Paper 109

Recent Development in 2D and 3D Seismic Imaging of High-Grade Uranium Ore Deposit Related Environments, in the Eastern Athabasca Basin, Canada

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ABSTRACT

The diverse and often strongly deformed assemblages of igneous and metamorphic rocks, of variable ages, host important mineral resources at variable depth (Eaton et al., 2003). Mapping of these subsurface environments can be extremely challenging. Recent seismic 2 and 3D reflection surveys in the uranium district of the eastern Athabasca Basin successfully outline the 3D subsurface setting of known ore deposits, revealed new previously unrecognized, target areas and determine the complexity of the ore related structural framework. In the active exploration district of the Russell Lake area, intersecting seismic profiles outline regional and local structural settings highly comparable to surroundings of known ore deposits, establishing specific drilling targets zones in depth. The results also demonstrate that some modifications are necessary, in both of the data acquisition and data processing phases of the reflection method, to achieve its successful implementation for exploration in the Athabasca Basin.

INTRODUCTION

In the past decade a number of high-resolution and regional multi-channel seismic reflection investigations were initiated, in the Athabasca Basin. The first was under the auspices of the AREVA (COGEMA) RESOURCES. This was followed by the highly successful EXTECH-IV Athabasca Multidisciplinary Uranium Studies Program and more recently by the support of Hathor Exploration Ltd. The two overall goals of the seismic program are to develop a functional seismic technique as an efficient tool for uranium exploration, and to contribute to the four-dimensional geoscience framework for uranium exploration within the deeper recesses of the Athabasca Basin. More specifically, objectives of the high-resolution 2D and 3D surveys were: 1) to define the basement structures underlying the basin; 2) to map the stratigraphic architecture of the Athabasca Group Sandstone; 3) to image the sandstone/basement unconformity; 4) to locate faults controlling the uranium deposits; 5) to establish possible relationships between sedimentation and deformation and 6) to determine the seismic signature of a known uranium deposit.

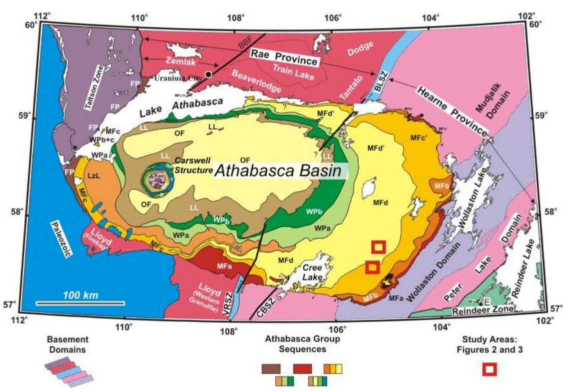

Figure 1: Geological framework of the Athabasca Basin with the location of the study areas, the McArthur River mine site (2) and Russell Lake area (3); more details on Figures 2 and 3.

GEOLOGIC FRAMEWORK

The Mesoproterozoic Athabasca Basin (Figure 1) consists of a maximum 1500 m thick succession of mainly fluvial-continental deposits, referred to as the Athabasca Group Sandstones. It is dominated by quartz-rich sandstones of varying grain-size

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associated with braided rivers and sheetfloods (Gyorfi et al., 2007). These Mesoproterozoic clastic sequences are overlying unconformably the medium-to-high grade metamorphic rocks of the Mudjatik and Wollaston basement rocks deformed mainly under ductile conditions during the Paleoproterozoic Trans-Hudson Orogeny (THO, 1.9-1.8 Ga). Later brittle deformational events have overprinted and partially reactivated the ductile basement structures (Hajnal et al., 2005).

The studied region is located close to the SE margin of the Athabasca Basin. The dominant orientation of regional basement structures is NNE-SSW (Figure 2). The P2 structural zone, hosting the high-grade uranium occurrences, at the McArthur River site, follows the same trend and is delineated in the study area by more than 50 boreholes. The following points are summarizing the key geological factors affecting data acquisition, processing and interpretation:

1) Presence of low-velocity glacial deposits with variable thickness in the survey area (Gyorfi et al., 2007). They are not only the cause of travel-time delays, but are the main source of shallow reverberations overprinting the seismic observations.
2) The Athabasca Sandstone was deposited entirely in continental environments. Subtle changes in the depositional conditions (channel, levee, overbank, sheetfloods etc.) result in discontinuous, wavy reflections which are difficult to correlate over long distances.
3) The basement is made up by middle-upper amphibolite facies rocks (P=6-9 kbar, T= 600-825 °C) of the Paleoproterozoic Wollaston Domain, strongly deformed under both ductile and brittle conditions (Annesley et al., 2005).
4) According to the available borehole data, individual faults have limited vertical offsets (tens of meters) and relatively high dips. Their correct imaging is a direct function of the resolution limit of the technique (higher frequencies are required) and the accuracy of velocities used in DMO and migration.
5) The lower part Athabasca Sandstone was subject to intense silicification (Hajnal et al., 2007). Sonic logs show that interval velocities within the silicified sandstone, over the mineralized zones, can increase as high as 5400-5600 m/s, vs. the non-silicified section (interval velocities between 4200-4500 m/s). When it is not gradational, this altered interval can be mapped by seismic techniques. Borehole data also indicate that the sandstone basement unconformity is, in most places, associated with either a significant paleo-weathered zone or high fracture density, creating sufficient changes in acoustic properties to be recognized by reflections signals.

DATA AQUISITION

In most parts of the basin, because of permitting requirements, seismic data have to be collected under extreme winter weather conditions, at ambient temperatures as low as -35 °C, testing the limits of functionality of any electronic equipment. The recent high-resolution surveys mainly utilize 3 component Vectorseis detectors, and one or two 22,000 kg IVI-2400 Vibroseis units as acoustic source. Geophone group interval is 5 m, while vibration interval is 20 m. Sweep frequencies ranged from 30-170 Hz (

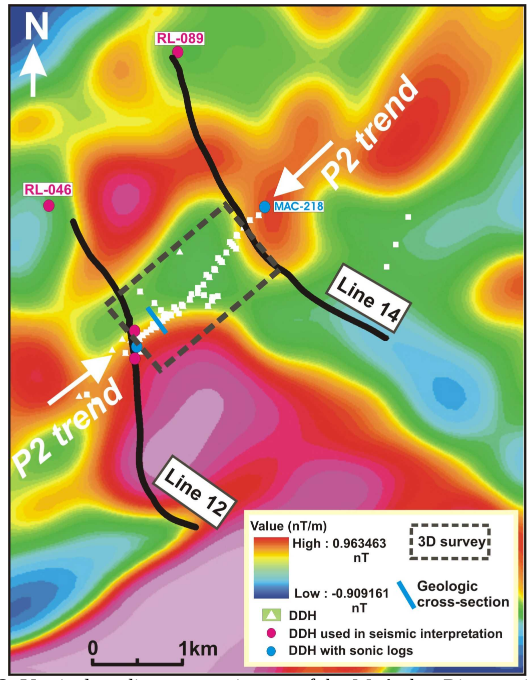

Figure 2: Vertical gradient magnetic map of the McArthur River region.

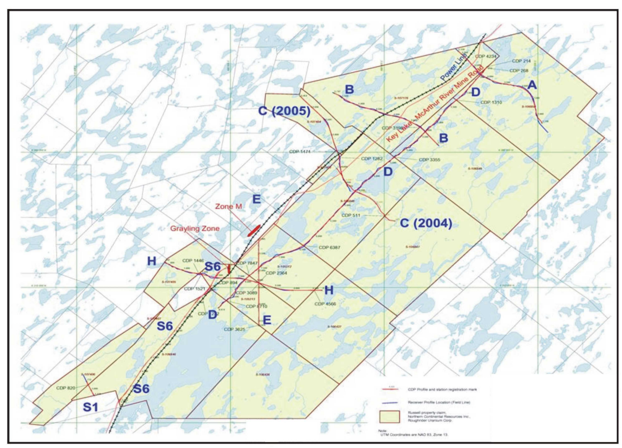

Figure 3: Survey configuration at the Russell Lake region.

non-linear, 12 dB/octave upsweep). The sweep length is 12 s, the correlated record length being 6 s.

The 3D survey has identical acquisition parameters, the only difference being that beside the 600 Vectorseis 3C units additional 960 IO-2000 geophones were employed. In fact this survey was one of the β-sites for testing the applicability of the Vectorseis 3C recording system in extreme temperature conditions. The acquisition geometry for the 3D survey (Figures 4 and 5) is irregular due to limitations imposed by topographic conditions, the infrastructure related to mine operations and the number of available recording units. This irregular acquisition geometry has certain impacts on data processing because: 1) the fluctuating fold coverage 2) the non-uniform offset and azimuth

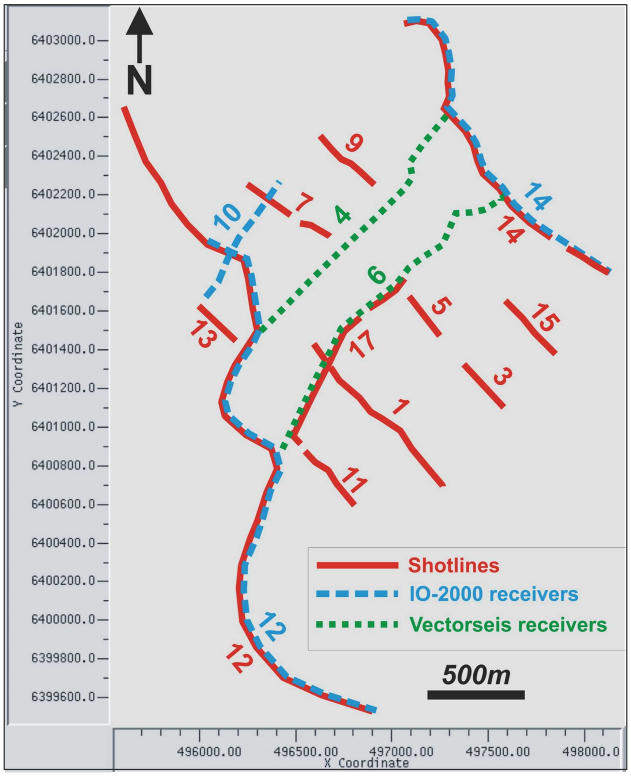

Figure 4: Acquisition geometry of the 3D survey and 2D profiles 12 and 14.

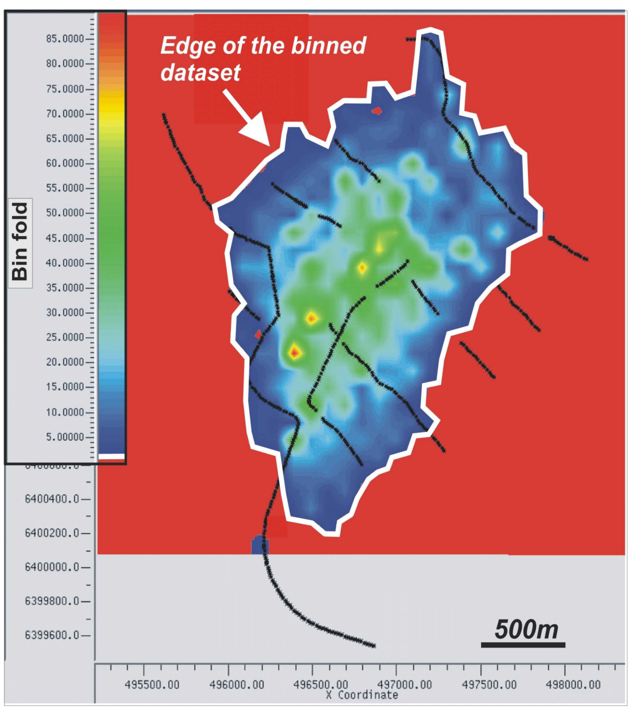

Figure 5: Fold coverage of the 3D data using 10x10 m bins.

distribution within CDP gathers and 3) scattering of CMPs from the bin center.

PROCESSING SEQUENCE

The processing sequence for the 2D and 3D surveys is very similar, thus we will discuss here only the flow implemented for the 3D survey. The raw data are exhibiting generally elevated noise levels; therefore significant effort was required to improve the S/N ratio. The IO-2000 and Vectorseis detector data are of comparable quality; however the later responds better to slightly higher frequencies and more uniformly to amplitude decay.

The processing flow applied includes the following steps: 1) Editing and geometry assignment; 2) Refraction statics (GLI 3D); 3) Data enhancement/filtering (FX decon, FK filter, predictive decon and Eigen-filter); 4) Muting; 5) Velocity analysis (2 iterations); 6) Residual statics (2 iterations); 7) NMO; 9) Post-NMO mute 10) Stacking; 11) 3D DMO; 12) Post DMO velocity analysis; 13) Post-stack Kirchoff time-migration. Residual statics and especially the adopted filtering sequence improved considerably the quality of individual shot-gathers.

In order to avoid spatial aliasing (Yilmaz, 2001) the choice of the correct bin size is of crucial importance. Parameters considered were: 1) expected dips; 2) average velocities; and 3) maximum frequency of the seismic signal. Based on these parameters, a 10x10 m bin size was established. Velocity analysis was difficult due to fluctuating fold coverage and non-uniform offset distribution within CDP gathers. Using available velocity information (sonic logs) and running two iterations (velocity analysis-residual statics) velocity picking became more feasible. Finally DMO and the post-stack Kirchoff time-migration resulted in considerable improvement of the stacked data.

INTERPRETATION

Our processing strategy described in the previous section resulted in final migrated sections of reliable quality. The imaged structures showed good agreement with borehole data and the overall reflectivity was close to the synthetics generated from sonic logs. Interpretation of the 2D high-resolution lines 12 (Figure 6) and 14, oriented sub perpendicular to the P2 structural trend, can be summarized as follows: 1) the basement is poorly constrained by borehole data. Its interpretation is conceptual, however constrained by regional geology, results of other regional and high-resolution surveys (Gyorfi et al., 2007). In our interpretation the basement is made up by interleaved Archean and Paleoproterozoic structural units related to the THO; 2) the characteristic seismic signatures of the basement/sandstone unconformity can be correlated reasonably in most places. However structural complexity (intense faulting) and/or absence of the basal weathered layer can create interpretation difficulty; 3) within the Athabasca Sandstone reflectivity changes laterally and vertically (continental environment, intense faulting, diagenesis etc.), but based on a few borehole data, the different sandstone members could be correlated all along the sections; 4) There are numerous inverse faults affecting the Athabasca

Sandstone and the P2 "fault" is in fact a broad zone of compressional deformation. The basement was involved in this late-stage faulting and the seismic data suggest that the brittle deformation is kinematically linked to earlier basement structures formed under ductile conditions; 5) thickness variations across faults seen in the upper parts of the Athabasca Sandstone (Manitou Falls Formations, MFc and MFd) are indicative for synsedimentary deformation, offering constraints on the age of compressive deformation; 6) comparison of lines 12 and 14 also revealed that although the overall style of deformation is similar, individual structural elements are difficult to correlate. Transverse faulting has been documented in boreholes, and the vertical gradient map (Figure 2) also suggested the existence of transcurrent elements. Thus the existence of lateral ramp running between lines 12 and 14 was postulated as the most plausible explanation; 7) the recently processed 3D survey fully supports this idea. Crossline 50 (Figure 7) running parallel with the P2 trend (for location see Figure 2) shows our preliminary interpretation on the structural style. High-angle transtensional faults are controlling the unconformity and laterally offsetting the P2 trend. The Russell Lake seismic profiles (Figures 8 and 9) recognize the structurally complex characteristics of the unconformity (UC). The seismic data also demonstrate that the complex seismic signatures of the UC are a manifestation of distinct changes in the basement lithology.

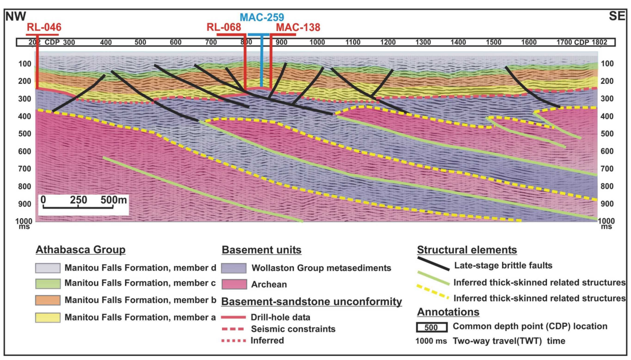

Figure 6: Interpreted 2D high-resolution line 12 running perpendicular to the P2 trend.

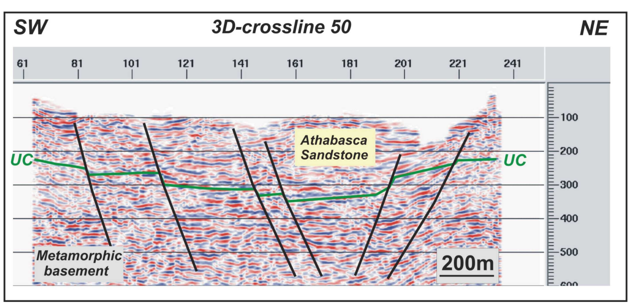

Figure 7: Preliminary interpretation of crossline 50 from the 3D survey. This line is parallel with the P2 trend.

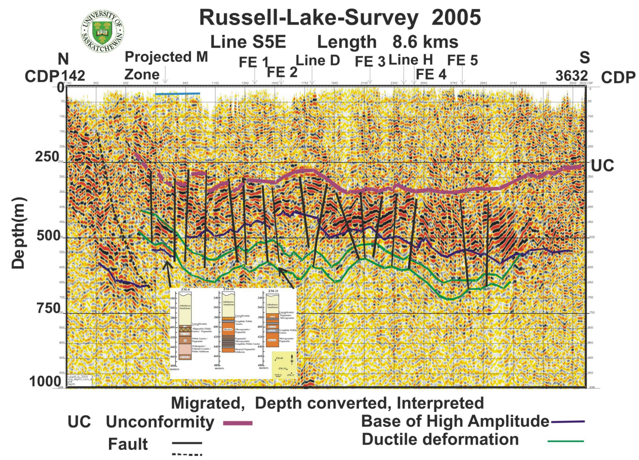

Figure 8: Seismic profile of line 5 from Russell Lake. Correlation to borehole geology illustrates the lithologic complexity in the vicinity of UC.

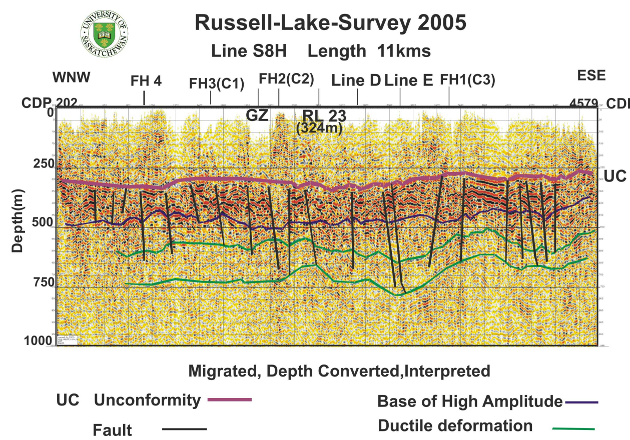

Figure 9: Seismic section of line 8 illustrates preservation of early ductile deformation in the basement.

CONCLUSIONS

The high-resolution 2D and 3D survey met successfully most of the objectives set initially. Contrary to the difficulties of the acquisition environment, limitations in the survey geometry and elevated noise levels, the final processed data successfully imaged the intricate and subtle stratigraphic and structural features associated with the P2 productive trend and the UC. Further efforts will concentrate on the study of possible seismic attributes associated with the ore bodies. The present study demonstrates that the seismic method is an extremely valuable exploration tool in any part of the Athabasca Basin. Following regional to sub-regional potential geophysical surveys, the seismic investigations can offer the opportunity to accurately define small-scale structures and this way can assist the development of a more efficient drilling program.

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