An ORION 3D DC/IP survey was conducted over the Denison Mines Phoenix Uranium Deposit at the Wheeler River Project in Northern Saskatchewan. The survey results provided 3D models that successfully delineated the known deposit at a depth of 400 m and provided an enhanced understanding of the three-dimensional geometry of the area NE of the deposit. In addition, significant differences in the characteristics of the rock units below and above the unconformity were accurately imaged.

**INTRODUCTION AND HISTORY**

The Wheeler River Property, comprising the Phoenix and Gryphon uranium deposits, is located in the southeastern Athabasca Basin, approximately 600 km north of Saskatoon, in northern Saskatchewan (Figure 1).

**Table 1.** Historic progression of work in the deposit area (after Roscoe, 2015).

<table>
<thead>
<tr>
<th>Year</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1978-present</td>
<td>The area was previously explored by AGIP and SMDC ( Cameco). Since 1978, several airborne and ground geophysical surveys have defined 152 km of conductor strike length in fourteen conductive zones.</td>
</tr>
<tr>
<td>1986-1988</td>
<td>AGIP, SMDC, and Cameco drilled a total of 192 drill holes encountering sub-economic uranium mineralization in the M Zone (1986), O Zone (1986), and K Zone (1988). Rare earth element mineralization was also discovered in the MAW Zone (1982).</td>
</tr>
<tr>
<td>2004</td>
<td>Denison assumed operatorship in 2004 and initially focussed on the footwall side of the quartzite ridge (west side of the Property) intersecting sub-economic uranium mineralization.</td>
</tr>
<tr>
<td>2008</td>
<td>In 2008, three resistivity targets were drilled leading to the discovery of the Phoenix deposit.</td>
</tr>
<tr>
<td>2008-2012</td>
<td>During the period 2008 to 2012, drilling predominantly focussed on defining the Phoenix deposits.</td>
</tr>
<tr>
<td>2012-present</td>
<td>Subsequent drilling has discovered the Gryphon deposit.</td>
</tr>
</tbody>
</table>

**PHOENIX AND ORION 3D**

The Wheeler River Property lies in the southeastern part of the Athabasca Basin where undeformed, late Paleoproterozoic to Mesoproterozoic sandstones, conglomerates, and mudstones of the Athabasca Group unconformably overlie early Paleoproterozoic and Archean crystalline basement rocks. The Phoenix deposit was discovered in 2008 and contains a significant uranium mineral resource.

**THE PHOENIX DEPOSIT**

The local geology of the Property is consistent with the regional geology of the Athabasca Basin. The Phoenix deposit occurs at the unconformity between the Athabasca Basin and basement rocks, approximately 400 m below surface (Figure 2). The sandstones are altered 200 m above the unconformity. Alteration is focussed along structures propagating upward from the shear and does not exceed 100 m width across strike.
Figure 2. Schematic cross-section through the Phoenix deposit (after Roscoe 2014).

Figure 3 shows photos comparing the sandstones above the unconformity with the character of the deposit.

Figure 3. Photos of core of overlying sandstone (upper) and Phoenix deposit (lower between arrows) in the unconformity domain (after Reipas, 2016).

THE ORION 3D SURVEY

The ORION 3D method is an evolution into 3D acquisition based on the successful characteristics of the TITAN 24 system. This distributed multi-parameter data acquisition system penetrates deeper than conventional geophysics using a combination of DC Resistivity, IP, and MT. Typical depths of exploration are 700 – 1,500 m. The surveys are effective for exploration at long offsets, and in noisy or mine site environments due to a combination of performance features such as 100% duty cycle transmits, high data density from combined Pole-Dipole and Dipole-Pole, monitoring of the current using an acquisition channel, time-series data acquisition and digital signal processing resulting in approximately 2000 samples per half-cycle (4 seconds), 24-bit sigma-delta filtering, a high input impedance (80 Mohm) and a sophisticated calibration model (for AMT).

ORION 3D is an omnidirectional DCIP and MT system that collects resistivity and IP data simultaneously across an array of receiver dipoles. The ORION 3D paradigm prefers an equal distribution of in-line and cross-line dipoles. This survey design allows data to be collected without geometry (or strike) bias and is the fundamental innovation of the ORION 3D method. Conceptually, the 3D inversion method progressed as follows: First, 2D survey lines were provided to the 3D inversion engine. It was quickly realized that 3D inversion of these data provided little additional information versus 2D inversion. The reason is that there is little cross-line information content. Next, 2.5D surveys were conceived where transmits might be offset from the receiver array, or 3 or 5 parallel receiver arrays might be deployed while the transmits occur on the center line. This provides crossline information and enhances understanding of the deep part of the model, but shallow information may be compromised because the small n-spacings are null-coupled. This is particularly true if the transmits are never run on the receiver lines (i.e. the transmits are only run between the receiver lines). One method to overcome the cross-line null coupling of small n-spacings and preserve the shallow information is to run cross-line dipoles. These may be run on a few tie lines, or, in an ultimate sense, be deployed in equal numbers in both in-line and cross-line directions. ORION 3D was conceived in this ultimate sense. Figure 4 shows one of the six-channel autonomous loggers that are distributed during an ORION 3D survey.

The six channels are configured with dipoles, three in each of the two orthogonal directions.

Data at Phoenix were collected using a layout (Figure 5) consisting of 294 @ 100 m sized receiver dipoles (Figure 4) and 297 current injections, resulting in over 140,000 data points to investigate a 2.1 km by 2.1 km area. Data were processed with Quantec’s proprietary software, and inverted using UBC 3D (Li and Oldenburg, 2000), Loke (Loke 2001) and ERTLab (Fischanger and LaBrecque, 2006) inversion codes. The resulting DC resistivity models provided information well below the unconformity at 400 m depth.

Figure 4. ORION 3D six-channel autonomous logger in green showing an ideal 3D deployment of three in-line and three cross-line dipoles.

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SURVEY RESULTS

The 3D survey mapped the WS conductor in correlation with the Phoenix deposit (Figure 8). The resolution and accuracy of the ORION 3D survey is demonstrated in Figure 9, showing the difference between images from above (UC+100) and below (UC-100) the unconformity.

Figure 7. Resistivity colour distribution for the following figures.

Figure 8. Resistivity cube after inversion, looking north.

Figure 9. Resolution above and below the unconformity showing (upper left) basement topography at the unconformity; and plan view of resistivity layer extracted from the inversion cube at (upper right) the unconformity, (lower left) 100 m above the unconformity and (lower right) 100 m below.

Figure 10. Comparing plan views of resistivity at (left) the unconformity horizon and (right) 100 m below the unconformity horizon, from inversions of (upper) stitched 2D survey and (lower) the Orion 3D survey.
When the historical 2D results are compared with 3D results (Figure 10) the character of the basement is much better resolved and additional features are mapped in the latter. High and low resistivities are more intensely separated, and edges are better defined. The complex strike directions mapped in 3D are consistent with foliation mapping (Figure 11) from drill results.

Figure 11. Foliations from drilling plotted on 3D view shown in Figure 9
Decomposition of the data into line directions permits confirmation that the 3D information is preserved. The cross-line direction is parallel to general strike and the WS conductor width is less well-defined, but truncation is perhaps more consistent with the strike length of the deposit. Figure 12 shows the 3D inversion results of decomposed datasets.

Figure 12. 3D inversion results of the decomposed datasets shown at 455 m depth – complete ORION3D dataset (left), in-line oriented dataset (center) and cross-line oriented dataset (right).

CONCLUSIONS
The high resolution of the 3D models obtained from the ORION3D survey provided geophysical results that were VERY consistent with the KNOWN basement and overlying geology. The correlation between the ORION3D inverted data and the drill hole information (foliation directions and major contacts in particular) is very good and helps resolve the geology in areas where the 2D acquisition failed, in part due to line orientation (oblique to geologic strike). The 3D models displayed more detail and reflected the geometry of the geologic system better than previous results from 2D surveys.

MT and IP results are also available from the ORION 3D survey. Decomposition of the dataset has improved the understanding of the information in the dataset.

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References

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