1424. EAGE

Structural Mapping for Uranium Exploration by Borehole Seismic

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Main objectives

The main objectives of the survey were to detect - directly or indirectly - uranium ore and to contribute to the understanding of the structural ore controls. Investigations from boreholes were aimed at imaging vertical and steeply dipping structures directly related to the uranium mineralization.

Summary

The McArthur River mine has become a testing ground for seismic techniques, as a part of Cameco's innovative and integrated multidisciplinary approach to exploration. Downhole side-scan seismic surveys were performed in boreholes MC-269 and MC-204 to a depth of 570m, using a tool consisting of a piezoelectric, swept-impact source and a string of 24 hydrophones. The main objectives of the survey were to detect uranium ore and structural ore controls. Downhole seismic profiling offers the possibility of mapping seismic reflectors and diffractors up to 200m away from the drill hole using high frequency seismic waves. Two parallel lines of processing were used, one aimed at imaging steeply dipping reflectors, the other at emphasizing point diffractors. Strong reflections associated with known structures were observed, which matched well the drill core logs The survey at McArthur River was successful in achieving its goals, by detecting diffraction and reflection patterns consistent with probable locations of mineralization. The survey also showed that delineation of fault zones, e.g. the P2 zone, is possible.

Introduction

The Athabasca Basin is a Paleo to Mesoproterozoic quartz rich sandstone basin located in the northern part of the provinces of Saskatchewan and Alberta, in central Canada (Figure 1). The McArthur River uranium mine has become a testing ground for seismic techniques, as a part of Cameco's innovative and integrated multidisciplinary approach to exploration.

Figure 1. *Location of the Athabasca Basin in northern Saskatchewan, Canada. The case history presented here is from the McArthur River mine site.*

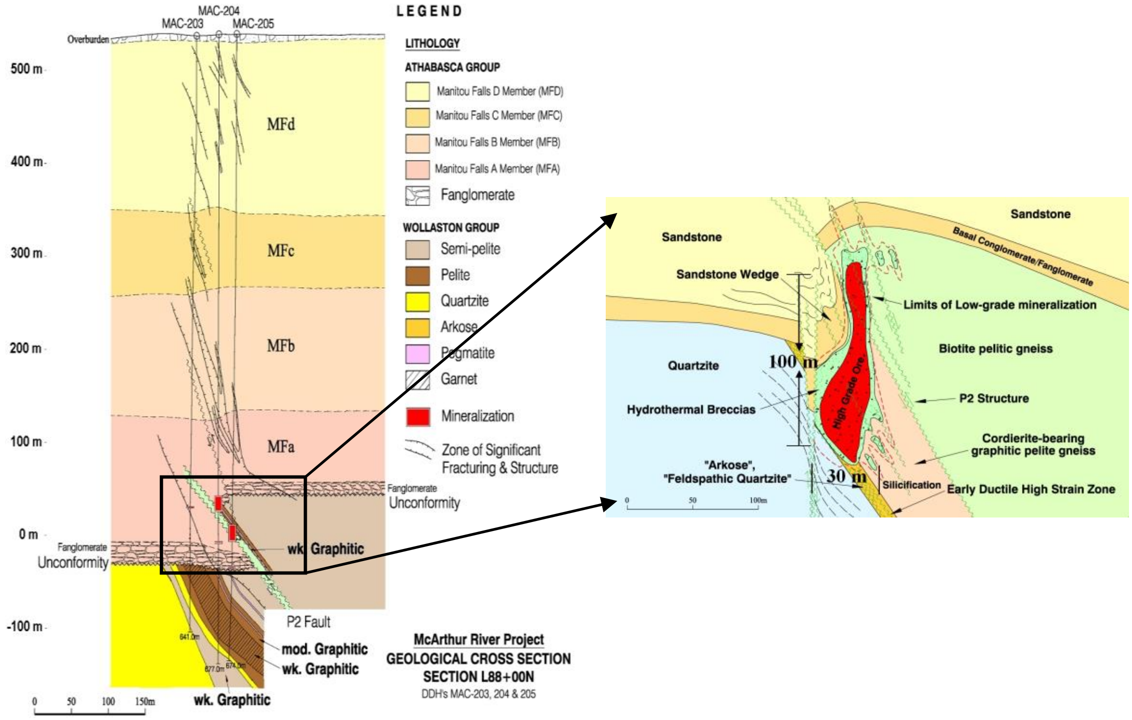
In 2004, the McArthur drilling exploration program was focused on the P2 reverse fault, which constitutes the primary control of the ore zones. The region of interest is located about 250 meters north of the current mine workings at a depth of roughly 520 m, and is largely restricted to the nose of the upthrusted basement wedge of the P2 fault, which has a throw of about 75 meters in the mine area. The geology of the McArthur River mine (Figure 2) is described in [McGill et. al., 1993]. Two of the more interesting intersections in the region of interest along the P2 fault, to date, are historic MC-269-3 and MAC-204 (2004).

Downhole side-scan seismic surveys were performed in boreholes MC-269 and MAC-204, using a tool consisting of a piezoelectric, swept-impact source (SPH54) operated at frequencies of 1-2 kHz, and a string of 24 hydrophones at 2 meters intervals.

The main objectives of the survey were to detect - directly or indirectly - uranium ore and to contribute to the understanding of the structural ore controls. Investigations from boreholes were aimed at imaging vertical and steeply dipping structures directly related to the uranium mineralization. Improved data quality was expected, compared to previous measurements made from surface, due to attenuation of the seismic signal related to the significant overburden layer comprised of glacial till.

Seismic surveys from boreholes at McArthur River mine

Tests on McArthur River ore samples suggested that high-grade ore would be detectable as a seismic reflector if frequencies in the kHz range could be used, and would therefore most likely be missed by surface seismic surveys due to the loss of the high frequencies in the overlying sandstone and glacial till. Conversely, surveys carried out from boreholes could conserve a frequency content high enough to accurately define the controlling structure(s) and detect ore bodies. Downhole seismic profiling [Cosma et. al., 2003] offers the possibility of mapping seismic reflectors and diffractors up to 200m away from the drill hole using high frequency seismic waves.



Single-hole measurements were done using a water-coupled SPH54 piezoelectric source with 1 kHz center frequency in borehole MC-269 and with 2 kHz center frequency in borehole MAC-204. The MC-269 section was measured from 306m to 571m and the section in MAC-204 from 257m to 571m.

Each 24-trace shotgather was subjected to filtering, spectral equalization, removal of tube waves and direct P-waves by median filtering and amplitude equalization. Subsequently, two parallel lines of processing were used. One consisted of DMO-correction, τ-p filtering and migration and was aimed at imaging steeply dipping reflectors. The other used a hyperbolic Radon transform to emphasize point diffractors.

Key stages of the processing scheme for borehole MC-269 are shown in Figure 3: an example of preconditioned shotgather (upper left), point-diffractor enhanced stacked profile (lower left) and reflector enhanced profile (right). The sharpness of the stacked images depends greatly on the accuracy of velocity model. With a basically one-dimensional model inferred from acoustic logging in the two boreholes, the stacking of higher frequencies was less sharp, especially in regions with strongly varying velocity. Indeed, better reflection images were obtained for the lower frequency data obtained with the 1kHz center frequency source in borehole MC-269 than with the 2 kHz source in MAC-204.

Results

Strong reflections associated with the P2 zone and parallel structures were observed, which matched well the drill core logs and contributed to a better definition of their position and extent. Several reflections oblique or perpendicular to the P2 were also observed.
High amplitude regions associated with diffractions indicate potential for detection of high-grade mineralization.

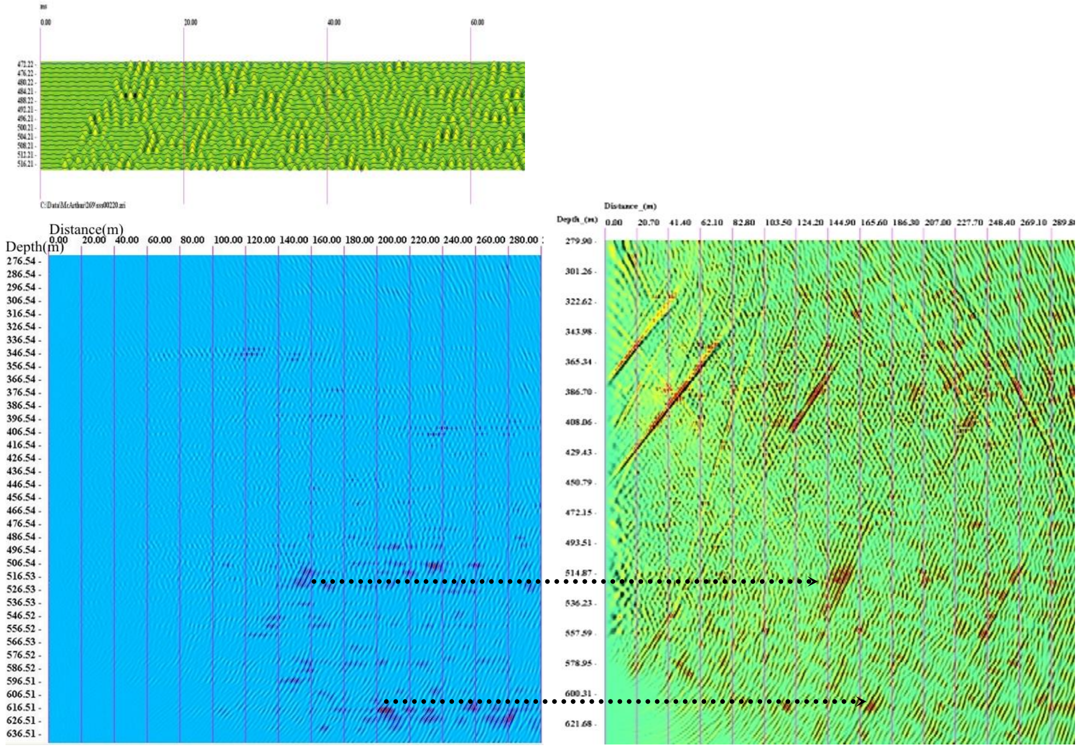


Figure 3. *Borehole MC-269. Example of shotgather (upper left), stacked profile with enhanced point diffractors (left) and stacked profile with enhanced steeply dipping reflectors (right).*

Stronger diffractions appear on the MC-269 migrated section, due to its optimal location distal to the P2 and associated cross-structures and ore intersections. Besides boundaries of a mineralized zone/alteration zone, possible fault/structure oblique to the P2 fault zone, regions of intense fracturing and increased pore space. The upper anomaly in Figure 4 (right), corresponding to the nose of the P2 wedge, is confirmed as a good point diffractor anomaly. The position of the deeper point diffractor anomaly is consistent with basement-hosted uranium along trend.

The diffraction patterns observed coincident with reflectors at the bottom of reflection image from MC-269 were of particular interest for the site characterization. These patterns are directly coincident with the offset of the reverse P2 structure (80 m throw) and therefore potentially have originated or are influenced by this major structure. An image complementary to the one obtained by reflection processing, a prestack migration emphasizing localized diffractors was also obtained. The two images are shown in Figure 3.

Conclusions

The survey at McArthur River was successful in achieving its goals, by detecting diffraction and reflection patterns consistent with probable locations of mineralization. Especially the diffraction clusters observed were deemed of significant exploration interest.

The survey also showed that delineation of fault zones, e.g. the P2 zone, is possible. A more extensive mapping of faults would however require surveys in several boreholes. The absence of a reliable velocity model made the process of obtaining sharp seismic images quite laborious. Performing surveys in several adjacent boreholes would allow the build-up of a usable 3D velocity model and largely alleviate the processing task.

Borehole high frequency seismic reflection data were successfully collected in an acoustically noisy brown field environment. The time-distributed swept-impact source, allowing a significant energy build-up at a relatively low power had an important contribution to this positive result. Borehole seismic is a viable exploration tool within a brown field exploration play.

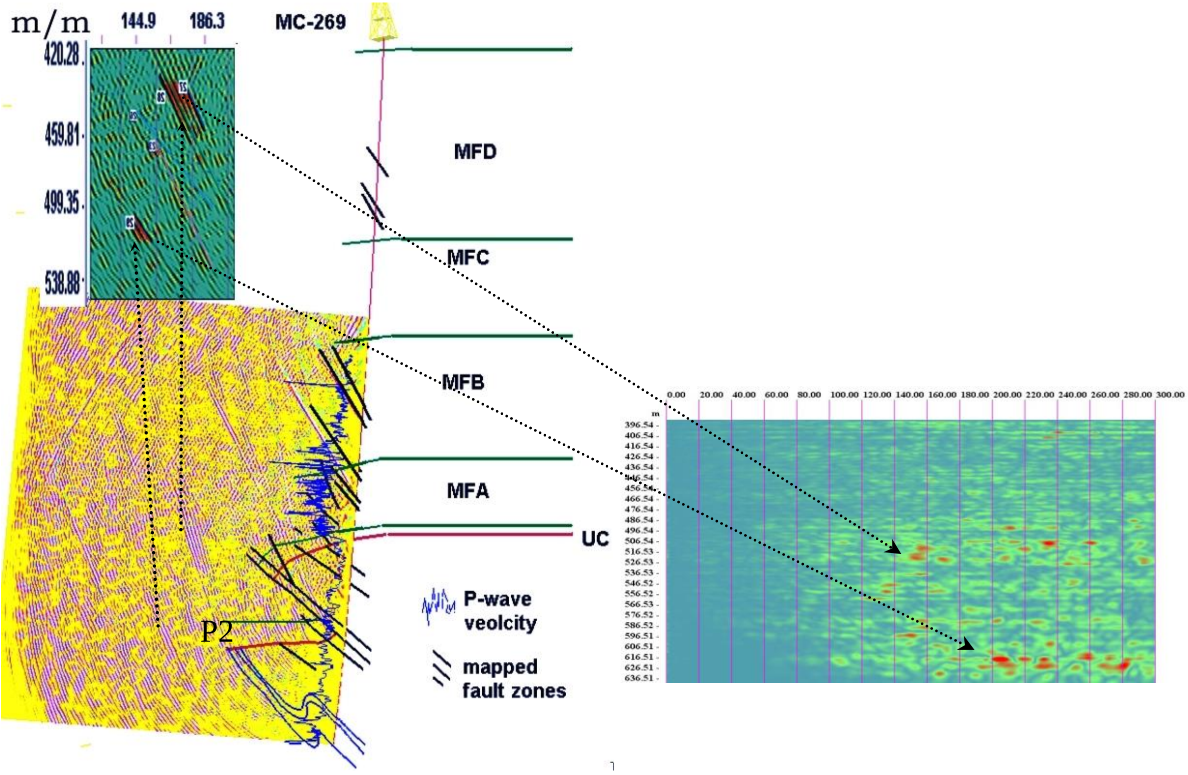


Figure 4. *Downhole seismic images from drill hole MC-269 showing defined faults, notably the P2 and related structures (left) and the enveloped point-diffractor processed profile (right). The two features marked with arrows indicate two coherent reflections and diffraction anomalies at depths corresponding to the upper and lower unconformity surfaces at the P2 fault.*

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