of resolution and basement penetration, as well as lower line-km cost, the pole-dipole array was adopted for the remainder of the DC/IP survey at M-zone.

One last but significant result for exploration is the relative lack of discernable powerline effect in the DC resistivity data and inversions, except as a narrow lineament in the shallowest depth levels (Figure 8a), relative to what might have been expected from transient EM. However, in spite of a similar result for the tensor MT (Figure 9e), the powerline no doubt contributed to below a average IP data

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quality that weakens the apparent IP effect over the M-zone for the northernmost lines at Wheeler River (Figure 9bd).

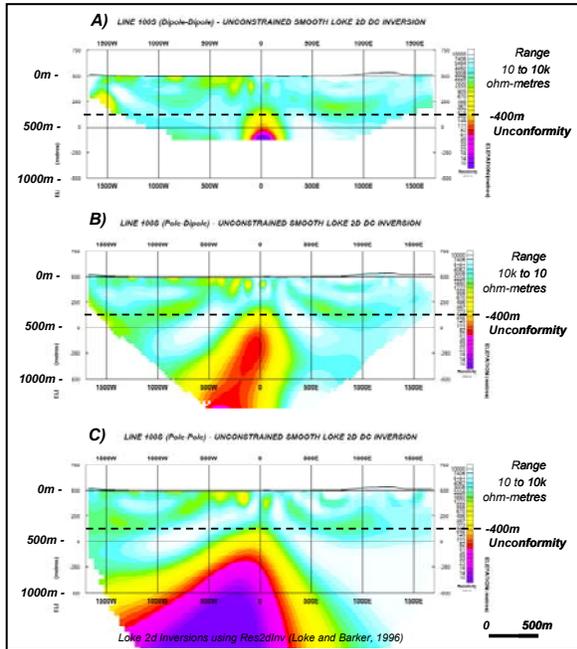


Figure 7: M-zone two dimensional DC resistivity inversions from L100S Titan-24 survey data, using a) Titan dipole-dipole, b) pole-dipole and c) pole-pole array measurements. Notice relative differences in vertical depth penetration versus shallow-deep resolution, including the apparent west-dip of the basement graphite and the inferred clay-alteration zone lying above 400m UC depth in sandstone directly over the M-zone conductor.

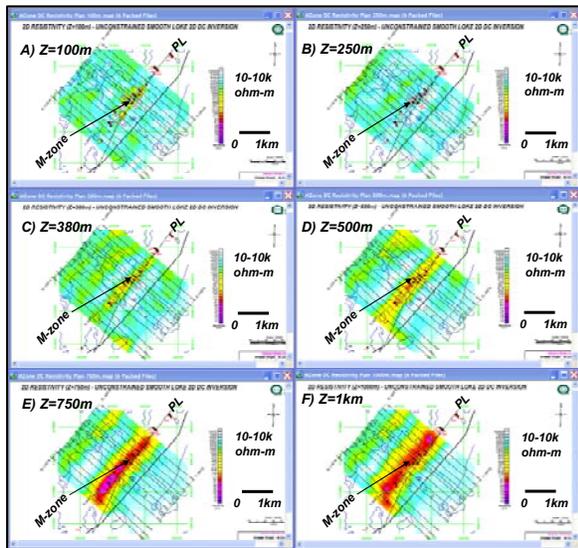


Figure 8: M-zone two dimensional DC resistivity inversion results, collated from thirteen survey lines and shown as depth slice plans, from 100m to 1000m. Notice: a) fault-like near-surface lineament at 100m that coincides with powerline (PL), b)

followed by relative homogeneity at 250m, c) at 380m the development of weakly conductive, alteration-like signature that coincides with M-zone, and d-f) from 500-1000m the progressive strengthening as well as SE-NW migration of a linear resistivity low in the basement that is consistent with M-zone graphitic conductor with a northwest dip.

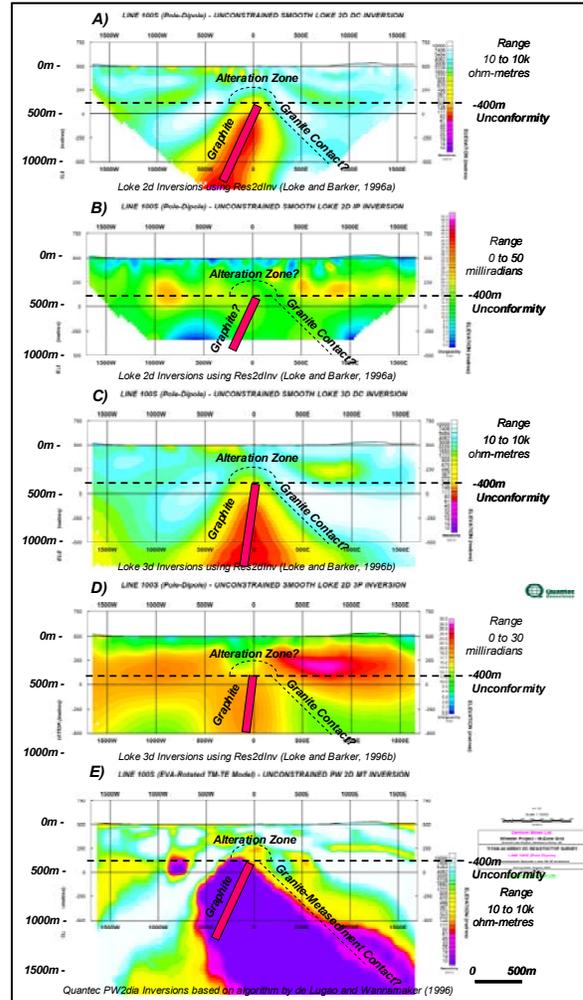


Figure 9: M-zone L100S two dimensional and three dimensional inversions of Titan-24 multiparameter DC resistivity, induced polarization and tensor audio magnetotelluric survey results, with geological interpretation overlain. A) 2D DC, B) 2D IP, C) 3D DC, D) 3D IP, E) 2D MT.

Multi-parameter Two & Three dimensional inversion

Figure 9 compares the two-dimensional DC, IP and MT inversions obtained over M-zone with three-dimensional inversion results that combined pldp data obtained from ten consecutive 100-200m spaced lines adjacent to M-zone. The 3d DC/IP inversions were performed using the *Res3div* code of Loke and Barker (1996b) and the 2d MT inversion was based on the *Pw2di* code of de Lugao and Wannamaker (1996). These highlight the remarkable

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similarities between the various technologies and model types, in relation to the geological interpretation overlay, such as: 1) the west dip of the M-zone conductor, albeit steeper in the 3d results, 2) the possible SE dipping granite-metasediment contact, best defined in the MT, 3) the unexplained layer-like polarizable unit in the overlying Athabasca sandstones above the UC, and finally 4) the coincident IP high/DC low feature, highlighted in the 3d results, that is consistent with the graphitic target host rock.

Conclusion

Two dimensional synthetic modeling and inversion studies have provided useful information on some basic questions regarding DC survey design and implementation in the Wheeler River-Moore Lake geological environment and other areas of the Athabasca Basin area that are being explored. DC resistivity surveys are an effective alternative to traditional methods in geologic mapping based on physical property contrasts. Multi-parameter and multi-dimensional inversion results offer complementary and sometimes contrasting images in complex 3d geology.

Acknowledgements

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