GEOLOGY OF THE FORT A LA CORNE KIMBERLITES, SASKATCHEWAN

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ABSTRACT

The Fort a la Corne kimberlite province comprises at least 70 magnetically defined bodies which range in size up >100 ha, and probably constitutes the largest known kimberlite province in the world. Most of the bodies are crater-facies Group-1 kimberlites. Although these kimberlites formed at 95 Ma during a period of fairly continuous marine sedimentation, they were subaerial volcanoes. The whole province may have taken some 25 Ma to form, with the main craters being restricted to the last 5-10 Ma. Most of the bodies seem to have shallow craters, usually less than 1300 m in diameter. Formation of these craters may be similar to that of maars. Development of the craters seems to have been confined to, and influenced by, the 200 m of poorly consolidated Cretaceous fine-grained sediments which overlie the indurated Paleozoic carbonates. Diatreme or root zones have not yet been identified. The craters were infilled relatively rapidly with primary pyroclastic airfall lapilli tuffs and ash, with little or no resedimentation. The styles of eruption were variable, but included lava spatter and lava fountaining. Other more explosive eruptive styles may be specific to kimberlites, reflecting the unusual properties of these magmas. Such eruptions can explain the unique mega-graded beds, which range up to 90 m in thickness. Unusual olivine-dominated crystal tuffs occur here also. The eruption processes can considerably modify the *in-situ* diamond grade relative to that of the original magma.

INTRODUCTION

The Fort a la Corne (FALC) kimberlite province was discovered by Uranerz Exploration and Mining Ltd. in 1988. Since then, evaluation of these bodies by drilling has been ongoing with joint-venture partners Cameco Corporation and Monopros Ltd. The province occurs 80 km east of Prince Albert in Saskatchewan and includes at least 70 magnetically defined bodies which range in size to >100 ha. So far, 41 of these anomalies have been confirmed as kimberlites by drilling. These bodies are located in a zone 45 km long and 30 km wide, and probably form the largest known kimberlite province in the world. Significant amounts of diamonds have been recovered, but no economic deposits have been found yet. Lehnert-Thiel *et al.* (1992) discussed the location, discovery, evaluation to 1991, and preliminary geology of these bodies. This paper presents the results of the investigation of the geology of 25 bodies on the basis of 44 drillholes containing approximately 5 km of kimberlite core.

GEOLOGICAL SETTING

These bodies are covered by ±100 m of Quaternary glacial material. The kimberlites were emplaced into Cretaceous rocks comprising ±100 m of clayey fine sediments, silts, and sandstone (Mannville Formation) overlain by ±100 m of marine shales (Ashville Formation). The Mannville formed in coastal marine, subaerial flood-plain and/or lacustrine environments (J. Christopher, R.G. Walker unpublished reports). The shales were deposited towards the edge of the Western Interior Seaway, a broad shallow epicontinental sea with migrating shorelines. Most of these sediments are still poorly consolidated. They unconformably lie on ±200 m of Paleozoic indurated carbonates below which is the Precambrian basement. Further details of the country rocks are given by Lehnert-Thiel *et al.* (1992).

CLASSIFICATION

These bodies are composed of volcaniclastic rocks, all of which are classified texturally as crater-facies. No hypabyssal or diatreme-facies rocks have been encountered. A petrological rock classification of crater-facies rocks is notoriously difficult as groundmass minerals usually have not had the opportunity to crystallize. The FALC rocks are composed of two generations of olivine and, in some clasts, groundmass monticellite, spinel, perovskite, mica, primary serpentine, and carbonate. These features are sufficient to show that most of the bodies consist of typical Group-I kimberlites. Some of the rocks can be classified mineralogically as monticellite kimberlites. Most of the kimberlites carry a typical suite of mantle-derived constituents. There is some variation in magma type, with a few less-kimberlite-like rocks resulting from different pre-emplacement petrogenetic processes.

CRATER SIZE, SHAPE, AND FORMATION

The drilled FALC kimberlite bodies have a shallow saucer to champagne-glass shape, with diameters mainly of 500 to 1300 m and depths of up to 200 m. Composite volcanic centres occur which include some larger bodies (>100 ha). Observed kimberlite to country-rock contacts range from 0 to 60°. Some contacts can be seen to crosscut the bedding in the adjacent sediments. These bodies are comparable in size and shape to the craters of kimberlites, lamproites, and maars, although some may have greater diameter/depth ratios. Development of the craters seems to be confined to, and influenced by, the 200 m of poorly consolidated Cretaceous fine-grained sediments. These bodies must represent craters explosively excavated into these soft sediments. Development of deeper pipes seems to be rare. Only one example was encountered (to a depth of 375 m), and it contains bedded crater-facies material. The FALC bodies, therefore, do not conform to the classic kimberlite pipe model as there is no evidence of the development of any diatremes or root zones. There is, however, a remarkable similarity to both the geological setting and the nature of the kimberlites at Mbuji-Mayi in Zaire (Meyer de Stadelhofen 1963; Demaiffe *et al.* 1991), suggesting that the FALC kimberlites are not unique. These similarities are unlikely to be a coincidence, and the deviations from the model, therefore, probably result from different near-surface geology. This difference may be the lack of a competent cap rock within the country rocks at FALC and in Zaire. In these instances the eruptions are similar to those of many other small volcanoes. In kimberlites elsewhere, a cap rock contains the very volatile-rich magma(s) subsurface, with diatreme development resulting from subsequent breakthrough (Clement 1982; Clement and Reid 1989). The apparent relationship of the near-surface geology to the different FALC pipe model supports, rather than negates, the classic kimberlite pipe model and suggested emplacement processes for these kimberlites (Hawthorne 1975; Clement 1982; Clement and Reid 1989).

The main FALC craters were preceded by common small kimberlites which comprise conformable graded beds up to 5m thick of unreworked pyroclastic airfall material within the Cretaceous sediments. The nature of the enclosing sediments suggests that the intra-Mannville kimberlites were deposited on subaerial flood plains or in lakes. One example of an intra-Ashville shale kimberlite could represent a submarine eruption.

As a generalization, excavation of the main FALC craters into the country rocks occurred with the deposition of little or none of the resulting primary or xenolithic material within the craters. No evidence of base-surge deposits is present in the kimberlite drillcores. Elsewhere in the world most base-surge materials associated with maars occur as extra-crater deposits related to crater-forming, not crater-infilling, events. No extra-crater deposits are available at FALC to allow further evaluation of the crater-forming events. The FALC crater formation was probably similar to that of maars, which are usually considered to result from phreatomagmatic eruptions. At FALC, a sandstone unit which occurs at the base of the Mannville Formation is a modern aquifer. This unit probably became saturated after the end of deposition of the Mannville Formation, following the marine transgression at the beginning of the Ashville. Only then could this unit form a source of water to fuel phreatomagmatic eruptions. The other Cretaceous country-rock sediments may have been wet but are unlikely to be permeable. The stratigraphic position of this aquifer is also the point from which many of the craters appear to flare. The timing of the formation of this aquifer is consistent with the presence of maar-like craters being formed during the Ashville, but not during the earlier Mannville. The effects of carbon dioxide on the formation of either maars or the FALC craters are not known.

MAIN CONSTITUENTS AND ROCK TYPES

These volcaniclastic kimberlites are composed predominantly of a mixture of juvenile lapilli and single crystals which are mainly olivine. The clasts are mostly <10 mm in size, but range up to 10 cm. The lapilli vary in shape from spherical or ovoid, to irregular-curvilinear or amoeboid. The groundmasses are quenched and can be composed of isotropic serpentine, but no true glass was observed. Some lapilli contain vesicles, but clasts resembling scoria are extremely rare. The nature of the juvenile lapilli results from the fragmentation of very fluidal magma. Fresh olivine is common. Other constituents form a minor part of these rocks. Kimberlite-transported xenolithic material comprises mantle-derived megacrysts, eclogites, peridotites that include garnet-bearing, coarse, porphyroclastic and metasomatic types, as well as clasts of the basement and Palaeozoic carbonates. Some autoliths are present, many of which can be discerned to consist of earlier crater-facies kimberlite. Xenoliths derived from the crater wall include poorly consolidated Ashville shale up to 13 m in size, and far less common xenoliths or quartz xenocrysts derived from the Mannville sediments. Most of the rocks have loosely packed clast-supported textures and are poorly sorted. The inter-clast matrix is composed of mainly serpentine, carbonate, and magnetite.

The proportion of juvenile lapilli to single grains of olivine varies; thus, the main rock types range from juvenile lapilli tuffs (or coarse ash) to crystal or olivine tuffs (or coarse ash). The total kimberlite package in any one drillcore or single rock does not equal that of a kimberlite magma. The deviations reflect post-eruption processes. Most rocks have undergone some sorting. Overall at FALC, ash and coarse ash-size clasts, comprising matrix and commonly single olivine phenocrysts, are not common. Some, but not all, of the drillcores display well-developed plane-parallel graded bedding. Individual beds vary from a few millimetres to at least 90 m in thickness. The latter seem to be unique as, elsewhere in the world, graded beds greater than 10 m in thickness are unusual, although examples up to 30 m are known (R.A.F. Cas and J.V. Wright, pers. comm.). Bedding dips vary from horizontal to 80°, and some disturbed bedding is present. There is also some suggestion of fining away from the vents in a few bodies. Although not easy to determine, deposits resulting from different pulses of mantle-derived kimberlite magmas were identified by using such features as lapilli type, the nature of the kimberlite-transported constituents, changes in nature of the bedding, and some internal contacts.

AGE

Micas from two samples of the main kimberlites have yielded isotopic ages of 94-96 Ma (Lehnert-Thiel *et al.* 1992). Stratigraphic constraints suggest that the FALC kimberlite eruptions span at least 25 Ma. The main kimberlite crater formation was probably confined to the last ±5-10 Ma (perhaps 97.5-91 Ma), and the small precursors formed from 119 to at least 100 Ma.

NEAR-SURFACE EMPLACEMENT

The internal geology of each body is different, but one overall model seems to apply to the province. The main constituents of these kimberlites must have formed by pyroclastic processes. Many features show that resedimentation of the pyroclastic material was not an important process here. These features include the low particle density; the presence of occasional welding or molding of plastic lapilli; bomb sags and possible draping; *in-situ* impact-fragmented xenolithic bombs; the occurrence of composite lapilli showing that mixed lapilli populations result from recycling not resedimentation; the presence of different phases of eruption with associated marker horizons and sharp internal contacts; evidence of large-scale sorting resulting in the overall paucity of ash and the presence of mega-graded beds; the significant lack of abrasion or breakage on most juvenile and xenolithic clasts, many of which are very fragile; the lack of cross-bedding and other sedimentary features; the lack of incorporation of crater-wall material; and the paucity of imbricate structures.

The age of the kimberlites relative to the well-established stratigraphy of the area, and the observed nature of the country-rock shales, suggest that the kimberlites are likely to have erupted in submarine conditions (*e.g.*, Gent 1992; Aaron Oil 1993; Nixon *et al.* 1993). Features within the FALC kimberlites, however, show that most of the pyroclastic activity was subaerial. These features include the occurrence of fluidal – not quenched – lapilli shapes, welding and molding, vesicular lapilli, poor sorting of a wide range of clast sizes, lack of resedimentation, and a general lack of fines. This evidence and the age of the kimberlites suggest that the main crater infilling is likely to have occurred during the ±3 Ma hiatus (approximately 94.5 - 91 Ma) in the marine sedimentation during a regression within the upper Ashville Formation (McNeil and Caldwell 1981). This suggests that the main process of deposition was pyroclastic airfall. Although the eruptions were predominantly subaerial, there is evidence for some subaqueous deposition of the airfall material into small volumes of standing water which must be crater lakes. This evidence is based mainly on the retention of more fines and much better sorting resulting in planar laminated bedding. No true fine-grained lake sediments were found, suggesting that the craters did not remain exposed for long periods. Very minor units of contrasting rock types suggest that limited resedimentation and submarine deposition may have occurred.

The styles of eruption were highly variable. The less explosive eruptions varied from lava spatter with welding/molding and no bedding, to higher lava fountains, to Strombolian-type eruptions in which bedding can occur. These eruptions resulted in the formation of amoeboid lapilli tuffs with bedding up to perhaps 12-15 m in thickness. Bed thicknesses may be greater here relative to other magma types as a result of high eruption columns relating to the faster ascent velocities of kimberlite magmas from the mantle. The ash produced in the higher energy range of these eruptions was commonly removed, presumably by wind action. Other much more explosive eruptive styles may be kimberlite-specific, reflecting the unusual properties of these magmas, mainly their low viscosities and high carbon dioxide contents. These eruptions resulted from the rapid degassing of some of the FALC magmas above the vent, a process which is the extrusive equivalent of the intrusive diatreme formation in other kimberlites. Pelletal lapilli similar to those characteristic of diatreme-facies kimberlites were also produced. These explosive eruptions must have formed high-energy eruption columns. Material from such eruption columns is readily transported from source, usually limiting the thickness of any resulting graded beds. The abundant carbon dioxide in the eruption column derived from the degassing at FALC must have inhibited movement of the pyroclastic material from the vent, thus resulting in the formation of the unique mega-graded beds within the craters.

The unusual olivine tuffs are thought to form by the physical separation of the crystals from low-viscosity magmas. Kimberlites, being some of the most crystal-rich and fluidal magmas known, are good candidates for the formation of crystal tuffs.

The inter-clast cement formed through the crystallization of minerals from kimberlitic fluids derived from subsequent eruptions. Multiple and sequential phases of cementation show that lithification occurred during the infilling of the craters.

CONCLUSIONS

Kimberlite emplacement at Fort a la Corne seems to have started with the conformable deposition of small beds of pyroclastic kimberlite within some Cretaceous floodplain sediments. Later shallow subaerial craters were explosively excavated into subsequently deposited poorly consolidated marine shales, probably by processes similar to maar formation. These processes may well have been phreatomagmatic eruptions relating to the formation of an aquifer after the eruption of the precursor kimberlites. The craters were relatively rapidly and completely infilled by primary pyroclastic airfall material. Eruption styles varied from lava spatter to lava fountaining, and to a probable kimberlite-specific type of explosive eruption which formed unique mega-graded beds. These and other unusual deposits within the FALC bodies reflect the different properties of kimberlite magmas. Some pyroclastic deposition into short-lived crater lakes occurred. During eruption, existing volcaniclastic deposits were cemented by upward-percolating kimberlitic fluids derived from subsequent eruptions. This early lithification not only prevented further interaction of the magma with the aquifer causing magmatic rather than phreatomagmatic eruptions, but also protected the kimberlites from reworking, alteration, and erosion. Extra-crater deposits must have formed, and may have consisted of xenolith-rich base-surge and airfall deposits overlain by distal xenolith-poor airfall material. These deposits are unlikely to have been cemented by vent-derived kimberlitic fluids, so the deposits would have been prone to erosion. The local geology is probably responsible for the lack of diatreme development. The Fort a la Corne mode of emplacement is therefore a second style of eruption or model which is applicable to kimberlites. If the FALC craters are similar to maars, the formation of each body may have been a very shortlived event despite the fact that the age of province spans some 25 Ma. The eruption processes considerably modified the *in-situ* diamond grade from half to triple that of the original magma.

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About the authors:

Barbara H. Scott Smith graduated in 1972 with a B.Sc. (Hons.) and then a Ph.D. in Geology from Edinburgh University in 1977, following which she worked fot five years as a Research Mineralogist for Anglo American Researach Laboratories in Johannesburg, South Africa. In 1982 she emigrated to Canada, where she works as a private consultant. Her activities have included investigations into the petrology of kimberlites and similar rock types, with an emphasis on petrography in relation to world-wide diamond-exploration programs and mining ventures. Her project experience includes Canada, USA, Greenland, Australia, South Africa, Lesotho, Zambia, Ivory Coast, Botswana, China, India, Europe, Brazil, and Russia. The is a registered Professional Geologist in B.C., a member of CIM and other professional societies, and is a member of the IUGS sub-commission for the nomenclature of kimberlite and related rocks.

Rodney Orr is a senior geologist with Uranerz Exploration & Mining Ltd. where he is responsible for diamond exploration, including the Fort à la Corne Joint Venture project. He graduated from Concordia University (Montrèal) in 1975 with a B.Sc. in geology, and joined Uranerz in 1977 in their Montrèal office. In 1982 he moved to the Saskatoon office, participating in a number of exploration projects throughout western Canada. In 1990, he assumed responsibility for the diamond-exploration programs. Mr. Orr is a member of CIM and GAC, and is currently the Chair of the Exploration Section of the Saskatchewan Mining Association.

Philip Robertshaw graducated in 1970 with an M.Sc. in mining geophysics from the University of London, England. Emigrating to Canada in 1970, he worked for six years as a geophysicist/party chief with Seigel Associates (later Scintrex Limited) of Toronto, in a variety of ground and airborne geophysical surveys in North and South America, Africa, Australia, and Asia. In 1976 he moved to Cominco Limited in Toronto, working on a base-metal exploration in eastern Canada. In 1978 he joined Uranerz Exploration and Mining Limited, initially in La Ronge, Saskatchewan, more recently based in Saskatoon. As senior geophysicist, he has been active in uranium exploration in the Athabasca Basin, the search for kimberlites in western Canada, and for gold in Canada and the USA. He is a member of SEG and CIM.

Ron Avery was educated at the University of Saskatchewan (B.A.) and at Queen's University, graduating there in 1988 with a B.Sc. degree. Since then, he has been employed as a geologist by Uranerz Exploration and Mining Limited working on a variety of projects, among them the evaluation of the Fort à la Corne kimberlites.

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Geology of the Fort a la Corne Kimberlites, Saskatchewan

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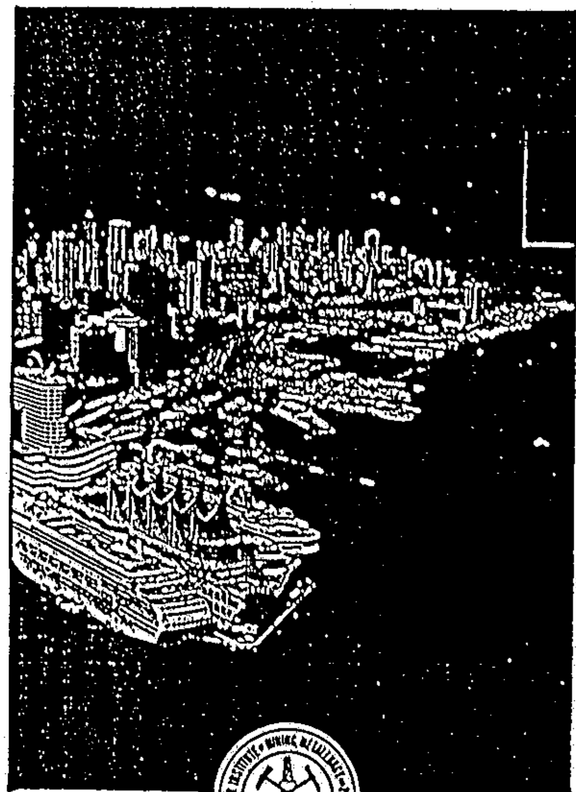
The Fort a la Corne kimberlite province was discovered under 100 metres of glacial cover by Uranerz Mining and Exploration Ltd. in 1988. Since then evaluation of these bodies by drilling has been ongoing with joint venture partners Cameco Corporation and Monopros Limited. The province comprises at least 70 magnetically defined bodies which range in size up to over 100 hectares. They are located in a 45 kilometre long and 30 kilometre wide zone and probably form the largest known kimberlite province in the world. Significant amounts of diamonds have been recovered but no economic deposits have been found yet. Most of the bodies comprise crater facies Group1 kimberlites. Although these kimberlites formed at 95Ma during a period of fairly continuous marine sedimentation, they were subaerial volcanoes. The whole province may have taken some 25Ma to form, with the main craters being restricted to the last 5 to 10Ma. Most of the bodies appear to comprise shallow craters usually less than 1,500 metres in diameter. Development of the craters appears to be confined to within, and influenced by, the 200 metres of poorly consolidated Cretaceous fine sediments which overlie the indurated Palaeozoic carbonates. Diatreme of root zones have not yet been identified. Formation of these craters may be similar to maars. The craters where infilled relatively rapidly with primary pyroclastic airfall lapilli tuffs and ash with little or no reworking. The styles of eruption were variable but included lava spatter and lava fountaining. Other more explosive eruptive styles may be specific to kimberlites reflecting the unusual properties of these magmas. Such eruptions can explain the unique mega-graded beds which range up to 90 metres in thickness. Unusual olivine dominated crystal tuffs occur here also. The eruption processes can considerably modify the insitu diamond grade relative to that of the original magma.



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