

A progressive geophysical exploration strategy at the Shea Creek uranium deposit

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The Athabasca Basin is a large Paleoproterozoic quartz arenite sandstone basin that occupies most of the northernmost quarter of Saskatchewan and a smaller portion of northeastern Alberta. The locations of the basin and the uranium discoveries discussed in this paper are shown in Figure 1. The majority of the unconformity-type uranium deposits of the Athabasca Basin are sandstone-hosted and are associated with post-Hudsonian, reactivated graphitic faults within Archean metasedimentary gneisses of the Wollaston Domain and the Wollaston-Mudjatik transition zone in the eastern portion of the Athabasca Basin. However, the Shea Creek deposit, consisting of the Anne, Kianna, and Colette zones, occurs in the western portion of the basin and is associated with the transition between the granitic Clearwater Domain and the Lloyd Domain.

Current uranium exploration strategies focus on delineating regions in which hydrothermal reactivation events have produced alteration haloes within the overlying sandstone units. Basement EM conductors with associated sandstone alteration haloes are considered priority targets (Figure 2). The references upon which much of the first paragraph, along with the "Regional geological and geophysical setting" section are in the "suggested readings."

The Shea Creek deposit is in the western part of the Athabasca Basin, approximately 15 km south of the Cluff Lake mine, which is within the Carswell Structure (Figures 1 and 3). The deposit consists of three mineralized uranium zones (Anne, Kianna, and Colette), with mineralization found in three locations: perched within the Athabasca sandstone, at the unconformity between the sandstone and underlying crystalline basement, and below the unconformity within the basement units (Robbins and Koning, 2006). At Shea Creek, the unconformity depth varies between 710 m and 750 m below ground level. The surface topography is quite variable with parkland areas intermingled with numerous lakes, streams, and low-lying, swampy areas. The relief of the Shea Creek area is low (~30 m) with average elevation of approximately 350 m above sea level. The soil profile is thin with a veneer (1-5 cm) of "A" horizon soil and a minimal "B" horizon overlying up to 30 m of glacial till composed of clean, moderately sorted sand.

Uranium exploration took place between 1969 and 1985 by various companies, with the bulk of the work carried out by Marline Oil Company from 1978 to 1981. The early programs were largely regional, comprising airborne magnetic and EM surveys, regional till, vegetation, lake and stream geochemical surveys, and geological mapping.

AREVA Resources Canada (formerly COGEMA Resources) resumed the exploration activity on the Shea Creek project in 1990, utilizing modern, deep-penetrating

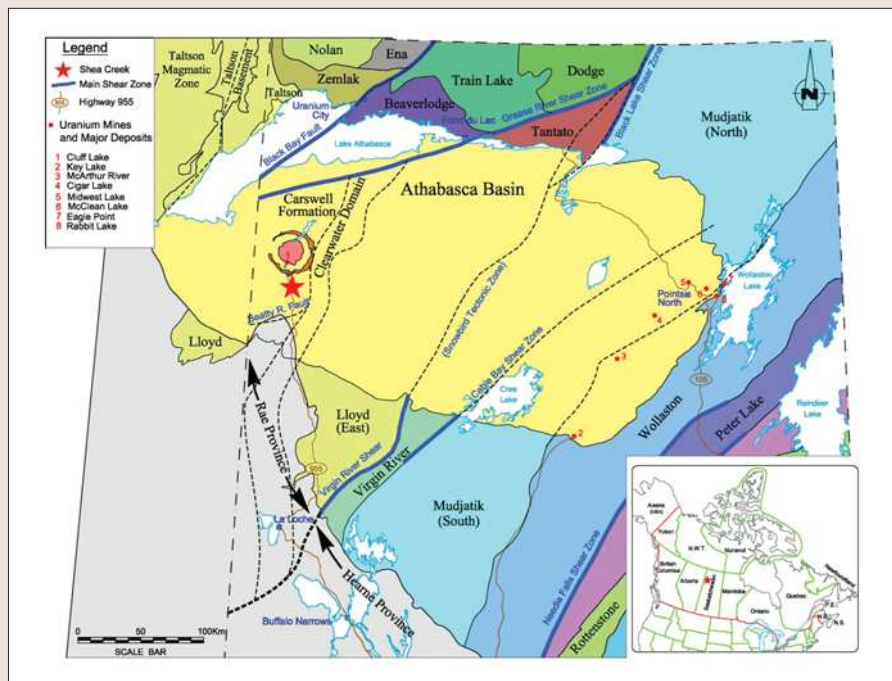


Figure 1. Project location and regional geological setting.

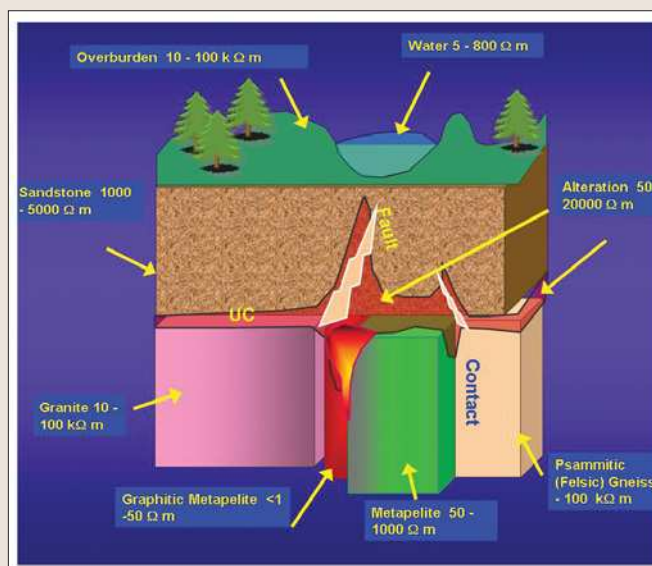


Figure 2. Exploration model.

airborne geophysical surveys. Subsequent ground magnetic, gravimetric, and moving-loop array electromagnetic surveys delineated a long strike-length, north-northwest trending, graphitic conductor termed the Saskatoon Lake Conductor (SLC). By the mid-1990s, further geophysical work extended the conductor's known strike-length to over 25 km.

Diamond drilling of the SLC began in 1992 and drillhole SHE-2 intersected favorable alteration (dravite, drusy quartz, chlorite) and minor graphitic, shear-zone-hosted, uranium mineralization (0.7 meters @ 0.6% U). Drilling to the north along the conductor led to the discovery of the Anne Zone

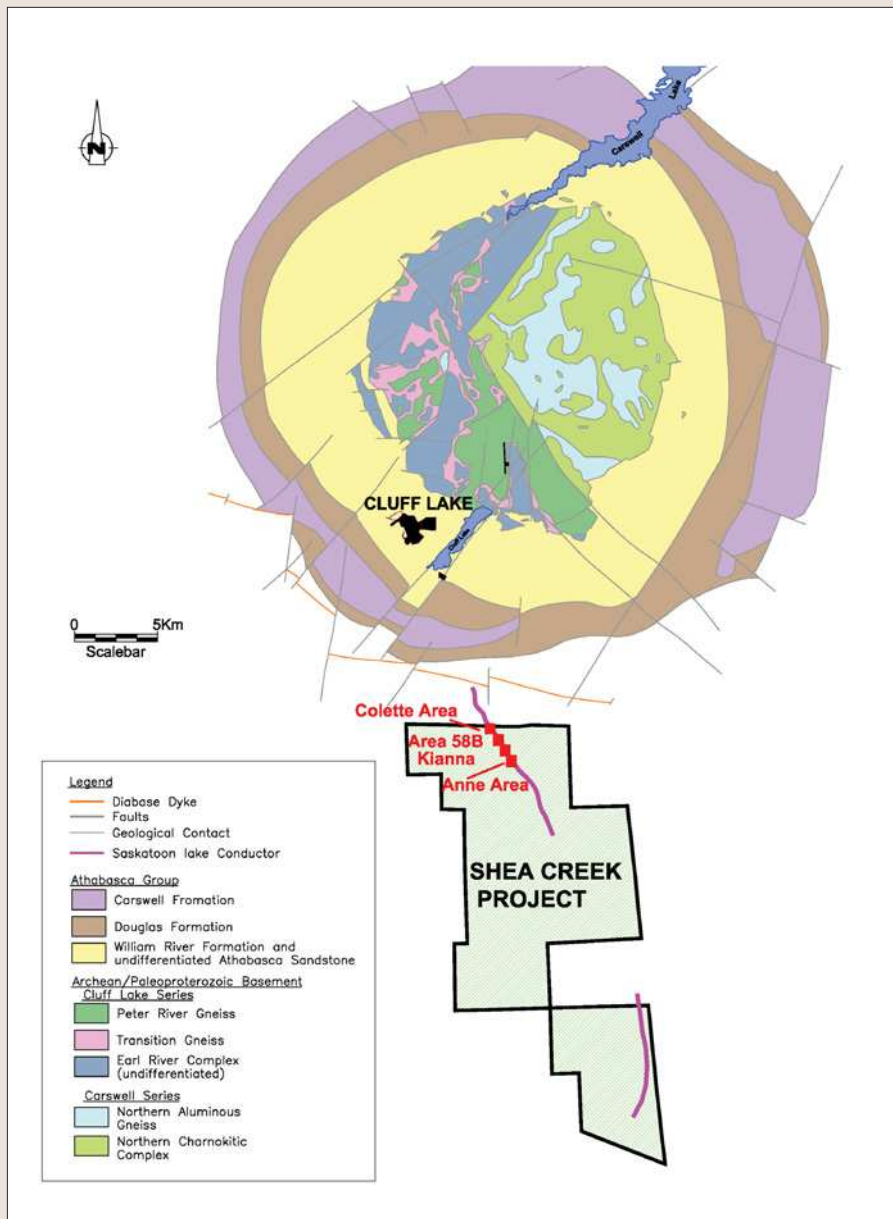


Figure 3. Project location map.

in 1995, the Colette Zone in 1997, and the Kianna Zone in 2000. In 2004, COGEMA signed a joint venture agreement with UEX Corporation to continue exploration along the Shea Creek trend.

In 2004, an aggressive exploration strategy was undertaken with the completion of regional airborne EM and gravity gradiometer (MEGATEM and FALCON) surveys flown over large areas of the western Athabasca Basin. Since 2004, a number of ground surveys have been completed over the Shea Creek deposit, including acquiring a large 3D pole-pole array dc-resistivity block, transient audio magneto telluric (TAMT), TITAN 24, and a UTEM double-loop EM survey.

Regional geological and geophysical setting. The northern part of Saskatchewan is underlain by rocks of the western Canadian Shield, comprising Archean and Proterozoic high grade metamorphic crystalline basement that is, in part, unconformably overlain by late Paleoproterozoic sedimentary rocks of the Athabasca Basin and Phanerozoic sedimentary rocks of Western Canadian Sedimentary Basin

(Figure 1). The crystalline basement is subdivided into the eastern Hearn Province and western Rae Province along the Snowbird tectonic zone. The Rae Province is further subdivided, south of the Grease River Shear Zone, into the Tantato, Lloyd, and Clearwater Domains, the latter cross-cutting the Lloyd Domain from southwest to northeast. The Shea Creek and Cluff Lake uranium deposits lie within the western Lloyd Domain of the Rae Province.

In the Shea Creek region, the Athabasca basement comprises a granulite facies metamorphic succession of upper felsic quartzofeldspathic gneiss, middle aluminous (pelitic) gneiss, and lower felsic gneiss (Figure 4.) The felsic gneisses also contain biotite ± garnet, while the aluminous gneiss are variably pelitic in composition with quartz, biotite, and garnet, ± graphite and cordierite

The William River Subgroup, the lowest part of the Athabasca Group, is present in the Shea Creek region. It is dominated by fine- to coarse-grained, variously pebbly quartz arenites. Clay interclasts are common in some formations. Subordinate pebble- and cobble-conglomerate are also present in addition to minor mudstone and clay-rich beds. The depositional environment is interpreted as a series of fresh-water, fluvial, braided stream systems that evolved in response to changing uplift/subsidence relating to regional tectonics and basin-fill.

The structural styles and ages of the sub-Athabasca basement rocks vary substantially and include early regional ductile and brittle-ductile structures that predate the deposition of the Athabasca Group, as well as syn- and post-Athabasca brittle structures.

Subsequent tectonic events during Phanerozoic time have reactivated some of these earlier structures. At Shea Creek, the brittle structures that postdate the deposition of the Athabasca Group are considered favorable loci for exploration activity. The intersections of the early and late structures provide the necessary “plumbing” to bring uranium-bearing oxidized sandstone brines in contact with reduced basement fluids to produce the redox-related uranium deposits.

The Shea Creek structural trend is defined by the Saskatoon Lake conductor (SLC), a northwest-southeast/, southwesterly-dipping graphitic zone. The conductor, interpreted to be a large-scale reverse (thrust) structure oriented parallel or sub-parallel to the main foliation, dips moderately (30–50°) to the southwest. In local terminology, it is commonly referred to as the “R3” structure. It is the earliest mineralization-related structure. The Colette, Kianna, and Anne deposits all lie on, or are adjacent to this structure.

The weak, polymetallic uranium mineralization at Shea Creek is considered to be a good representation of the “dia-

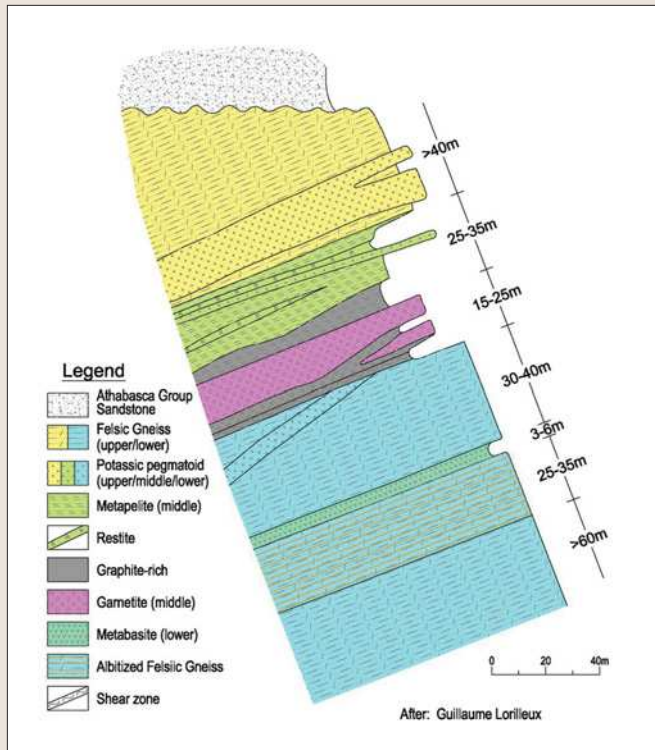


Figure 4. Stratigraphic section (from Baudemont and Lorilleux, 1998).

genetic-hydrothermal unconformity-type” model of deposition in which saline, oxidizing, uranium-bearing fluids mix with reducing fluids along structural corridors and deposit uranium along “redox” boundaries (Hoeve and Sibbald, 1978, Hoeve and Quirt, 1984, 1987). The locus for fluid mixing typically occurs near the sandstone-basement unconformity, but may occur at significant distances above and/or below the unconformity. Such is the case at Shea Creek, where three different, yet commonly overlapping, styles of mineralization have been identified: perched mineralization in the sandstone, mineralization around the unconformity, and basement mineralization.

Mineralization-related, host-rock alteration is made up of a variety of features in both sandstone and basement lithologies: desilicification, silicification, illitization, chloritization, bleaching, hematization, and tourmalinization. These alteration features are superimposed on diagenetic alteration present in the sandstone, paleoweathering alteration of the basement, and retrograde metamorphic basement alteration.

Regional geophysics. Prior to most exploration programs, regional airborne geophysical surveys are undertaken to determine the underlying lithologies and structures. Historically, exploration for uranium mineralization in the Athabasca Basin has concentrated on discriminating Archean metasediments from Archean granites using airborne magnetic and electromagnetic surveys. The metasedimentary rocks generally display low magnetic susceptibilities and are usually conductive because of the presence of graphite. Archean granites for the most part display higher magnetic susceptibilities and are considered non-conductive. Figures 5 and 6 illustrate examples of airborne magnetic and electromagnetic surveys. The Shea Creek mineralized zones occur in a magnetic low adjacent to a linear EM response interpreted to represent conductive Archean metasedimentary basement rocks. The magnetic values range from -380 nT (blue portion) to 880 nT (pinks). The apparent conductance values range from 11 000 μS (blue) to over 1 78 500 μS . (pink portion).

Ground geophysical surveys. Following airborne geophysical surveys, ground-based geophysical surveys are undertaken to accurately locate and resolve structure and Precambrian basement conductive trends. Conductors are detected and located using various EM arrays while resistivity surveys are used to map structural zones and alteration haloes in the sandstone that are associated with hydrothermal alteration. dc-resistivity surveys are effective in mapping these alteration haloes to depths of at least 700 m. However with increasing depth to basement, AMT techniques are used to extend the depth of investigation to > 1 kilometer.

UTEM III Survey. The UTEM system is a step response system where the data are normalized to the primary field and then reduced to channel 1 to remove topographic and loop-size effects. UTEM data are traditionally normalized to channel 1 by subtracting the channel 1 response from all other channels. For EM responses that contain a channel 1 EM response, channel 1 data

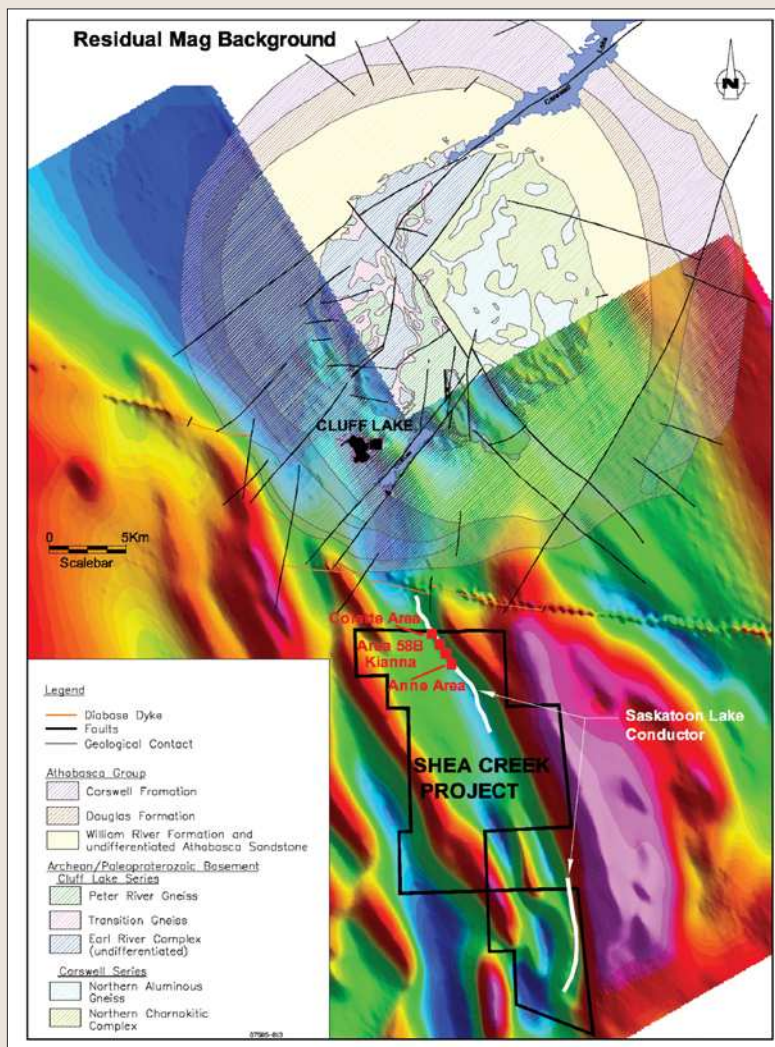


Figure 5. Regional residual airborne magnetics, Shea Creek Area.

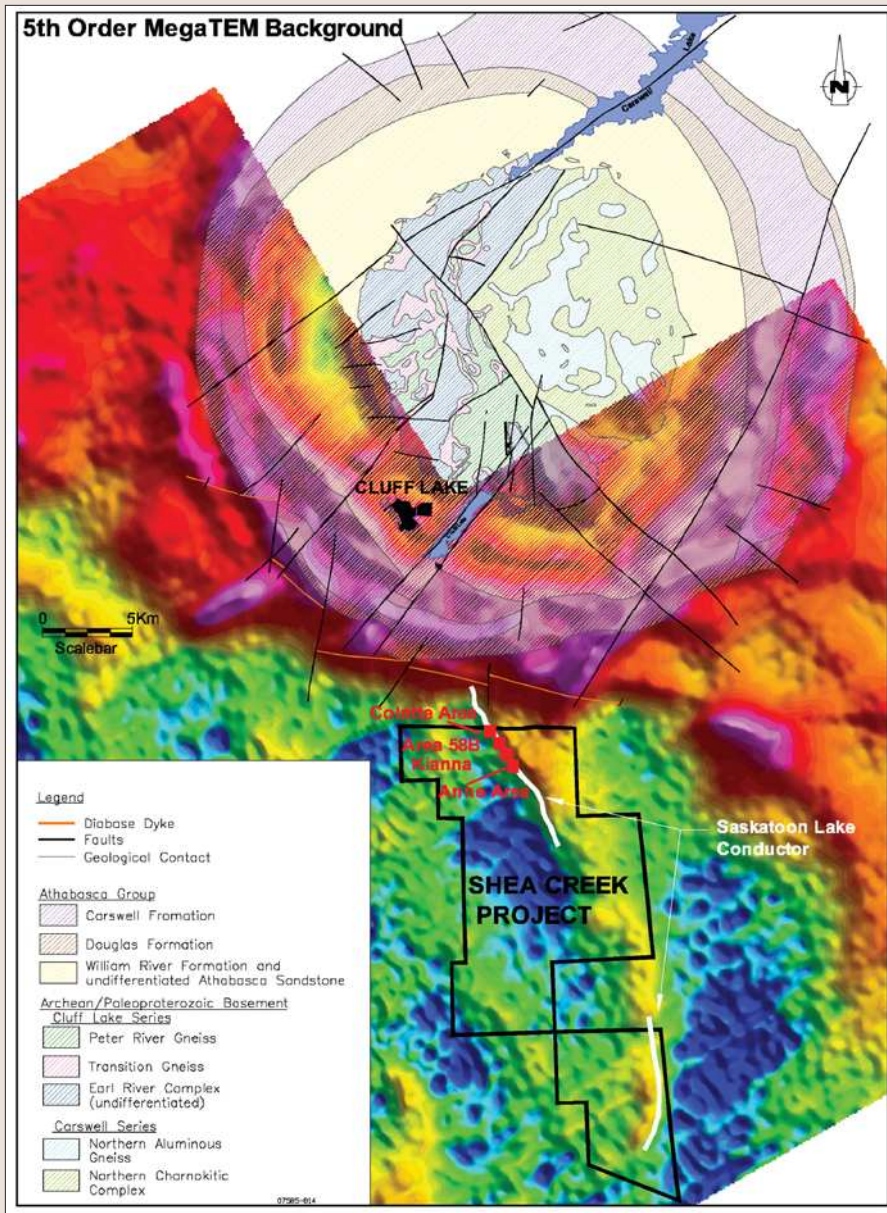


Figure 6. Apparent conductance derived from fifth-order moment B field Z data, Shea Creek area.

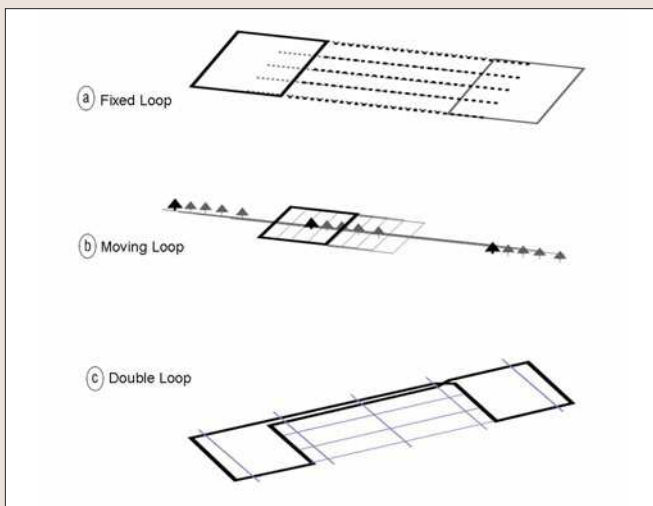


Figure 7. Common EM arrays.

should be filtered as required and added back into the other EM channels. Measurements obtained from selected areas in the Athabasca Basin suggest ranges of Tau from <5 for poor conductors to >10 for good conductors. The response parameter " τ " (tau) obtained by this process is then used in simple approximation formulas to determine conductance.

Normally, the output current transmitted into the loop wire is accomplished using a continuous triangular waveform operating at a frequency of 31 Hz. Its signal in the ground is sensed by a ferrite core coil that responds to the time derivative of the local magnetic field (step response). For each component, 10 time channels are sampled that span an interval from 25 microseconds to 12.8 milliseconds. These data are digitally recorded within the receiver unit. Figure 7 illustrates the loop arrays normally used to collect the EM data.

Fixed and moving loop EM surveys. In fixed loop mode, the UTEM system makes use of large fixed rectangular loops. The loop size used is dependent upon the target depth. Loop sizes can range from 400 x 400 m for shallow targets and up to a size of 2400 x 2000 m for deep conductors. In the fixed loop mode, the profile data can be presented either continuously or point normalized. In the case of continuously normalized data, the component values (H_x and H_z) are reduced using the total primary field at each respective survey point, while for point-normalized data, a constant primary field value is used at all stations on that particular line. The point-normalized data preserve the shape of the anomaly and are used

for interpretation. Continuous normalization equalizes the amplitude of the response with respect to the location along the survey line. It is a good method for quickly determining the presence of a conductor.

In the moving loop mode, all data are continuously normalized. Two receivers are generally used to collect the data. The size of the loop and the positioning of the two receivers are dependent upon the search depth. For small loop sizes, the magnetic field approximates a magnetic dipole as observed by a distant receiver, however the dipole moment is small and for deeper targets it is necessary to increase the dipole moment by increasing the loop size. Receivers positioned at a large distance from the transmitting loop tend to degrade the anomaly resolution. The best location for the receiver with the conductor geometry is obtained where the primary field lines cross the conductor at right angles. A general rule of thumb is that the loop size should approximate the search depth, while the distance from the center of the loop to the receiver should be approximately twice the con-

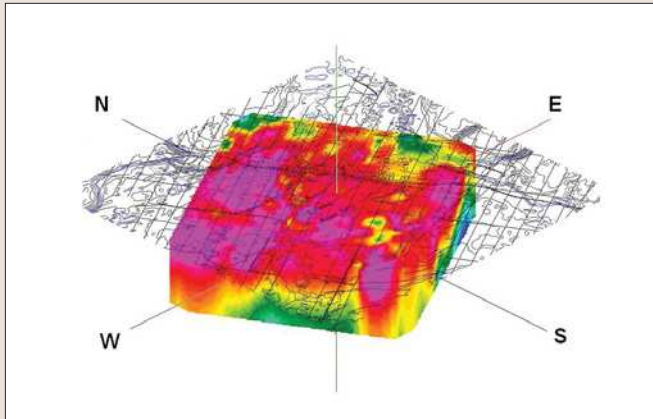


Figure 8. Shea Creek 3D resistivity block model.

ductor depth.

During field operations, the transmitting loop moves in step with the two receivers along the cut lines. The plotting position is the midpoint between the center of the transmitting loop and the receiver. The anomalous response in the Hz profile data is comparable to a conventional HLEM-type trough response with corresponding positive shoulders. The conductor is in the center of a trough. In the Hx profile data, the center of the conductor is normally located on the steeper flank of the Hx (inflection point) positive anomaly peak.

Double loop EM survey. A double loop EM survey was completed over L72+00N and L76+00N (Kianna deposit). Two rectangular transmitter loops (1200 x 1000 m) were offset at a distance of 2400 m and connected such that the primary field in one loop was positive, while the primary field in the second was negative. After reading the two lines using the double-loop configuration, the loops were disconnected and the lines were re-read from both fixed loops separately.

The receiver advanced with 50-m stations over the center of the lines and 100-m intervals nearer the loops. Ten channels, at a base frequency of 30.974 Hz, of both the vertical (Hz) and inline horizontal (Hx) magnetic field components were measured. A minimum of 2 x 4096 (4K) half-cycles of the waveform were stacked at each station.

The utility of the EM methods is to better locate the conductor in an "across strike" or "lateral" sense.

dc-resistivity survey. The dc-resistivity survey was completed in two phases in the fall/winter of 2004 and the summer of 2005. The summer phase allowed the contractor to collect data over land-based areas, while the winter phase allowed data to be collected over the frozen lakes and rivers. For this program the pole-pole array was chosen. Compared with other arrays, the signal strength measured with the pole-pole array decreases less rapidly when the dipole separation factor (n) is increased. The pole-pole array used shows a maximum theoretical depth penetration equivalent to the largest separation measured.

The receiver voltage (V) measurements are taken in line at an "a" spacing of " $n \times a$ " distances from the current source. A receiver "a" spacing of 150 m with $n = 1-7$ were used to collect the pole-pole data. For each receiver spread, the current electrode advanced at 50-m intervals, measuring n values of 0.5, 1.5, 2.5, 3.5, 4.5, 5.5, and 6.5 to double the data density.

The survey at Shea Creek consisted of the collection of 17 profiles, each approximately 7 km in length, on lines spaced at 400 m intervals. The infinite poles were centrally

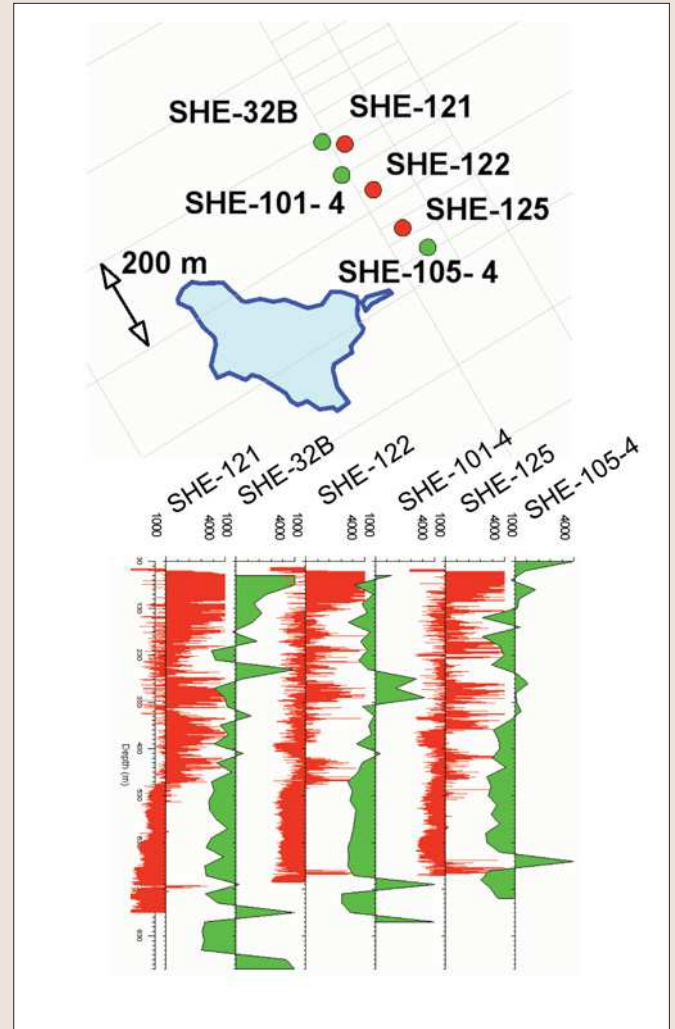


Figure 9. Comparison of downhole resistivity probe and core resistivity values. (Probing is in red, core data in green).

located approximately 7 km southeast and northeast of the survey grid. The "a" spacing for the survey was 150 m and 14 "n" levels were recorded (0.5-7). For the inversion, a total of 9646 data points were imported into the software, which automatically determines a three-dimensional resistivity model for the subsurface using the data obtained from a 3D electrical imaging survey. The inversion routine used by the program is based on the smoothness-constrained least-squares method.

TAMT survey. In the audio bandwidth, the largest naturally-occurring signals are of a transient nature due to electromagnetic radiation from individual lightning discharges. A transient AMT or TAMT receiver captured individual transient events in a time-localized fashion in the range of 5-32 kHz. The transient approach is especially important in times of low source field activity (winter/high latitude) and in general ensures that the highest possible signal-to-noise ratio (SNR) data are obtained.

Adaptive polarization stacking (APS) properly reflects the polarization properties of the source field, sample size, and the SNR in the final Earth response curve estimates and errors. Given typical polarization characteristics of transient data, the APS algorithm displays a higher-order bias convergence than conventional AMT methods (remote-reference) and requires only four channels for essentially unbiased estimation of the impedance tensor or three for

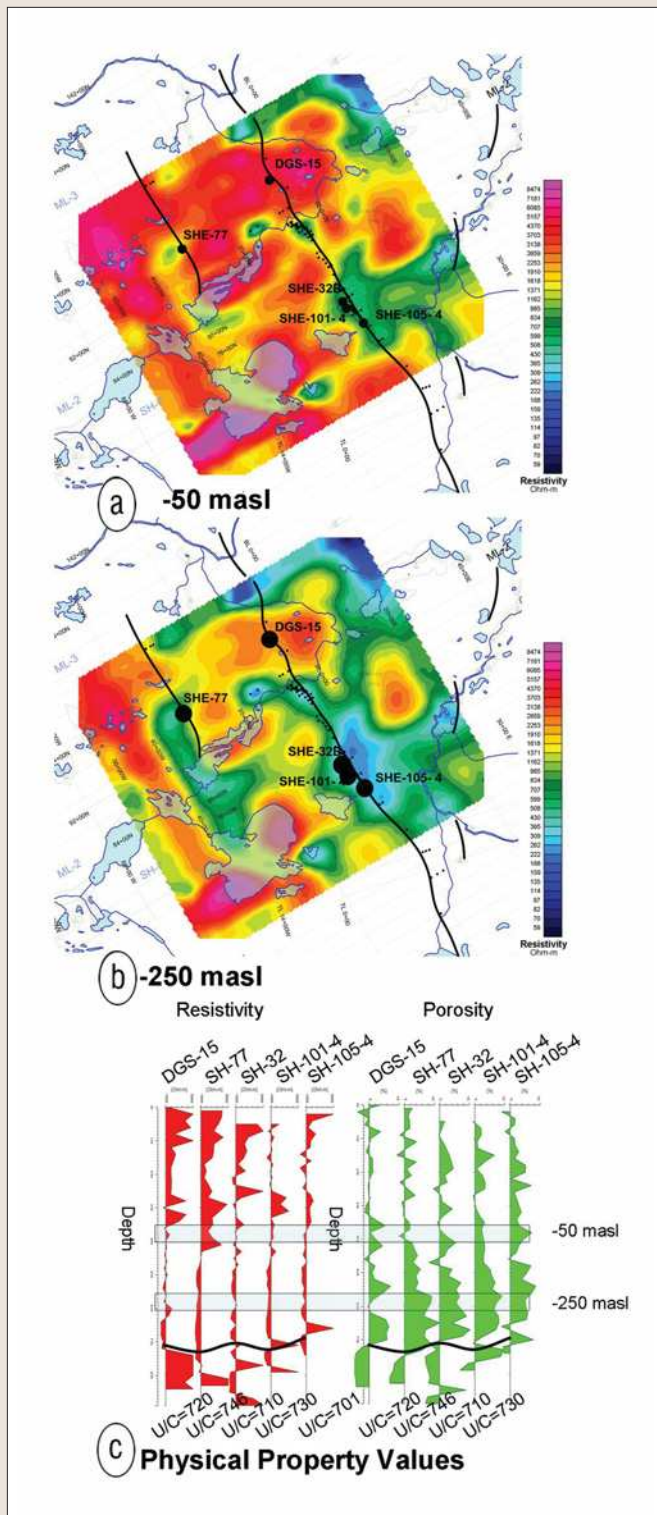


Figure 10. Shear Creek, comparison of apparent resistivity: (a) -50 masl, (b) -250 masl, and (c) physical property values.

the magnetic field tipper.

The transverse electric (TE) mode occurs when the electric field lies parallel to strike. The transverse magnetic (TM) mode occurs when the electric field lies perpendicular to strike. The TE mode is purely inductive, while the TM mode additionally has a galvanic component inherent to its response. This makes the TM mode higher-resolution with respect to defining lateral contacts, and it is more robust to 3D effects associated with conductive structure. However,

when searching for vertical conductors, for example, the TM mode is only weakly excited, while the TE mode can show a very strong response with large spatial extent. Therefore, the interpretational weight of each mode depends on the orientation (vertical, horizontal) and nature of the target (resistive, conductive) and the amount of 3D distortion in the data.

For the Shear Creek program, interpretational emphasis was placed on the tipper for mapping basement conductors and the TE mode impedance for mapping shallow sandstone alteration. The TM mode impedance should be well-coupled to approximately flat-lying or very shallow-dipping, conductive structure at the depth associated with the SLC. The survey used 50 m E field dipoles at each station. Stations were spaced at 100-m intervals along the survey lines. Both E and H field data were recorded at all stations over the deposits while H field data were recorded at 200-m intervals away from the deposits. The reduction in recording the H field data away from the deposits was facilitated to improve survey productivity.

TITAN 24 survey. The Titan 24 system employs a distributed array technology for data acquisition. The Titan system combines tensor magnetotelluric resistivity (MT) and galvanic dc-resistivity and induced polarization (dcIP) surveys. By measuring 24 or more stations simultaneously, Titan can record and process a vast amount of data efficiently. By sampling more data, faster and simultaneously, the system provides increased reliability and accuracy of information compared to other methods.

For the dc-resistivity recordings, an extended hybrid pole-dipole-dipole array was used. The contractor used a receiver configuration whereby 24 inline voltages and 12 crossline voltages were recorded using 150-m dipoles, for an effective array of 3.6 km. The transmitter was frequency domain using square-wave current. The receiver recorded a full-waveform time series with the data processing/output in frequency domain. The AMT used a remote-referenced base station with 24 inline Ex-field dipoles and 12 crossline Ey-field dipoles.

Borehole physical property logging. To verify the results of the resistivity methods, rock physical property measurements were completed on core samples from five drillholes, obtained at 20 m intervals downhole. Downhole resistivity logging was also completed in a series of drillholes in the Kianna area to corroborate the results of the physical property measurements conducted on the core and the results of the surface resistivity survey programs.

For the downhole resistivity logging, a Dual Guard Focused Resistivity Slim Tool Sonde manufactured by GEO-VISTA provided a medium and a deep LL3 focused resistivity log with finer vertical resolution than the traditional normal resistivity sonde.

Discussion. The historical geophysical exploration programs using airborne magnetic and electromagnetic surveys were completed to outline favorable geological settings. A variety of ground-based surveys were then conducted to further refine drill targets. These surveys comprised primarily EM techniques; however, various other surveys were also completed, such as magnetic, gravity, dc-resistivity, among others. Until recently, neither the software nor the computing power required to invert the obtained data were readily available. With the advent of 3D dc-resistivity inversion codes, the exploration approach has changed from ground EM surveys following up airborne EM conductors to completing grid-based dc-resistivity surveys over the identified airborne EM conductors. The dc-resistivity surveys are con-

ducted to outline higher-priority targets longitudinally along the strike of the conductors (particularly the SLC), followed by ground EM techniques to better locate the conductor position laterally across the conductor strike.

Following inversion of the apparent resistivity data, the data were georeferenced and imported into a 3D block modeling program (Figure 8), and subsequent depth slices and vertical sections were derived from this model. For comparison purposes, all the resistivity data are presented with the same logarithmic color scale with a minimum of 50 ohm-m and maximum of 10 000 ohm-m.

Physical property measurements were determined on drill core taken at 20 m intervals down 5 drillholes (DGS-15, SHE-32B, SHE-77, SHE-101-4, and SHE-105-4). The drill hole locations are indicated by large dots in Figure 9. These holes were chosen because they are in areas characterized by low resistivity to moderate resistivity values as outlined in the depth slice. SHE-77 was included as physical properties related to alteration of the sandstones in this drillhole were considered representative of regional background.

The downhole in-situ resistivity values compare very favorably to the resistivity values obtained directly from the core samples. Profiles obtained from the probe (red profiles) and core (green profiles) are presented in Figure 9.

Resistivity values and calculated porosity values are plotted in Figure 10 as profiles for the 5 drillholes along with a -50 masl (300 m above the unconformity) and -250 masl (150 m above the unconformity) depth slices. The porosity profiles for the upper sandstone display low values that appear to be slightly variable, while the lower sandstone exhibits higher porosity values and less variability. The resistivity values show the opposite pattern, with the upper sandstone values being more than 1 000 ohm-m and the values associated with the lower sandstone decreasing to approximately 500 ohm-m. These trends correspond with the dc-resistivity depth slices providing the longitudinal prioritization along the SLC.

Increased clay content and higher fractures (i.e. increased porosity) have been identified in drill core in areas displaying low sandstone resistivity values in other uranium deposits located in the Athabasca Basin.

A vertical resistivity pseudosection obtained from the 3D resistivity block is presented in Figure 11 along with the porosity and resistivity values measured on the drill core from SHE 101-4. Core samples from within the low-resistivity region show an increase in porosity and decrease in resistivity

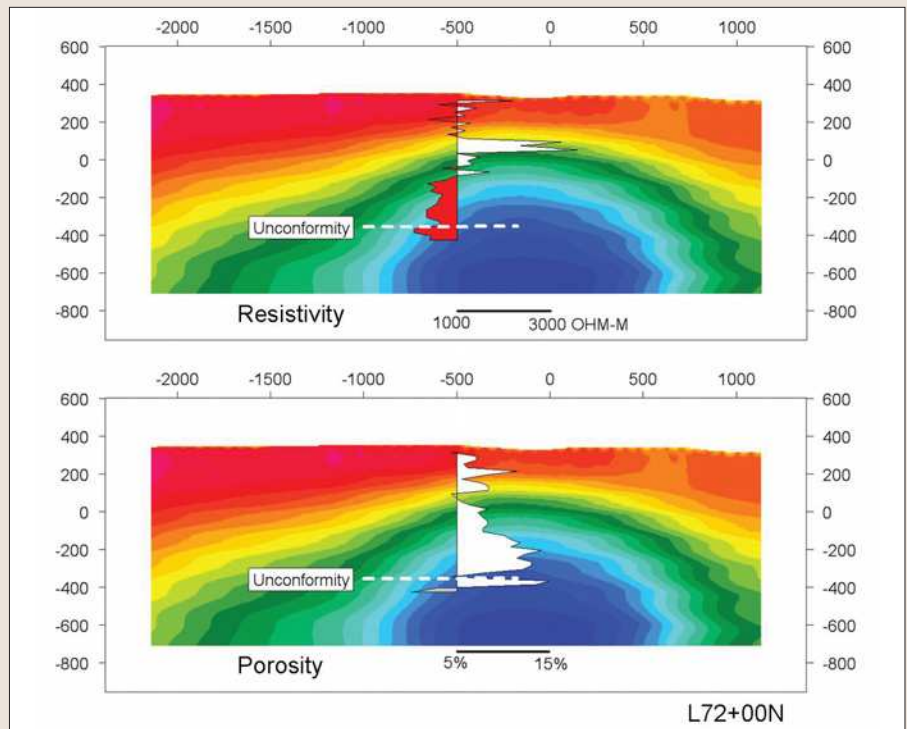


Figure 11. Shea Creek, comparison of apparent resistivity with core porosity and resistivity values.

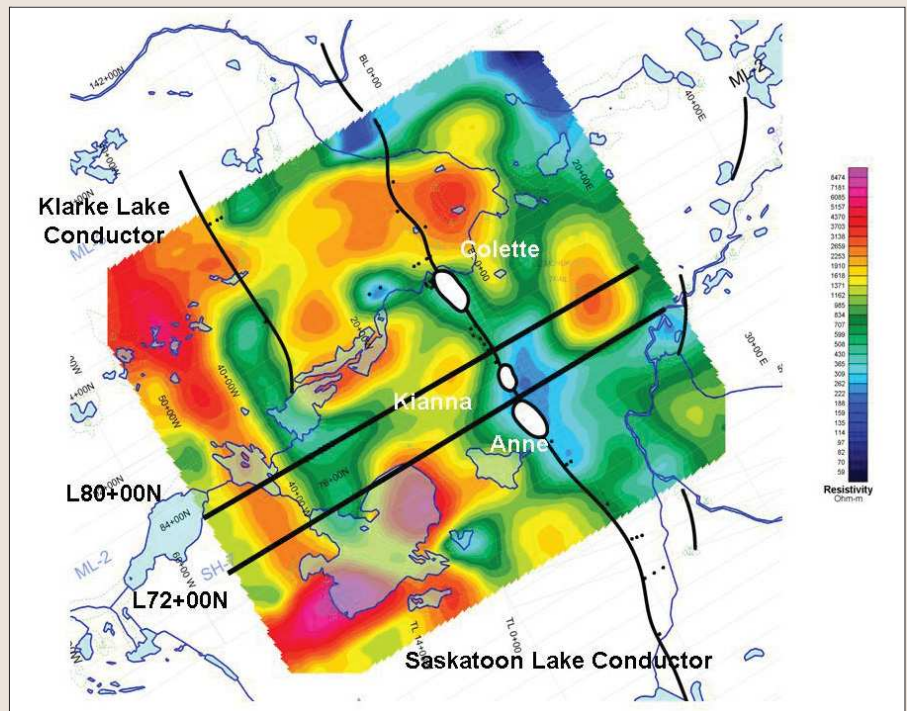


Figure 12. Shea Creek resistivity depth slice at -250 masl (150 m above unconformity).

This correlates well with the dc-resistivity values measured by the surface surveys validating the pole-pole resistivity results. It should be noted that the low resistivity values extend approximately 300 m above the unconformity. The location of the SLC is at approximately 5+00W. The low-resistivity zone located at 35+00W is associated with another known conductor—the Klarke Lake conductor.

A resistivity depth slice at -250 masl was extracted from the 3D resistivity block and is presented in Figure 12. This depth slice represents the resistivity values of the sandstone

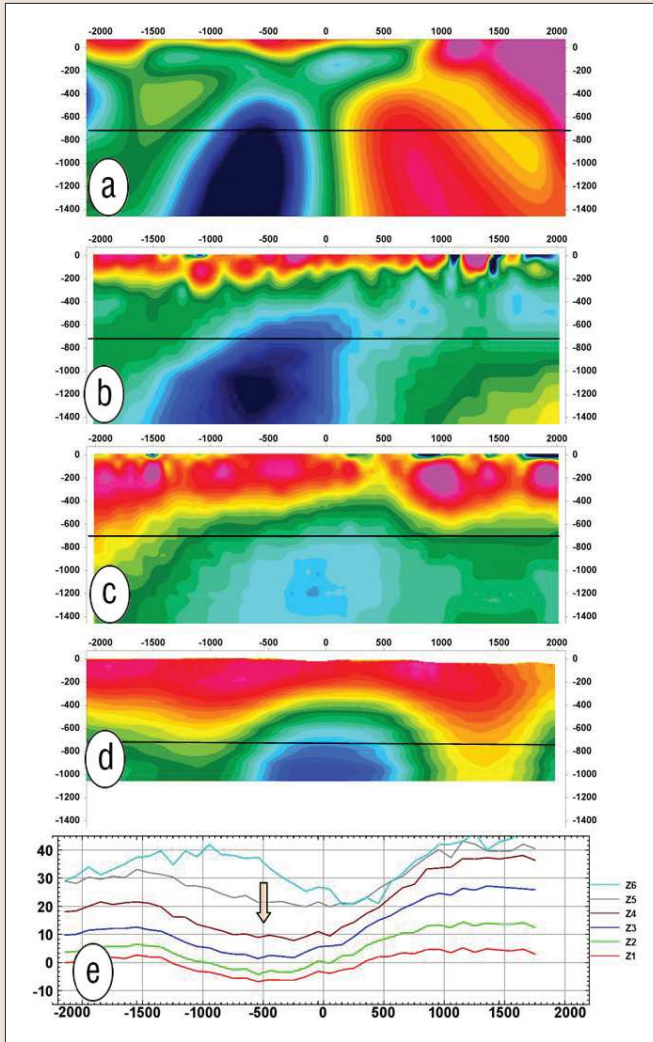


Figure 13. Shea Creek line 80+00 N inversions: (a) Titan 24 RLM TM, (b) TAMD Tipper, (c) TAMD TM, (d) dc resistivity inversion; and (e) UTEM moving loop data.

rocks approximately 150 m above the unconformity. Superimposed on the figure are white ovals indicating the approximate location, from north to south, of the Colette, Kianna, and Anne zones. The black line represents the axial trace of the SLC, while the short line to the west indicates the location of the Klarke Lake conductive trend. Current drilling along both trends are represented as black dots. A distinctive zone of low resistivity values is associated with the three mineralized zones. These values are interpreted to reflect regions affected by structural reactivation and possible associated hydrothermal alteration processes resulting in increased sandstone porosity. Along the northern part of the SLC, elevated sandstone resistivity values between 1000 and 2000 ohm-m suggest that these rocks have not been subjected to significant reactivation processes.

A compilation of the resistivity data obtained from the TAMD, Titan 24, and the dc-resistivity surveys for L80+00N is presented in Figure 13. The top panel (a) represents the 2D inversion results obtained from the Titan 24 survey with the data processed using the Randy Mackie's (RLM) inversion code. The second panel (b) is the 2D inversion results obtained from the TM data collected during the TAMD survey. The third panel (c) is the TE processed data also from the TAMD survey. The fourth panel (d) is the apparent resistivity values obtained from the dc-resistivity survey. The

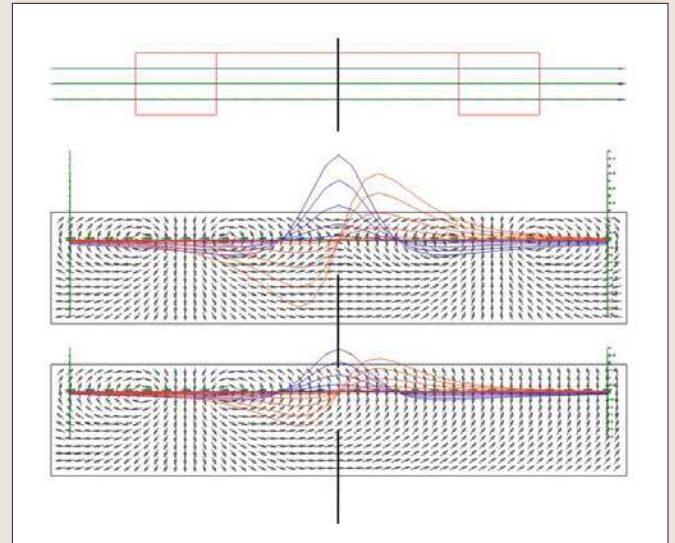


Figure 14. Double loop EM array and primary field vectors (top and middle), and one loop only (bottom, left side).

black lines superimposed on the panels represent the approximate location of the unconformity in the area. The bottom panel (e) is a portion of historical regional profile of large moving loop EM data showing the late time channels measured a receiver offset 2,000 m from the center of an 800 m X 800 m transmitter loop. Station spacing for the profile was 100 m.

The top panel, the RLM TM processed Titan 24 AMT data (Figure 13a), is dominated by a low resistivity zone with values less than 50 ohm-m located at approximately 5+00W with the top of the zone located at a depth of 650 m below ground level. This feature continues to the bottom of the section. West of this prominent resistivity low, the section outlines moderately higher resistivity values between 750 and 1500 ohm-m.

The second panel, showing tipper mode TAMD data (Figure 13b), displays a zone of low resistivity values centered at approximately 5+00W, with a lateral extent from 15+00W to 0+00. This feature extends from the unconformity at approximately 700 m below ground level to the bottom of the section.

This feature is very similar to the resistivity low outlined with the Titan 24 system. One major difference between the apparent resistivity values displayed in Figure 13a and Figure 13b is the Titan data outlined a broad resistivity high between 0+00 and 15+00E. The TAMD processed data outline a less intense resistivity high located at the eastern end of the line at the bottom of the section. The differences may be attributed to different survey equipment, survey parameters, and inversion codes.

TM mode TAMD data (Figure 13c) displays a broad zone of resistivity low values along the bottom half of the section that are associated with the basement rocks. Located between 0+00 and 5+00E and from approximately 200 m below ground level extending to the interpreted unconformity, the section outlines low resistivity values within the sandstone units.

Figure 13d is a section extracted from the 3D dc-resistivity pole-pole survey. The section is dominated by a relatively homogeneous resistivity high that extends from surface to the unconformity except between approximately 5+00W and 5+00E. The resistivity values for the near surface zone range from 2000 to over 5000 ohm-m.

Both the Titan 24 and TAMD surveys outline low resis-

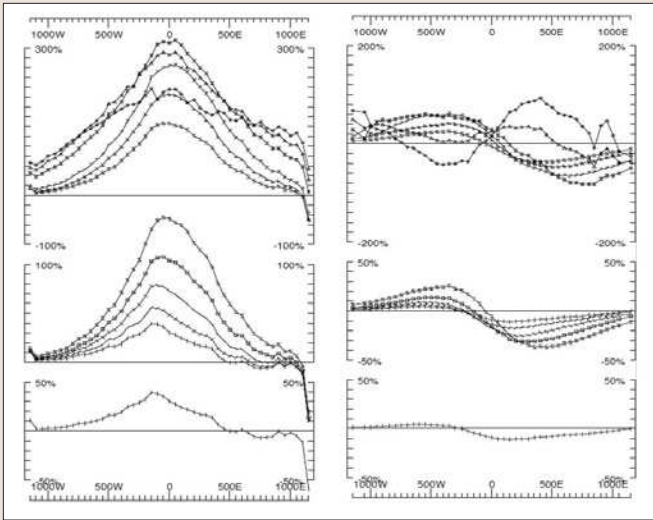


Figure 15. Shea Creek L72+00N: Double loop UTEM III, inline horizontal and vertical (right) components (L72+00N).

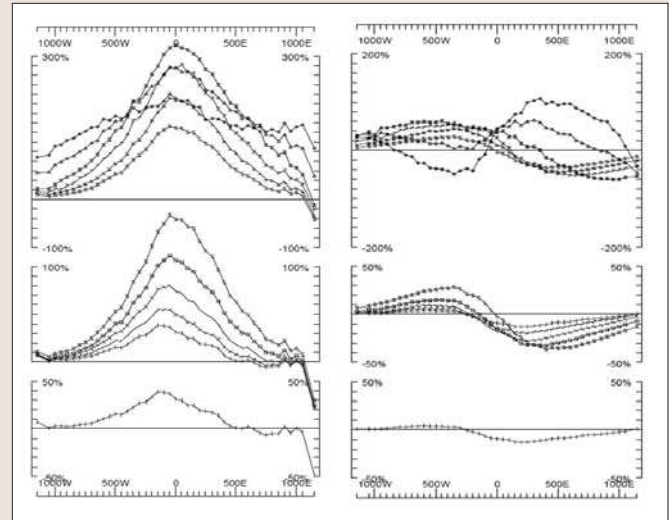


Figure 16. Shea Creek L72+00N: Combined double loop UTEM III, inline horizontal and vertical components.

tivity zones within the basement that correlate with the location of the SLC. The surveys also appear to outline a localized zone of low resistivity values within the sandstone units between 0+00 and 5+00E. This layer is interpreted to represent unaltered fresh sandstone rocks. The low resistivity zone above the approximate location of the unconformity may represent evidence of hydrothermal and structural reactivation events that have affected the sandstone in this region.

The UTEM Slingram profile (Figure 13e) displays a strong migration of the EM fields from Z5 (mid-time channel) to Z1 (late time channel), where the later time channels focus on the basement SLC at 5+00W. There have been numerous internal discussions regarding the source of the mid-time anomaly at 3+00E to 5+00E. It has been postulated that a weak, poorly graphitic basement conductive trend is the source of the mid-time response. It corresponds to the location of the resistivity low outlined by the dc-resistivity and TAMT TM-mode data. There does not appear to be any basement TAMT TE-mode response associated with this mid-time channel, and as such, this feature is likely related to a source within the sandstone.

The configuration of the double-loop EM array employs two separate fixed loops connected in series with opposite polarities to increase the amplitude of the primary field at the conductor at depth, over what would be achievable with a conventional fixed loop array.

As well, the array increases the region within the earth where the primary field would be optimally coupled to vertical conductors. Figure 14 presents a model comparing the conventional fixed-loop array to the double-loop array. Continuously normalized Hx and Hz profiles of the double loop results are presented in Figure 15 for L72+00N. The single fixed Loop data are merged into one Combined double-loop EM data set in Figure 16.

Both the Hx and Hz components of the double-loop and Combined double-loop EM results are extremely similar in their response. This would indicate that there is no need to physically connect the loops together to increase the primary field to energize basement conductors. The primary disadvantage of using separate loops and combining the data would be that the survey line has to be read from both loops doubling the survey time.

Conclusion. Physical property studies conducted on drill core corroborate the dc-resistivity results. It appears that AMT is also capable of delineating resistivity lows within the sandstone units that may reflect hydrothermal alteration zones.

Combined dc-resistivity and AMT surveys are effective exploration strategies in deep-basin environments to outline basement conductors.

The downhole resistivity probe data and the physical property resistivity values measured on the sandstone compare very favorably with the surface resistivity data. This further supports the conclusion that the resistivity values and apparent depths obtained from the inversions are reasonable.

The 3D dc-resistivity survey over the Shea Creek deposit clearly images an intense resistivity low apparently located in the lower sandstone. This low-resistivity region may be interpreted to represent structural reactivation associated with possible hydrothermal alteration along the EM conductor—a favorable loci for uranium mineralization. Resistivity surveys are thus an effective way to prioritize airborne EM targets and to optimize drilling programs by providing locations of high priority portions along the SLC.

Historically, a common approach to exploration projects was to fly to prospective areas with airborne EM and magnetic surveys to identify favorable basement conductors and magnetic lithologies. This was followed by ground-based EM surveys to verify the airborne results. This approach resulted in identification of portions of the conductor that have a long time constant indicating higher conductivity. Conductors exhibiting high time constants are considered higher priority targets. There was little attempt to upgrade these targets by obtaining evidence of hydrothermal activity and structural reactivation associated with the basement conductors. This historical approach has changed as a result of the great improvements that have been made in geophysical modeling software and data acquisition hardware.

Present and future exploration projects use, or will use, a more integrated approach, including acquisition of airborne EM surveys combined with high sensitivity magnetics and airborne gravity gradiometry and current geological knowledge. Priority airborne targets are then followed up on the ground using either dc-resistivity or AMT depending on the required depth of investigation. Positive results—identification of anomalous regions along the strike of the conductor trace—provide the location(s) for focused ground EM surveys which then provide better locations of the conductor across the strike of the airborne conductor trace.

This approach will provide improved vectoring to the highest priority drill targets while reducing the drilling time along less prospective portions of otherwise lengthy conductor traces.

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