SEDIMENTOLOGIC AND STRATIGRAPHIC CONSTRAINTS ON EMPLACEMENT OF THE STAR KIMBERLITE, EAST-CENTRAL SASKATCHEWAN

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INTRODUCTION

The Fort à la Corne kimberlite field, located 40 kilometres east of Prince Albert, Saskatchewan is one of the largest kimberlite clusters in the world. Although diamonds were first reported in the late 1940's, the first kimberlite was not discovered until the late 1980's (Lehnert-Theil et al., 1992). Detailed aeromagnetic surveys helped in the identification of over 70 anomalies. By the end of 1991, drilling had penetrated kimberlite at eighteen of these targets (Jellicoe et al., 1998). Subsequent drilling activity has shown that at least 71 distinct kimberlite bodies occur in the Fort à la Corne cluster.

Elongate, vertically oriented, carrot-shaped diatremes are the most commonly described kimberlite bodies (Mitchell, 1995). Because kimberlites most commonly occur in ancient craton-centre settings dominated by prolonged erosional histories, pyroclastic kimberlite is rarely observed. Even the most complete described examples (i.e. A/K1, Botswana and Mwadui, Tanzania) have experienced considerable erosion of pyroclastic rocks and are limited to crater infill deposits (Edwards and Howkins, 1966; Field et al., 1995). Kimberlite bodies in the Fort à la Corne kimberlite cluster are unique in the completeness of their preservation. In addition to elongate pipes, planar, variably extensive, horizontally bedded kimberlite aprons also occur. These sheet-like deposits are the first known example of extra-crater primary airfall kimberlite (Nixon et al., 1993; Leckie et al., 1997; Leahy, 1997; 2001 Nixon and Leahy, 1997; Zonneveld et al., 2002a; 2002b).

Recent analyses of kimberlite from the Fort à la Corne cluster provided the first detailed descriptions of pyroclastic kimberlite in the scientific literature (Leckie et al., 1997; Leahy, 1997; 2001 Nixon and Leahy, 1997). Although many kimberlite bodies in the Fort à la Corne cluster have been identified by drilling, most bodies have been perforated by relatively few core (commonly only one). The present study focuses on the Star Kimberlite, a large kimberlite body located north of the Saskatchewan River at the southern end of the Fort à la Corne cluster, approximately 60 kilometres east of Prince Albert. The Star body is characterized by an exceptional core database, with 15 cores penetrating the crater/vent area and another 20 core delineating the surrounding kimberlite apron. The Star Kimberlite was discovered in 1996 by drilling three core holes through an atypically large (~ 300 hectare) magnetic anomaly. These holes penetrated a total of 124.55 metres of kimberlite encased in siliciclastic sediment of the Lower Cretaceous Mannville and Colorado groups. Caustic fusion of 383.5 kilograms of split core taken from these three drill holes resulted in recovery of 169 diamonds. To date a total of 35 core holes have been drilled in the vicinity of the Star kimberlite with every hole intersecting kimberlite. One of these, Star-020 intersected 539 metres of continuous kimberlite. This hole, drilled to 627 metres total depth, is the thickest intersection of kimberlite drilled in North America to date.

Integration of multi-disciplinary data sets has helped to refine and resolve models for emplacement of the Star Kimberlite. Detailed core logging has provided the foundation for sedimentological and volcanological studies and in constructing a regionally consistent stratigraphic and architectural framework for the study interval. Micropaleontologic and biostratigraphic analysis of selected sedimentary rocks, and U-Pb perovskite geochronology on kimberlite samples have been integrated to define periods of kimberlite emplacement. High-resolution 2-D and 3-D shallow seismic studies, complemented by multi-parameter borehole geophysics on drill holes within the same body, has aided in determining the 3-D geometry and internal lithologies of the Star Kimberlite.

GEOLOGIC SETTING

The Fort à la Corne kimberlite cluster occurs on the eastern rim of the North American Interior Platform, with Precambrian basement rock occurring approximately 700 meters below the surface (Leckie et al., 1997). Although core data through basement rock in the study area are sparse, geophysical and geochronological data suggest that crystalline basement rocks belong to the Archean/Paleoproterozoic Sask Craton, locally exposed to the north in tectonic windows (Collerson et al., 1989; Lewry et al., 1990). In the Fort à la Corne region, crystalline basement rocks consist of schist, orthogneiss and local banded iron formation (Collerson et al., 1989). Nd model ages for basement rocks from this area indicate mantle separation ages between 3.12 and 2.35 Ga (Collerson et al., 1989) while crustal xenoliths have been dated between 3.2 and 2.1 Ga (Davis et al., 1998).

Precambrian basement rocks are overlain by 300-500 metres of Paleozoic mixed siliciclastic-carbonate sediments (Cambrian through Devonian). These strata are overlain by approximately 250 metres of Lower Cretaceous sediments (~175 m Mannville Group coastal plain, deltaic/estuarine and shoreface sediments and ~75 metres Colorado Group shoreface to proximal offshore sediments) and approximately 85 metres of Pleistocene glacial till.

Emplacement of the majority Fort à la Corne kimberlites occurred >99 Ma during the Lower

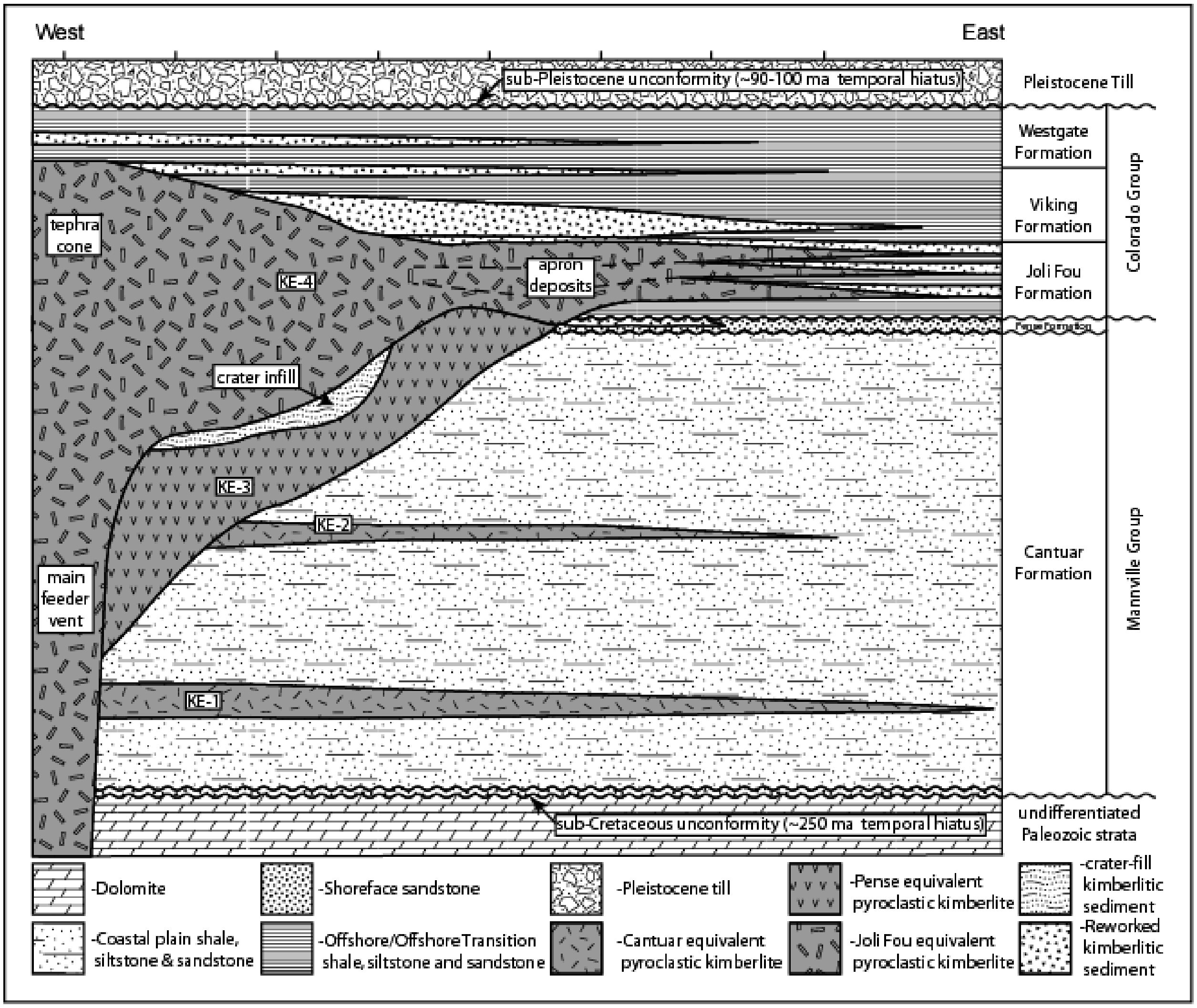

Fig. 1. Schematic west to east cross-section across the Star kimberlite body. At least four distinct eruptive intervals occur in this succession (KE-1 to KE-4). The first two (KE-1 and KE-2) occur at discrete horizons within the Cantuar Formation and may be related to an eruptive center outside the present study area. The third kimberlite succession (KE-3) occurred contemporaneous with deposition of the Pense Formation and resulted in a feeder vent/tuff ring. During an interval of volcanic quiescence a crater lake developed within the tuff ring, evidenced by a variably thick succession of terrestrial shale with numerous kimberlitic silt, sand and breccia beds, commonly characterized by abundant plant debris. Periodic desiccation of the lake is attested to by the presence of rooted horizons and pedogenic alteration of kimberlitic shale, silt and breccia horizons in the crater. The fourth and primary eruptive interval (KE-4) occurred coetaneous with deposition of Lower Colorado Group strata. Interfingering of distal primary airfall kimberlite with cross-stratified kimberlitic (olivine-dominated) sandstone and black shale of the Joli Fou and Viking formations suggest that this late eruptive phase is an amalgamation of several discrete eruptive intervals.

Cretaceous (Heaman and Kjarsgaard, 2002). At this time, loading caused by thrust faulting on the western margin of the continent, and ongoing erosion of the Rocky Mountains that caused subsidence of the Western Canada Foreland Basin. Throughout its development this basin played host to a myriad of epicontinental seaways. The Fort à la Corne area is situated along on the eastern margin of this basin. Transgressions and regressions of these seaways, resulting from a mix of tectonic and eustatic controls, played a strong role in the nature, distribution and preservation of kimberlite in the study area.

STRATIGRAPHIC EVOLUTION OF THE STAR KIMBERLITE

Kimberlite in the study area is interstratified with siliciclastic strata of the Cantuar, Pense, Joli Fou, Viking and Westgate formations (Fig. 1). These units record an overall transgressive succession, from coastal plain and deltaic/estuarine to shoreface and proximal offshore sediments. Kimberlite in this succession occurs in several forms, from primary pyroclastic airfall to a wide variety of secondary (reworked or remobilised) kimberlitic sediment. Secondary kimberlite deposits in the study area include fluvial channel deposits, shoreface olivine sandstone beds, and offshore (marine and lacustrine) tempestites, mass flows and turbidites. Grain flow and rock fall / talus slope deposits have also been recognized within the tuff ring/crater area.

LOWER MANNVILLE KIMBERLITE (CANTUAR FORMATION)

Evidence for older kimberlite volcanism in the Fort à la Corne area consists of variably abundant indicator minerals (primarily ilmenite, magnetite, and garnet) in fluvial channel sandstone beds in the lower Cantuar Formation. In one core these occur in a pebble-rich coarse sandstone unit that immediately overlies the sub-Cretaceous unconformity, a 250-270 Ma unconformity separating the Cantuar Formation from subjacent Upper Devonian carbonate strata. Their presence in this interval implies kimberlite volcanism that either predates, or occurred contemporaneous with, the basal Cantuar in central Saskatchewan.

The oldest kimberlite in the vicinity of the Star body occurs as pyroclastic airfall deposits in the Cantuar Formation. In the study area the Cantuar Formation consists of a heterolithic succession of planar laminated to blocky shale, current ripple laminated siltstone and normally graded, rippled to cross-stratified, medium- to -fine grained sandstone. Thin organic shale and coal beds are common in the lower Cantuar Formation. Trace fossils, albeit low in diversity, are abundant in the upper Cantuar Formation. This assemblage, consisting of minute forms of *Cylindrichnus, Trichichnus, Gyrolithes* and *Planolites*, as well as the presence of low-diversity foraminiferal assemblages, suggest brackish conditions in the upper Cantuar Formation and a transition from fluvial to deltaic and/or estuarine conditions.

Kimberlite units in the lower Cantuar Formation are rare. Although this is, in part, due to a paucity of core that penetrate the entire Cantuar interval, it is also related to the nature of the lower Cantuar depositional setting on the margin of the Western Canada Sedimentary Basin. Low rates of fluvial aggradation in the lower Cantuar resulted in laterally extensive sheet sandstone geometries with numerous scour surfaces and only rare preservation of overbank fines. Pyroclastic airfall would have had very low preservation potential in this depositional regime. The few kimberlite beds observed in this part of the succession all exhibit strong indications of reworking such as admixture with non-volcaniclastic sediment such as quartz sand, chert pebbles, coal clasts and mud clasts. Kimberlitic debris flows are locally common suggesting sudden relocation of pyroclastic airfall into adjacent lows such as stream valleys and ponds, possibly as a result of liquefaction after rainstorms.

Kimberlite in the upper Cantuar Formation in the vicinity of the Star Kimberlite consists of several, laterally extensive, planar beds and bedsets of olivine crystal and juvenile lapilli tuffs (KE-1 and KE-2, Fig. 1). These units are interpreted as medial to distal primary pyroclastic airfalls sourced from an as yet unknown volcanic vent. Perovskite fractions were analysed from one of these pyroclastic airfall deposits, resulting in a weighted average ^{206}U-^{238}Pb date of 103.9 ± 1.4 Ma (Heaman and Kjarsgaard, 2002). The kimberlitic material draped the coastal plain forming a roughly even sheet over both topographic highs (interfluves) and lows (lakes, channels, etc.). Several core in the upper Cantuar penetrated the thalweg of kimberlite infilled fluvial channels. In most cases minimal evidence of fluvial reworking suggests that an overwhelming influx of eruptive material caused channel avulsion and abandonment. Fluvial systems are laterally restricted entities that are prone to incision during base level fall. Thus, preservation of kimberlite in a setting normally prone to erosional destruction and fluvial transportation may be attributed to deposition during a period of rising base level, likely foreshadowing imminent transgression by the Cretaceous inland seaway.

UPPER MANNVILLE KIMBERLITE (PENSE FORMATION)

In the study area, the Pense Formation consists primarily of silty/muddy fine- to medium-grained, highly bioturbated sandstone with subordinate dark grey to black silty shale. A diverse trace fossil assemblage dominated by *Zoophycos, Teichichnus, Thalassinoides* and *Palaeophycus* supports an offshore transition to lower shoreface interpretation for this unit. A sharp basal contact, commonly characterized by an indicator mineral-rich lag and a low-diversity *Glossifungites* assemblage supports the presence of a hiatal surface at the Pense-Cantuar contact in the study area. Absence of Pense sandstone units in part of the study area may imply localized subaerial exposure in this area, possibly coeval with kimberlite volcanism.

Pense-equivalent eruptions produced the first kimberlite in the study area demonstrably related to the Star Kimberlite. Primary kimberlite is largely restricted to proximal vent infilling and pyroclastic deposits and adjacent tuff ring deposits in the western part of the study area (KE-3, Fig. 1). Cross-stratified, fine- to medium- and rarely coarse-grained olivine-dominated sandstone is common, lateral to the vent/crater and suggests extensive reworking during regional marine transgression.

LOWER COLORADO KIMBERLITE (JOLI FOU, VIKIING & WESTGATE FMS)

The youngest eruptive events associated with the Star Kimberlite occur within the predominantly marine Lower Colorado Group (Joli Fou, Viking and Westgate formations). The Lower Colorado Group consists of a heterolithic succession dominated by black, silty shale with subordinate siltstone and silty, commonly glauconitic, very fine-grained sandstone. Kimberlite beds, which occur at several horizons within the Joli Fou Formation, consist of terrestrial airfall deposits near the vent and marine airfall deposits, that commonly exhibit evidence of wave-reworking, in more distal settings (KE-4, Fig. 1).

Correlations based on mineralogy, geochemistry and geochronology indicate that kimberlite that occurs in the main Star 020 feeder vent and tephra cone was deposited contemporaneous with several kimberlite airfall horizons encased by black shale of the Joli Fou Formation in more distal settings. Cross-stratified and current ripple-laminated fine- to medium-grained olivine-dominated sandstone commonly caps primary airfall kimberlite and occurs subjacent to either shale beds (distal settings) or airfall kimberlite horizons (proximal settings). In several cases, abrupt hiatal surfaces characterized by *Glossifungites*-assemblage burrows and large fractures separate reworked olivine sandstone beds from overlying primary airfall kimberlite. Perovskite fractions analysed from Joli Fou feeder vent and overlying kimberlite pyroclastic samples resulted in two ^{206}U-^{238}Pb perovskite dates of 103.0 ± 1.0 Ma and 102.8 ± 0.8 Ma (Heaman and Kjarsgaard, 2002).

Kimberlite beds that occur in the Westgate Formation also consist of pyroclastic airfall olivine lapilli tuffs that commonly exhibit evidence of wave reworking. It is as yet uncertain whether Westgate kimberlites are sourced from the Joli Fou eruptive complex or from another, as yet unlocated vent. Black shale-encased kimberlite beds, deposited as subaqueous debris flows and turbidites are common in the Lower Colorado Group, particularly the Viking and Westgate formations. These occur throughout the study area, however they are thicker and coarser grained towards the Star vent complex on the western side of the study area.

SUMMARY

Radiometric age determination and micropaleontologic evidence support the hypothesis that multiple kimberlite eruptive phases occurred. Interfingering of kimberlitic and non-kimberlitic lithologies, as well as physical bedforms and rooted horizons observed in drill-core provide additional evidence that multiple eruptions occurred, and appreciable time elapsed between eruptions. Our analyses show that, during its multi-eruptive history, the Star Kimberlite body evolved from a feeder vent and overlying shallow asymmetric tuff ring, into a positive-relief tephra cone. Initial volcanism resulted in formation of a pipe-shaped feeder vent and overlying maar complex. Subsequent eruptions, dominated by subaerial deposits, resulted in a positive-relief, cone-shaped tephra cone over the Star Kimberlite feeder vent/tuff ring. The shape of this tephra cone was modified during marine transgression, resulting in wave-reworked kimberlite sand along the fringes of the cone and kimberlitic event deposits (tempestites, turbidites, debris flows) in more distal settings.

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