Paper 113

Seismic Delineation of the Orion South (140/141) Kimberlite, Fort à la Corne Field, Saskatchewan

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ABSTRACT

The Orion South (140/141) kimberlite is a diamondiferous multiphase complex within the Fort à la Corne kimberlite field of Saskatchewan, Canada. High-resolution Vibroseis seismic reflection profiles were acquired along a network of 7 2D profiles totaling 10 km in length. These data are interpreted in conjunction with an extensive set of drillhole geological logs and limited geophysical logs to delineate the large-scale architecture of the kimberlite body.

INTRODUCTION

The Orion South (140/141) kimberlite is one of approximately 70 kimberlite bodies located within the Fort à la Corne kimberlite field of central Saskatchewan, Canada (Figure 1). The 140/141 kimberlite constitutes a multiphase kimberlite complex that was formed from ca. 106 Ma to ca. 99 Ma by at least seven episodes of kimberlite volcanism (Kjarsgaard et al., 2006) punctuated by periods of volcanic quiescence, erosion, and sedimentary deposition within the Western Canadian Sedimentary Basin. An extensive drilling program has been conducted during the past 5 years to delineate the subsurface extent of this kimberlite complex. In addition, a complementary network of 2-dimensional seismic reflection profiles was acquired as a basis to constrain interborehole geological correlations. In this paper, we present interpretation of the seismic reflection profiles integrated with borehole geophysical and geological logs.

GEOLOGY

The sedimentary rocks that host the 140/141 kimberlite form a 700 m thick sequence overlying Precambrian basement rocks (Leckie et al., 1997b). Cambrian through Devonian mixed siliciclastic-carbonate sedimentary rocks forming the lowermost 300 to 500 m of the column above the basement, are overlain by approximately 150 m of Lower Cretaceous sediments and 85 to 115 m of sand and glacial till. Kimberlite is interstratified with terrestrial to marginal marine Cretaceous Mannville Group (Cantuar and Pense formations) and marginal to deep marine sediments of the Lower Colorado Group (Joli Fou, Viking and Westgate formations; Kjarsgaard et al., 2006). Near the study site the Pense and uppermost Cantuar formations comprise predominantly siltstone and very fine-grained sandstone, whereas the Lower Colorado Group is largely shale.

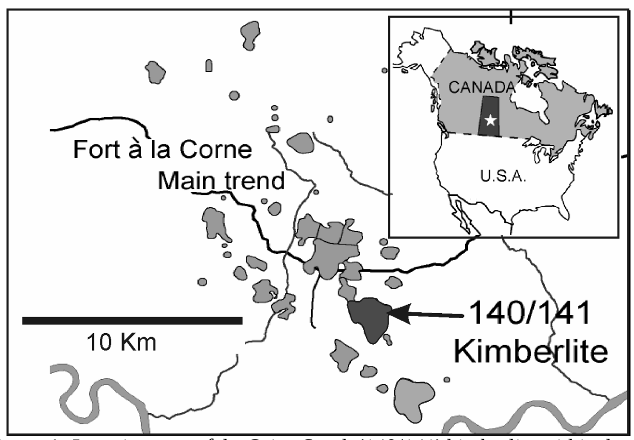

Figure 1: Location map of the Orion South (140/141) kimberlite within the Fort à la Corne Main Trend. Inset shows the location of the field in North America. Figure is modified from Zonneveld et al. (2004).

The earliest kimberlite eruptive phase at the 140/141 body is Cantuar equivalent in age, which forms thin airfall deposits around an aerially restricted feeder vent. The next major kimberlite eruptive events are Pense equivalent in age (P-1, P-2, P-3). P-1 is interpreted as a pre-cursor event to the eruption of P-2, a medium to coarse grained matrix to just clast supported volcaniclastic kimberlite which is typically massive to poorly bedded and has a large, flared feeder vent. Clast supported olivine-rich kimberlite (P-3) forms separate deposits and is also observed interbedded with P-2. The next major kimberlite

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eruptive phases are Joli Fou equivalent in age. Well bedded pyroclastic kimberlite breccia/pyroclastic kimberlite fining up couplets or coarse PK/fine PK couplets are typical of EJF-1 and EJF-2 deposits. EJF-1 is observed in the 140 sector of Orion South and EJF-2 in the 140 and 141 sectors. These kimberlites are overlain by LJF kimberlite, which is a predominantly very fine grained, massive, clast supported volcaniclastic kimberlite.

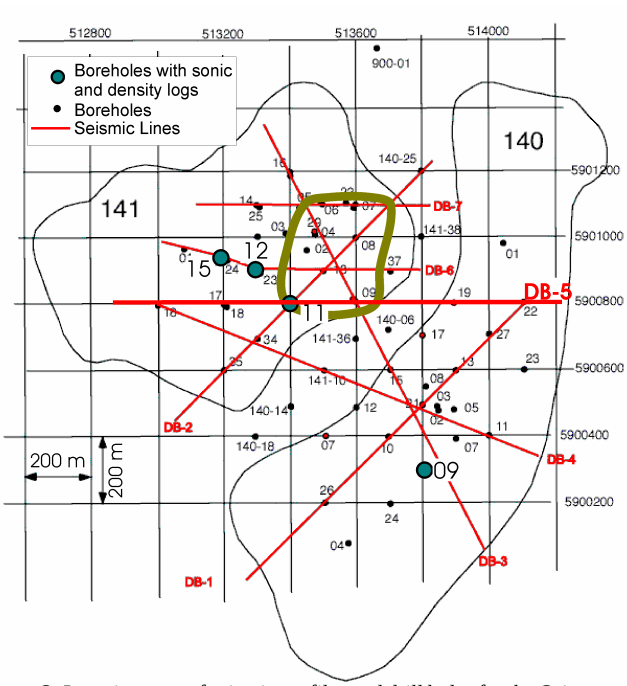

Figure 2: Location map of seismic profiles and drill holes for the Orion South kimberlite. The original magnetic outlines of the 140 and 141 bodies (which do not correspond to the outline of the Orion South kimberlite body) are indicated. The green outline indicates the outer boundary of a ring fault system associated with a multi-feeder vent complex identified on the grid of seismic lines (see text for description).

KIMBERLITE SEISMIC REFLECTIVITY

The delineation of the Orion South kimberlite is based on detailed logging and analysis of drillcore using a variety of criteria. Individual eruptive phases have been identified using criteria such as bedding thickness and type, clast size, nature of matrix material, indicator minerals and whole-rock geochemistry (Kjarsgaard et al., 2006). The effectiveness of seismic reflection methods as a complementary tool for more detailed delineation of the Orion South kimberlite complex is largely determined by the variation of acoustic impedance (or density and compressional wave velocity) of the kimberlites and the sedimentary rocks that host them. In general, there may be no direct relationship between the criteria used for geological logging (e.g., geochemistry, indicator minerals) and the seismic properties of the rocks, and thus it is recognized that the seismic image of the kimberlite, although complementary, may depict characteristics of the kimberlite that are quite distinct.

An assessment of the reflectivity characteristics in the vicinity of the 140/141 kimberlite can be made using existing regional borehole sonic logs as well as sonic logs and density measurements acquired at the study site. Regional sonic velocity logs (Matieshan and Gendzwill, 1994; Christopher, 1997; Leckie et al., 1997a) indicate that large contrasts in sonic velocity exist at the boundary between Lower Colorado Group (Joli Fou formation) and the Mannville Group (Pense formation), as well as at the boundary between the Mannville Group (Cantuar formation) and underlying Devonian carbonates. In contrast, the boundary between the Pense and Cantuar formations is characterized by a relatively small change in sonic velocity.

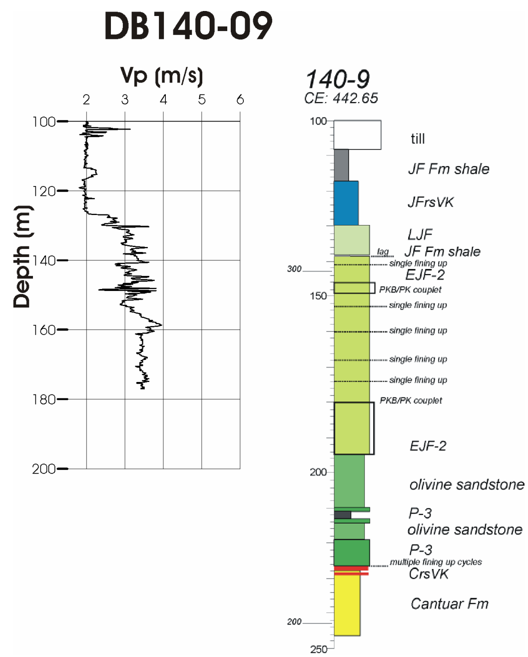

Figure 3: Sample sonic and geological logs from borehole 140-09.

Sonic and density logs acquired at the study site (see Figure 2 for location and Figure 3 for an example) demonstrate the contrast in seismic properties of the kimberlite body and the rocks which overlie it (till and Westgate/Joli Fou formation shale). Sonic velocities in the shales are typically ~2000 m/s as compared to more variable values of 2500-3500 m/s within the kimberlites. In some cases the variations in seismic properties of the kimberlites correspond to the interpreted eruptive phases, (e.g., LJF and EJF in Figure 3 and in the 140-11 log; not shown) wherease in other cases variations within single eruptive phases are just as large (e.g., logs from 141-12 and 141-15, not shown). Density measurements (not included here) on a limited set of samples demonstrate insignificant differences between most of the kimberlite samples with the exception of the EJF, P-3 and CfT units which have significantly higher densities. The sonic logs and core density measurements together suggest that at least in some cases, seismic reflections should be expected from boundaries of some of the individual eruptive units, but there should also be significant reflections within individual phases. Sonic velocities for the Mannville Group in the study area are

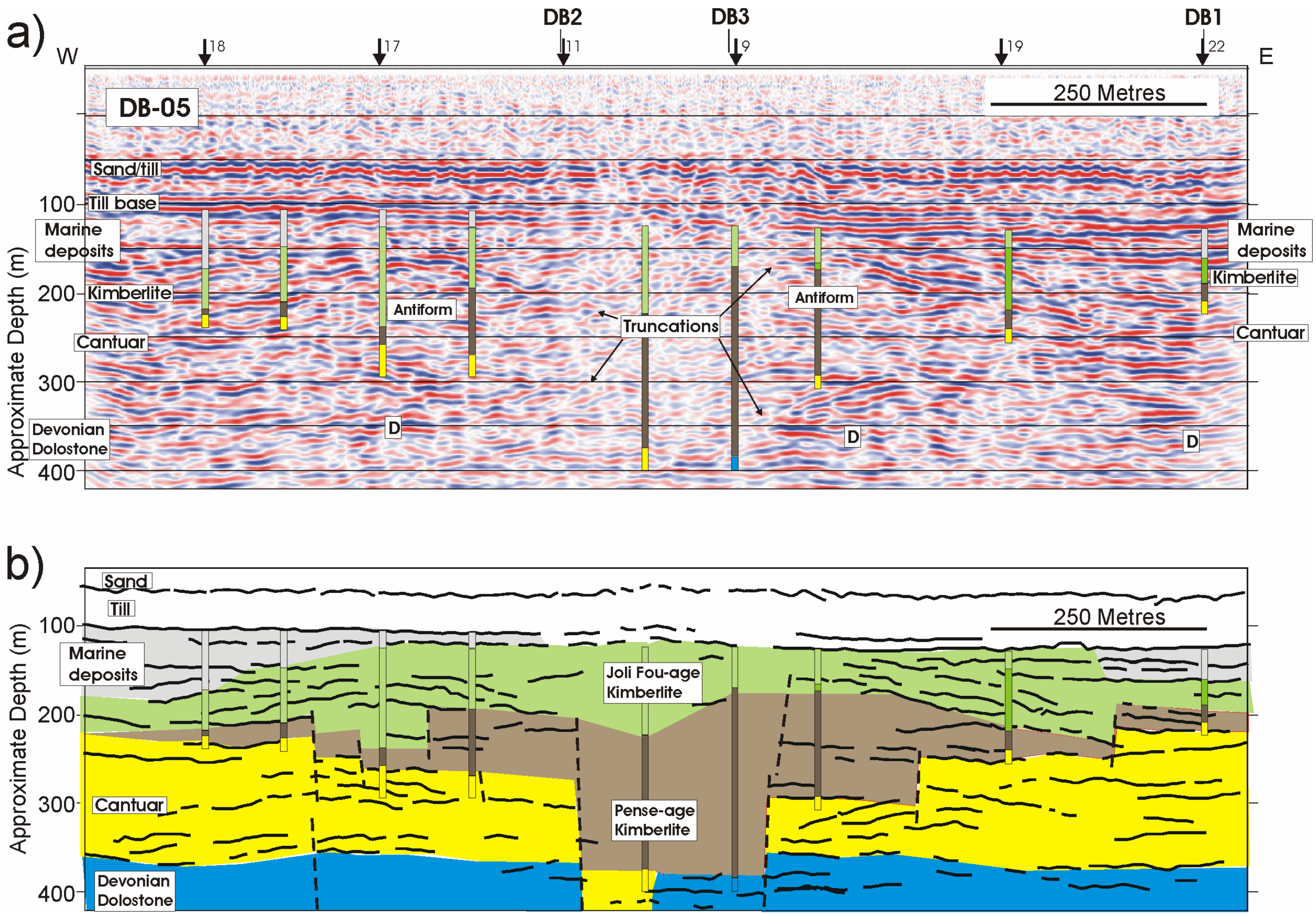

Figure 4: a) Migrated seismic data for line DB-5. The data are converted to depth using a constant velocity of 3000 m/s and thus correlation with the borehole geology (true depth) will only be approximate. The locations of drillholes and intersections with other seismic profiles are indicated along the top of the plot. Simplified geology for several boreholes along the line is also plotted. For correlation purposes, the bottom of the till marker from the boreholes was aligned with the interpreted till-bottom reflection. The thickness of the marine shales from the geological logs has been adjusted to account for the high velocity used to convert the seismic data to depth. b) Seismic interpretation superimposed on a computer-generated linedrawing of the seismic data.

comparable to the lower range of values observed for the kimberlite units suggesting that the reflections from the Cantuar/kimberlite contact will be variable in strength.

SEISMIC ACQUISITION AND PROCESSING

Seven 2D profiles were acquired across the Orion South kimberlite with a total length of 9700 m (see Figure 2). Data were acquired using a IVI-T2500 Mini Vibrator with source points at 21 m intervals, sweep frequencies of 30-300 Hz, and twelve 15 s sweeps per vibration point. Geophones with a 10 Hz resonant frequency were located at 3 m group intervals, 6 geophones per group planted over 3 metres, with all stations within a line recording all shots along that line. Data processing included the following steps: geometry application, noisy trace editing, 50 ms automatic gain control, zero-phase spiking/predictive deconvolution, refraction statics, spectral whitening (45-240 Hz), top-mute, iterative semblance velocity analysis, normal-moveout correction, residual statics, stack, 200 ms automatic gain control, f-x deconvolution, finite-difference time-migration. Details concerning any of these standard processing steps can be found in Yilmaz (2001).

SEISMIC INTERPRETATION

Migrated data for profile DB-5 are shown in Figure 4. A semi-quantitative interpretation of the data is accommodated by a wealth of borehole geological logs. However, depth correlations between the seismic data and borehole geology are limited by having only approximate velocity information for the subsurface. Detailed depth correlations will be possible once sonic log data extending into the underlying Cantuar formation are acquired. The time-migrated data have been converted to depth using a constant velocity of 3000 m/s. This velocity is most representative of the kimberlite units and thus thicknesses of the kimberlite units will be approximately correct, whereas the thicknesses for the other units (particularly the sand, till and marine shales) will be overestimated on the seismic section.

The following observations pertain to the migrated seismic section (Figure 4a). The interpreted sand/till and the till-shale or till-kimberlite interfaces in the upper part of the section represent the most prominent reflections on the section. On either side of the section, marine deposits (predominantly Joli Fou/Westgate formation marine shales) form an inward thinning mantle above the underlying domal shaped kimberlite, pinching out completely before the centre of the section. Below this, reflections that diverge toward the centre of the section correspond generally with the kimberlite units mapped in the corresponding boreholes. The base of this zone, although difficult to follow in places, is interpreted as the boundary between the kimberlite complex and Cantuar formation, and is interpreted to step-down along a series of fault offsets. Within the intervening depth range, there are prominent reflections that are clearly internal to the kimberlite body. These reflections are generally conformable with the boundaries between the different eruptive phases (as mapped geologically), and in some cases correlate directly with them. This might be expected in a volcano-sedimentary environment as seismic reflections tend to follow time-stratigraphic surfaces (e.g., bedding surfaces or unconformities; Vail et al., 1977). Near the bottom of the section (at ~350 m depth) a laterally semi-continuous reflection is interpreted as the top of the Devonian carbonate based on the appropriate depth (compared to regional data), correlation with drillhole 140-09 and the large contrast in seismic properties expected at this interface.

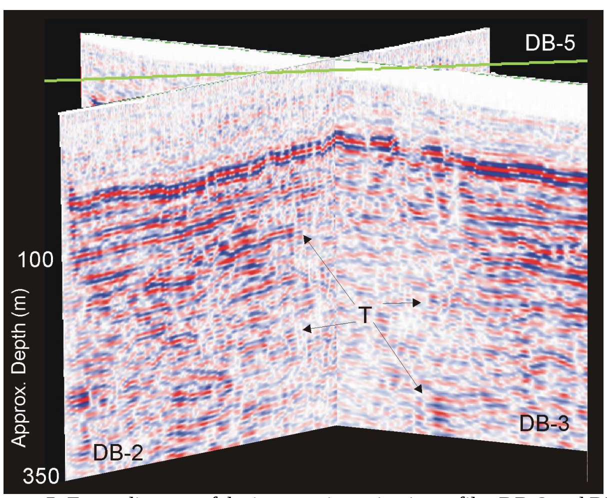

Figure 5: Fence diagram of the intersecting seismic profiles DB-2 and DB-3. Truncations marking the extremities of the ring-fault system discussed in the text (and plotted in plan view in Figure 2) are indicated by the label ‘T’. The view is looking toward the north. The surface location of profile DB-5 (Figure 4) is indicated by the green line.

The most conspicuous feature of the seismic section is the zone of reduced reflectivity in the central part of the section, the edges of which are demarcated by the truncation of reflections approaching this region from either side. This zone corresponds to the greatest thickness of kimberlite along the line. The lack of observed reflectivity within this zone is related to the presence of massive to poorly bedded volcaniclastic kimberlite (phase P-2). The EJF-2 kimberlite, which overlies the P-2 kimberlite is typically bedded (pyroclastic kimberlite breccia/pyroclastic kimberlite couplets; Fig 3) and is represented by internal reflectors in this unit. The overlying LJF kimberlite tends to be massive, and is thickest in the central and western part of the section, an area with few internal kimberlite reflectors. This same zone of chaotic reflectivity bounded by truncations on either side is observed along DB-2 and 3 (see Figure 5), as well as along DB-6 and DB-7. A plan view plot of this zone (Figure 3) as defined by the multiple seismic lines encompasses a region that is approximately 300x300 metres in extent. This steep-sided zone is the locus of multiple feeder vents encompassing vents associated with eruptions of Pense-age equivalent (P-2 vent in drillholes 141-9 and 141-13) and Joli Fou-age equivalent kimberlites (LJF vent in drillhole 141-2 and EJF-2 vent in the vicinity of 14-1-06 and 141-29) kimberlites (Kjarsgaard et al., 2006). The seismically defined boundary is interpreted as the outer limit of a series of concentric ring faults that encircle the kimberlite feeder vents.

CONCLUSION

A network of seismic reflection profiles delineates the large-scale architecture of the Orion South (140/141) kimberlite complex and the sedimentary column that hosts it. Interpretation of these data in conjunction with detailed drillhole geology and limited borehole geophysical logs allows further definition of the kimberlite structure between boreholes and is particularly useful for delineating steep structures such as the zone of ring faulting surrounding the feeder vents. The acquisition of sonic logs extending into the underlying basement will allow a more quantitative interpretation of the seismic data in future.

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