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Geology of the Victor Kimberlite, Attawapiskat, Northern Ontario, Canada: cross-cutting and nested craters☆

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Abstract

The pipe shapes, infill and emplacement processes of the Attawapiskat kimberlites, including Victor, contrast with most of the southern African kimberlite pipes. The Attawapiskat kimberlite pipes are formed by an overall two-stage process of (1) pipe excavation without the development of a diatreme (sensu stricto) and (2) subsequent pipe infilling. The Victor kimberlite comprises two adjacent but separate pipes, Victor South and Victor North. The pipes are infilled with two contrasting textural types of kimberlite: pyroclastic and hypabyssal-like kimberlite. Victor South and much of Victor North are composed of pyroclastic spinel carbonate kimberlites, the main features of which are similar: clast-supported, discrete macrocrystal and phenocrystal olivine grains, pyroclastic juvenile lapilli, mantle-derived xenocrysts and minor country rock xenoliths are set in serpentine and carbonate matrices. These partly bedded, juvenile lapilli-bearing olivine tuffs appear to have been formed by subaerial fire-fountaining airfall processes.

The Victor South pipe has a simple bowl-like shape that flares from just below the basal sandstone of the sediments that overlie the basement. The sandstone is a known aquifer, suggesting that the crater excavation process was possibly phreatomagmatic. In contrast, the pipe shape and internal geology of Victor North are more complex. The northwestern part of the pipe is dominated by dark competent rocks, which resemble fresh hypabyssal kimberlite, but have unusual textures and are closely associated with pyroclastic juvenile lapilli tuffs and country rock breccias ± volcaniclastic kimberlite. Current evidence suggests that the hypabyssal-like kimberlite is, in fact, not intrusive and that the northwestern part of Victor North represents an early-formed crater infilled with contrasting extrusive kimberlites and associated breccias. The remaining, main part of Victor North consists of two macroscopically similar, but petrographically distinct, pyroclastic kimberlites that have contrasting macrodiamond sample grades. The juvenile lapilli of each pyroclastic kimberlite can be distinguished only microscopically. The nature and relative modal proportion of primary olivine phenocrysts in the juvenile lapilli are different, indicating that they derive from different magma pulses, or phases of kimberlite, and thus represent separate eruptions. The initial excavation of a crater cross-cutting the earlier northwestern crater was followed by emplacement of phase (i), a low-grade olivine phenocryst-rich pyroclastic kimberlite, and the subsequent eruption of phase (ii), a high-grade olivine phenocryst-poor pyroclastic kimberlite, as two separate vents nested within the original phase (i) crater. The second eruption was accompanied by the

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formation of an intermediate mixed zone with moderate grade. Thus, the final pyroclastic pipe infill of the main part of the Victor North pipe appears to consist of at least three geological/macrodiamond grade zones.

In conclusion, the Victor kimberlite was formed by several eruptive events resulting in adjacent and cross-cutting craters that were infilled with either pyroclastic kimberlite or hypabyssal-like kimberlite, which is now interpreted to be of probable extrusive origin. Within the pyroclastic kimberlites of Victor North, there are two nested vents, a feature seldom documented in kimberlites elsewhere. This study highlights the meaningful role of kimberlite petrography in the evaluation of diamond deposits and provides further insight into kimberlite emplacement and volcanism.

Keywords: Pyroclastic; Juvenile lapilli; Petrography; Olivine phenocryst; Hypabyssal; Emplacement; Evaluation; Volcanology

1. Introduction

The ca. 170 Ma Victor kimberlite is the largest in a cluster of 19 kimberlites discovered in the James Bay Lowland, some 100 km west of Attawapiskat in Northern Ontario (Fig. 1; Kong et al., 1999). Victor comprises two adjacent but separate pipes, termed Victor North and Victor South, with a total area of approximately 15 ha (Fig. 2). Victor South is dominated by pyroclastic kimberlite, whereas Victor North is internally more complex, consisting of pyroclastic kimberlites similar to those in Victor South, plus hypabyssal-like rocks (Fig. 2). The shapes of the Victor pipes, the kimberlite infills and thus the emplacement processes, are different to those of most southern African kimberlites (Field and Scott Smith, 1999). Victor also differs from other kimberlite occurrences in Canada, such as the Gahcho Kue (Hetman et al., this volume) and Lac de Gras kimberlites (Graham et al., 1999; Carlson et al., 1999). The Victor and Fort a la Corne kimberlites (Scott Smith et al., 1998; Berryman et al., 2004) have contrasting pipe shapes and host rock geology; however, both are infilled predominantly with pyroclastic kimberlite and both lack diatreme facies kimberlite (sensu Field and Scott Smith, 1998, 1999).

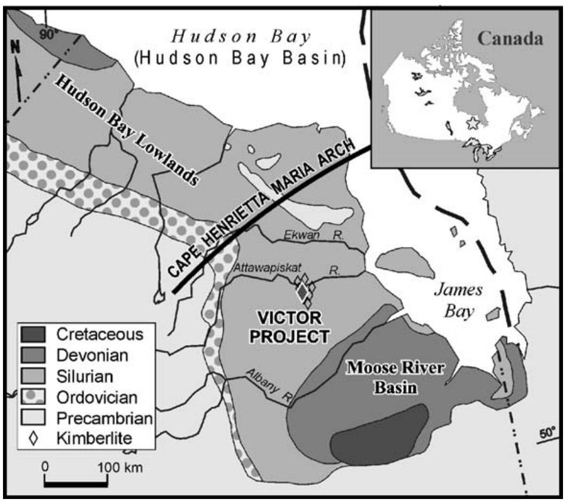


Fig. 1. Regional geological setting and location of the Attawapiskat kimberlites and Victor Project (after Kong et al., 1999; Norris, 1986).

The exploration history and general geology of the Attawapiskat kimberlites, including Victor, are described by Kong et al. (1999). Fowler et al. (2001) outline the phased approach used by De Beers for diamond exploration in Canada, with reference to the Victor kimberlite. Wood (2000) provides additional information on the advanced exploration and evaluation of Victor.

This study provides insight into the volcanology of a single kimberlite occurrence and is based on data obtained during a 15-year period by a multidisciplinary team. Pre-1998 data for Victor, which included eight preliminary delineation drill holes, were presented by Kong et al. (1999). Subsequent investigations are founded on recent extensive drill core logging (71 holes; Fig. 3), petrographic examination of drill core samples (approximately 600 samples), modal analysis by pointcounting of 12 selected samples and macrodiamond results obtained from the recent short interval bulk sampling of 36 large diameter drill holes (each 610 mm in diameter and drilled to maximum of 252 m), as well as from earlier medium-diameter drill holes (Fowler et al., 2001). Kimberlite textural terminology and classification is after Field and Scott Smith (1998).

Bulk sampling of the identified Victor mineral resource indicates an estimated average grade of 25

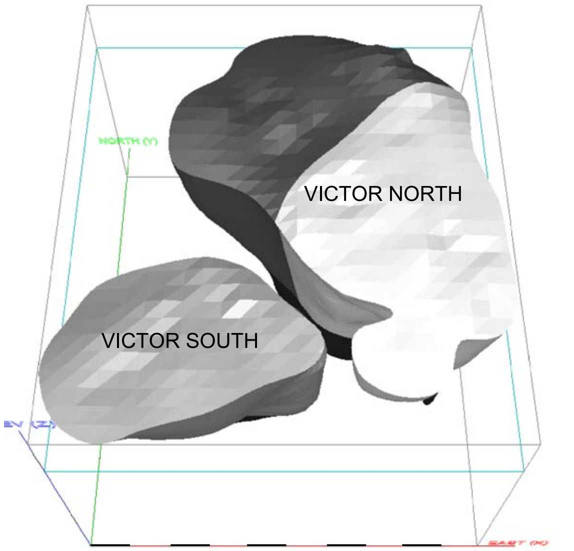


Fig. 2. Victor South and Victor North kimberlite pipes. Pale and medium grey = pyroclastic kimberlite; dark grey = hypabyssal-like kimberlite. Intervals on the east axis are 50 m.

carats/100 tonnes, although diamond distribution within Victor North is complex and highly variable, most probably due to the complex internal geology, which shows evidence for both cross-cutting and nested craters.

2. Geological setting and local country rock geology

The Attawapiskat area is part of the Hudson Platform that consists of flat-lying Paleozoic sedimentary rocks unconformably overlying the Precambrian Superior craton (Kong et al., 1999). The Attawapiskat kimberlites are located on the southern flank of the Cape Henrietta Maria (or Transcontinental) Arch, which separates the erosional remnants of two adjacent cratonic sedimentary basins, the Hudson Bay Basin and the Moose River Basin (Fig. 1; Norris, 1986). The Paleozoic sediments can attain thicknesses of up to 800 m in the Moose River Basin and up to

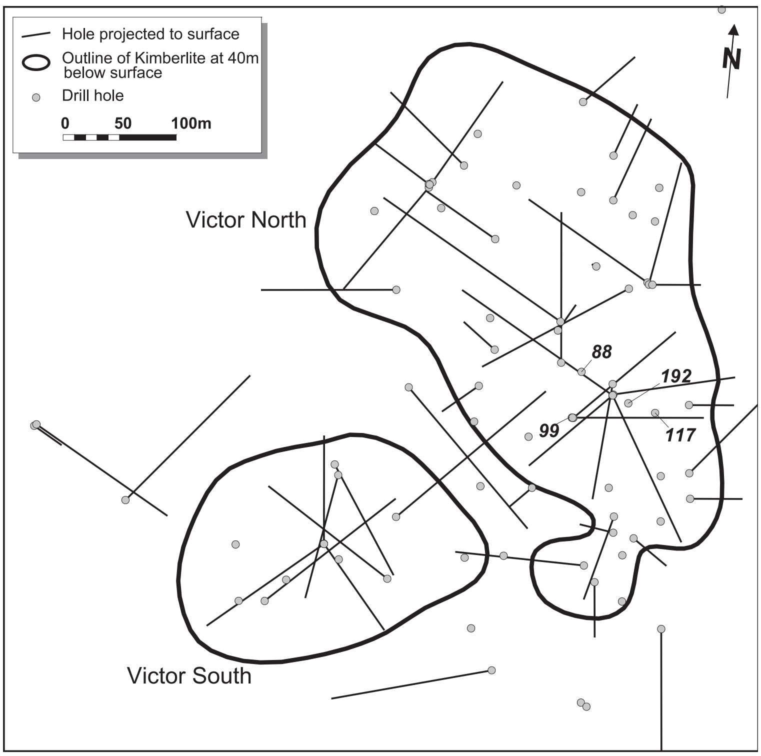


Fig. 3. Map showing outline of Victor North and Victor South with drill core collar locations. Data for samples from the four numbered holes are given in Tables 1 and 2 and discussed in Sections 4.2.2 and 4.2.3.

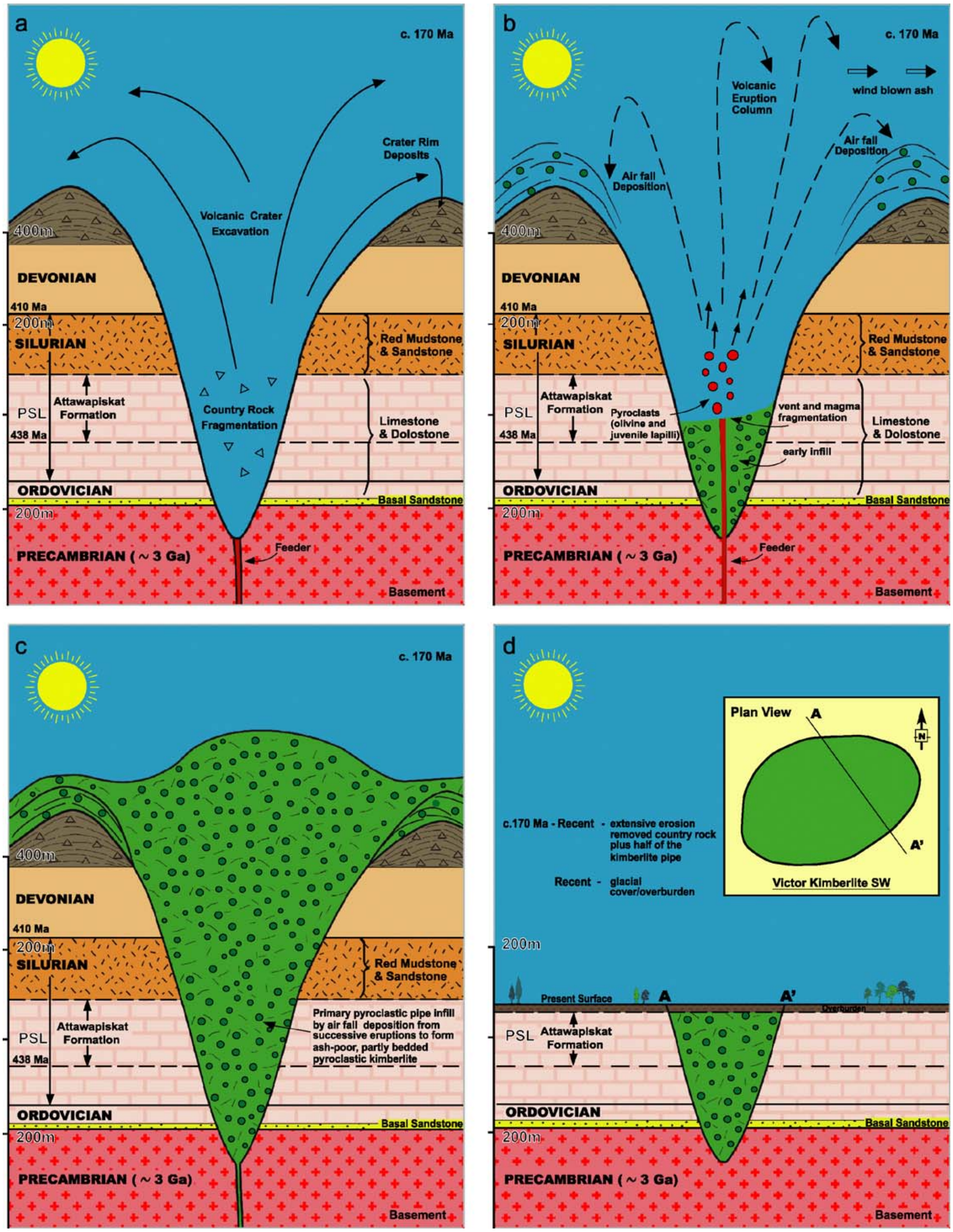


Fig. 4. Emplacement model for Victor pyroclastic kimberlite: (a) initial crater excavation by possible phreatomagmatic eruption processes (crater flares from basal sandstone unit, a known aquifer); (b) subsequent crater infilling by subaerial pyroclastic fire-fountaining processes; (c) the crater infill; and (d) the present erosional surface with a thin veneer of glacial overburden; pipe shape was based on modeled cross section A–A′ through Victor South. PSL = present surface level.

1800 m in the Hudson Bay Basin, although they thin towards the arch (Norris and Sanford, 1968) and are approximately 250 m thick in the vicinity of the kimberlites. The Attawapiskat area is transected by a set of minor faults striking northwest–southeast and northeast–southwest, in addition to the Winisk River Fault system and the Mackenzie and Matchewan/Hearst dyke sets.

The Paleozoic sediments hosting the Victor kimberlites consist of Ordovician massive microcrystalline limestone and dolostone with a basal sandstone–siltstone unit, which unconformably overlies the basement rocks. The Ordovician sediments are unconformably overlain by Silurian sedimentary rocks, which consist of a basal mudstone and shale unit, limestone of the Severn River Formation, limestone and dolostone of the Ekwan Formation, and fossiliferous limestone of the Attawapiskat Formation (Kong et al., 1999). Upper Silurian and Devonian sediments once overlay the now-exposed Attawapiskat Formation, but have been eroded due to the continued uplift of the Transcontinental Arch (Norris, 1986) during the late Paleozoic to Mesozoic era (Johnson et al., 1991). The original thickness of the sediments at the time of kimberlite emplacement in the Jurassic (Kong et al., 1999 and references therein) is estimated at about 600 m, suggesting that the kimberlite pipes have been significantly eroded, with only approximately half the original pipes now being preserved. Pleistocene glacial till sheets and coastal Holocene deposits overlie the Attawapiskat kimberlites and vary in thickness from 0 to 30 m (Kong et al., 1999).

3. Geology of the Victor pipes

The adjacent Victor South and Victor North kimberlite pipes (Fig. 2) define subcircular plan view surface expressions and are steep-sided, with pipe walls dipping ~70°. Although the pipes occur as separate bodies at the present surface, their close proximity and the slope of the pipe contacts suggest that they coalesced or cross-cut at higher levels. Both pipes appear to flare at or just below the Precambrian basement–Ordovician sediment unconformity, approximately 275 m below the present surface (Fig. 4). Early core drilling of both pipes enabled an initial assessment of pipe shapes, internal geology and emplacement processes (Kong et al., 1999). Subsequent, more extensive drilling, including vertical, shallow and deep delineation, as well as geotechnical drill holes (Fig. 3), has led to the advances in understanding of the Victor kimberlite presented in this study.

Victor is predominantly composed of archetypal spinel carbonate kimberlite and less common monticellite kimberlite. The pipes are dominated by two contrasting textural types of kimberlite (Fig. 2): pyroclastic and hypabyssal-like kimberlite (see Section 4).

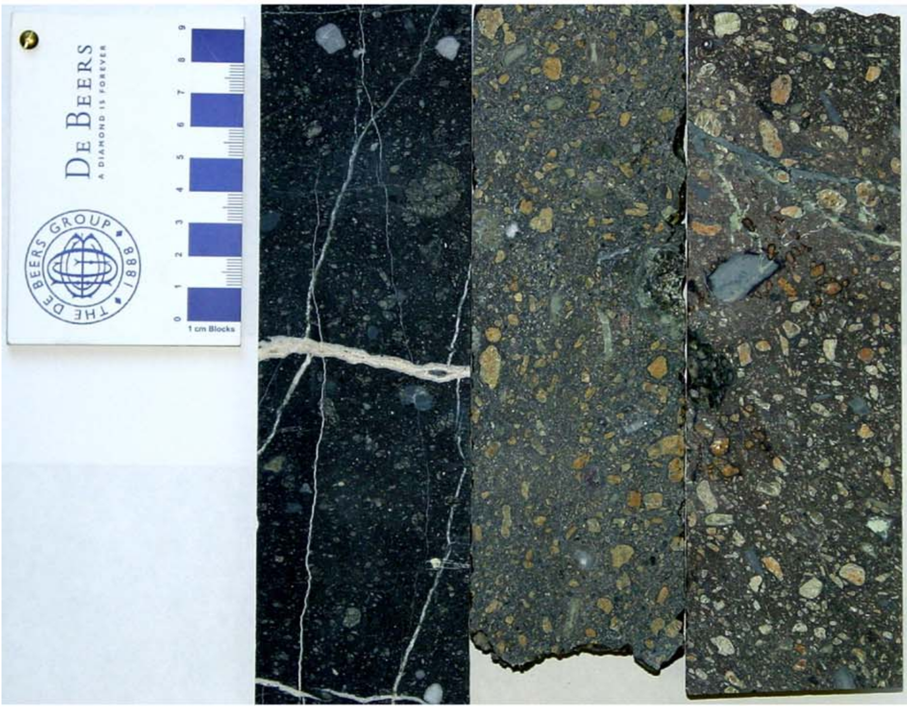
Kong et al. (1999) interpreted the dominant infill of Victor South and the main part of Victor North as pyroclastic kimberlite, based on a number of diagnostic macroscopic and microscopic characteristics. Features that negate a tuffisitic kimberlite interpretation were also outlined in that study. The pyroclastic kimberlites at Victor are predominantly composed of clast-supported, discrete macrocrystal and phenocrystal olivine grains and juvenile lapilli, set in serpentine and carbonate interclast matrices. Minor country rock xeno-

Table 1
Results of modal analysis by pointcounting of 12 Victor North pyroclastic kimberlite samples

Sample	Drill hole	OM-d	OM-jl	OP-d	OP-jl	G-jl	Xc	CRX	ICM
VNloPK									
2036	117	26.0	18.0	3.5	2.2	15.7	1.2	2.3	31.1
2042	117	26.6	17.1	3.9	2.8	14.7	3.1	4.2	27.6
2571	192	27.9	17.5	3.0	2.7	13.9	5.0	6.3	23.7
2577	192	26.6	17.9	2.8	3.3	15.4	5.1	4.0	24.9
1343	99	32.2	14.5	4.0	3.3	13.9	3.5	3.3	25.3
1345	99	22.2	13.8	4.9	2.1	11.1	5.9	5.9	34.1
Mean		26.9	16.5	3.7	2.7	14.1	4.0	4.3	27.8
VNhoPK									
2053	117	9.4	20.0	16.8	7.0	9.1	9.0	6.1	22.6
2057	117	21.4	3.3	16.1	5.3	2.2	7.1	16.2	28.4
2599	192	14.4	13.7	10.4	9.7	15.0	6.9	6.5	23.4
2602	192	15.5	9.1	15.0	4.3	9.4	9.3	10.6	26.8
1354	99	28.5	7.3	12.0	7.1	8.3	7.0	9.6	20.2
1360	99	20.2	15.7	8.0	10.8	13.1	7.3	5.6	19.3
Mean		18.2	11.5	13.1	7.4	9.5	7.8	9.1	23.5

OM-d, OP-d = discrete olivine macrocrysts and olivine phenocrysts, respectively; OM-jl, OP-jl = olivine macrocrysts and olivine phenocrysts, respectively, constituting juvenile lapilli; Gjl = juvenile lapilli groundmass (i.e., juvenile lapilli excluding constituent olivine); Xc = mantle-derived xenocrysts (e.g. garnet); CRX = country rock xenoliths; ICM = interclast matrix. VNloPK (olivine phenocryst-poor) and VNhoPK (olivine phenocryst-rich) refer to contrasting pyroclastic kimberlite phases in Victor North (Section 4.2). A total of 1000 points per sample was counted.

a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A DIAMOND IS FOREVER
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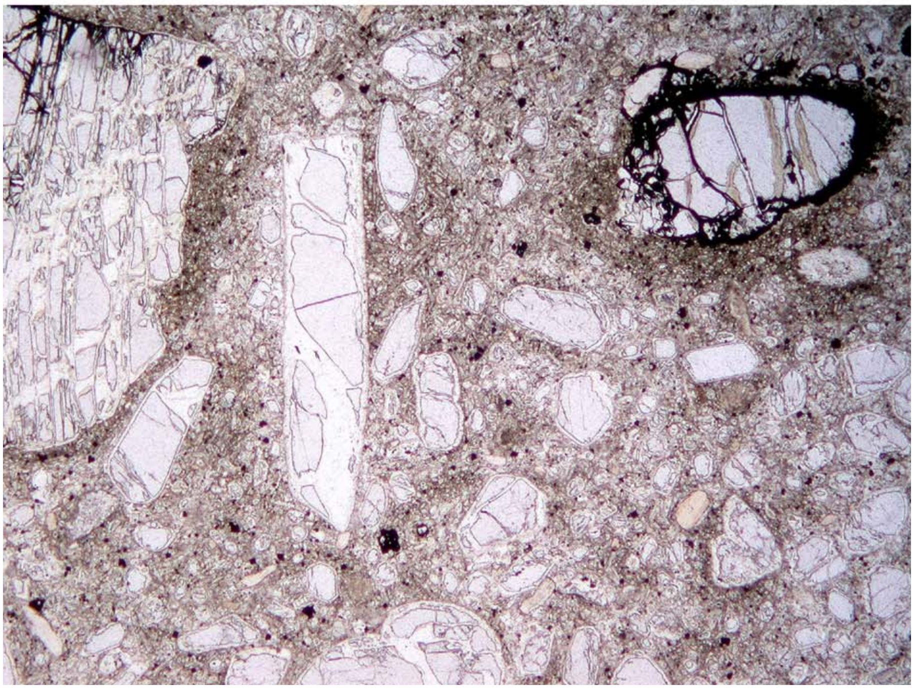
b



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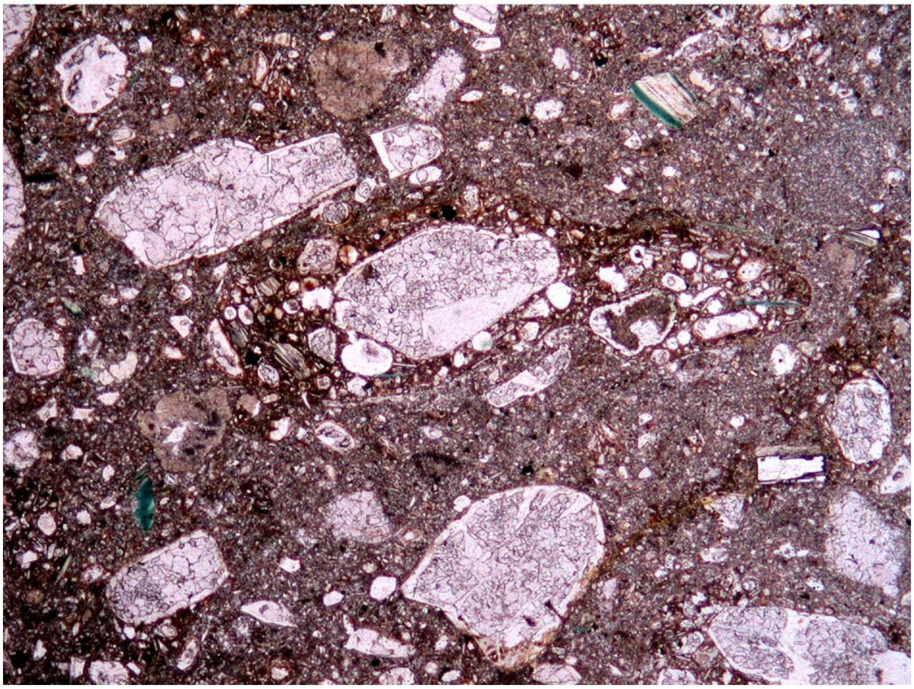


Fig. 5. Typical appearance of the hypabyssal-like kimberlite in (a) polished drill core slab and (b) thin section, and (c) typical appearance in thin section of the pyroclastic juvenile lapilli tuffs that occur between the contrasting phases of hypabyssal-like kimberlite in the northwestern part of Victor North. Photomicrograph b shows abundant uniformly distributed partly fresh macrocrystal and phenocrystal olivine, clast- to matrix-supported in a spinel and phlogopite-bearing carbonate-rich groundmass, and the unusual incipient lapilli-like texture of the hypabyssal-like kimberlite. Note the diffuse margins of the lapilli-like structures with the surrounding groundmass. PPL. FOV = 8 mm. Photomicrograph c shows the fine, ash-sized, carbonate-rich nature of the interclast matrix and an irregular vesicular lapillus in the juvenile lapilli tuffs. PPL. FOV = 3 mm.

liths and mantle-derived garnet, ilmenite, chrome diopside and mica are also present. In this paper, the term juvenile lapilli refers to discrete bodies formed from magma during eruption, i.e., juvenile pyroclasts. The juvenile lapilli in the Victor pyroclastic kimberlites may comprise partial or complete magmatic selvages on juvenile or xenolithic kernels (cores) or magmatic bodies without kernels. The majority of the Victor pyroclastic juvenile lapilli fall within the size range of lapilli (2–64 mm) in standard volcanological classification schemes (Cas and Wright, 1987). Table 1 presents the results of modal analysis by pointcounting of 12 representative Victor North pyroclastic kimberlite samples. The modal proportions of the main constituents of the samples are similar. The rocks are characterised by approximately equal proportions of discrete olivine grains (31% average), juvenile lapilli (31% average) and interclast matrix (26% average). Low proportions of country rock xenolithic and mantle-derived xenocrystic components are also present (average 6.7% and 5.9%, respectively). The pyroclastic kimberlites are further discussed in Section 4.

As noted by Kong et al. (1999), the presence of extrusive pyroclastic kimberlite to at least 300 m below the present surface in Victor North indicates that the Victor pipes are deep volcanic explosion craters. Those authors proposed that Victor South and much of Victor North formed in subaerial conditions by an overall two-stage process of (1) pipe excavation *without* the development of a diatreme (sensu Clement and Reid, 1989) and (2) subsequent pipe infilling by primary pyroclastic airfall processes. The pipes have been significantly eroded since emplacement, with only approximately half the original pipe depths now preserved. Victor South appears to have a relatively simple pipe shape and primary pyroclastic infill and, therefore, is used to illustrate the above emplacement model in Fig. 4. Victor South has a bowl-like shape that appears to flare from just below the basal sandstone of the sediments that overlie the basement. The sandstone is a known aquifer, suggesting that the crater excavation process was possibly phreatomagmatic (Lorenz, 1987). The overall low proportion of country rock xenoliths within the pyroclastic kimberlite (Table 1) implies that whichever volcanic process was involved, the excavation of the crater resulted in efficient expulsion of the country rock material before subsequent pipe infilling by juvenile-rich pyroclastic kimberlite. The potential crater-forming processes are considered further by Kong et al. (1999). Thus, the Victor South and North pipes differ from most of the southern African kimberlite pipes, both in terms of the nature of the pipe infills and the emplacement processes involved in their formation (Field and Scott Smith, 1999). Tuffisitic kimberlite, the common infill of the diatremes of southern African pipes, is not present at Victor.

Kong et al. (1999) interpreted the hypabyssal-like kimberlite (Fig. 5a), which occurs only in the northwestern part of Victor North, as a subsurface intrusion below sedimentary rocks that were considered to be in situ. Only a single vertical drill core had been drilled in the northwest of Victor North at the time of that investigation. The hypabyssal-like kimberlite has been reinterpreted in the light of new information. The nature of this kimberlite and the complex internal geology of Victor North are further discussed below.

4. Geology of Victor North

Victor North has a more complex pipe shape and internal geology compared to Victor South. Both of the main textural types of kimberlite are present (Fig. 2): pyroclastic and hypabyssal-like kimberlite. Evidence is presented below to show that they were formed in two cross-cutting craters, termed northwest and main.

4.1. Victor North: northwest crater

The northwestern part of Victor North (Fig. 2) is dominated by dark competent rocks that resemble fresh hypabyssal kimberlite (HK; Fig. 5a). Further drilling and more detailed investigations indicate that the internal geology of this area of Victor North is complex, contrasts with kimberlites elsewhere in Victor and is not straightforward to interpret. Single drill cores contain many phases of kimberlite (Fig. 6) that cannot readily be correlated laterally. The hypabyssal-like kimberlite is intimately associated with a number of minor, but important, juvenile lapilli tuff horizons, as well as sedimentary rock breccias.

4.1.1. Sedimentary rock breccias

Drilling of an additional 20 cores in the northwestern part of Victor North (Fig. 3) has shown that the sedimentary rocks that form a thick (20–60 m) upper unit in this part of the pipe (Fig. 6) are in fact not in situ (as suggested by Kong et al., 1999), but rather comprise coarse breccias, dominated by disrupted and brecciated mudstones, siltstones and lesser limestone and dolostone. Breccias similar to the upper unit also occur along parts of the pipe margins. Bedded lithologies display variable dip angles, ranging up to 90°, clearly showing that they are not in situ formations. Comparison with the subhorizontally bedded country rock units intersected in drill holes adjacent to the Victor pipes reveals that certain of the constituent blocks in the breccias are composed of rocks that contrast with the present sedimentary country rocks and thus appear to derive from now-eroded younger stratigraphic units. Of particular note is the occurrence of distinctive red mudstones, which are believed to derive from the Upper Silurian Kenogami Formation. The sedimentary rocks that make up the breccias are also different to the xenolith suite of the hypabyssal-like kimberlite, both in terms of size and lithology. The breccias are rarely associated with volcaniclastic kimberlites, which occur as narrow (1–3 m), normally graded horizons, within or directly below the breccias (Fig. 6). These units are generally weathered; however, fine- to medium-grained discrete olivine pseudomorphs, subround juvenile lapilli, mica and rare garnet can be discerned in a carbonate-rich matrix. Coarse lithic-rich bases grade upwards to finer-grained material characterised by lower xenolith contents.

The presence of volcaniclastic kimberlite within the sedimentary rock breccias shows that at least the overlying breccias must be of volcaniclastic origin. Certain of the breccias along the pipe contacts contain country rock clasts and blocks of now-eroded host

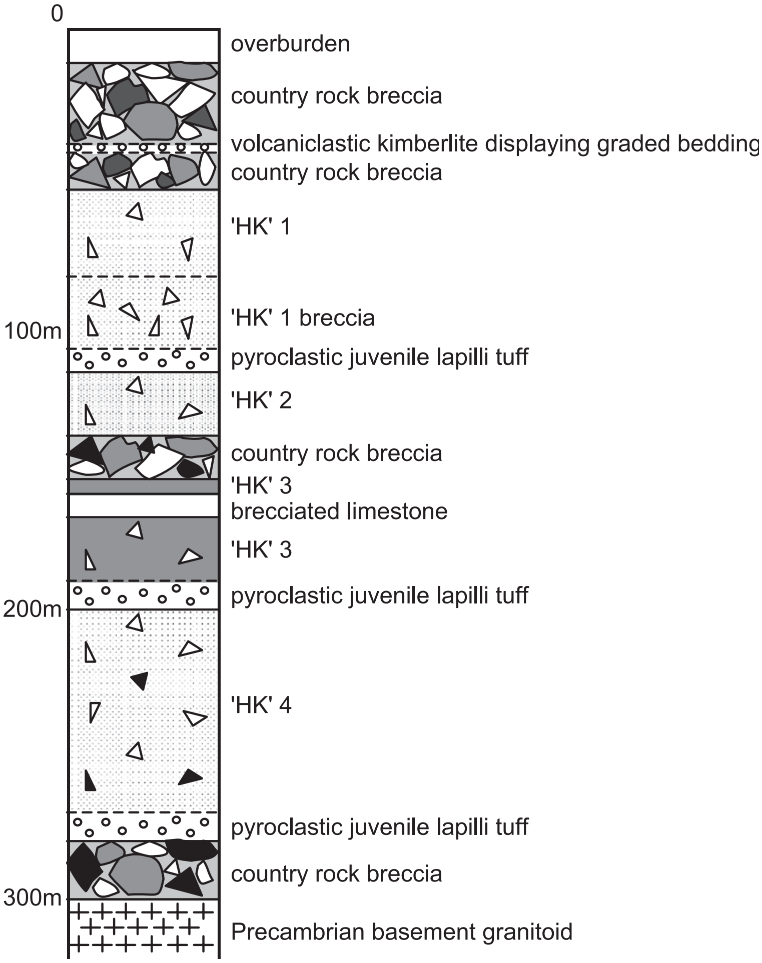


Fig. 6. Schematic graphical log of the northwestern part of Victor North showing the complex internal geology, presence of numerous different phases of hypabyssal-like kimberlite and associated sedimentary rock breccias and juvenile lapilli tuff horizons.

rock units, suggesting that these breccias also are of volcaniclastic origin and that this part of Victor North was once an open crater. Thus, the dominant hypabyssal-like kimberlites are surrounded by an 'envelope' of volcaniclastic breccias. Similar sedimentary rock breccias also occur within the hypabyssal-like kimberlite, where they appear to have a random lateral and vertical distribution (Fig. 6). There is no obvious evidence for the hypabyssal-like kimberlite being intrusive into the breccias.

4.1.2. Hypabyssal-like kimberlite

The hypabyssal-like kimberlite or 'HK' is the volumetrically dominant rock type in the northwestern part of Victor North. Drill core intersections of the 'HK' range from 5 to 170 m in thickness (Fig. 6). The rocks are composed of variable, but overall high proportions of medium- to coarse-grained, commonly fresh macrocrystal and phenocrystal olivine (Fig. 5a,b), set in groundmasses composed of carbonate, spinel, serpentine, mica ± monticellite, apatite and perovskite. The carbonate occurs as lath-shaped crystals displaying subparallel alignment in places, and as interstitial groundmass plates. Textural and mineralogical variations within the 'HK' suggest the presence of a number of different phases, as indicated schematically in Fig. 6. For example, the coarse-grained, highly macrocrystic 'HK' 1 and 'HK' 2 contrast with the medium-grained, poorly macrocrystic 'HK' 3 and 'HK' 4. The 'HK' phases are all spinel- and perovskite-bearing phlogopite carbonate kimberlites; 'HK' 2 also contains monticellite. 'HK' 4 is characterised by common broken olivine. The country rock xenolith content and type also varies between the different 'HK' phases. The 'HK' in Victor North is thus considerably more complex than non-sheet-like hypabyssal kimberlite bodies elsewhere. The mantle-derived xenocryst content of all the 'HK' is similar and contrasts with that of the Victor North and South pyroclastic kimberlites. The latter contain abundant fresh or partly altered garnet (majority as fragments without kelyphite rims), ilmenite and Cr-diopside. In contrast, the 'HK' contains comparatively low proportions of fresh garnet with kelyphite rims, and rare chrome diopside and ilmenite.

Within one phase of 'HK', the macroscopic distribution of olivine is for the most part uniform, with little or no evidence for sorting or layering. However, microscopic examination reveals variably matrix- to clast-supported olivine, and minor small-scale textural variations and fabrics that suggest possible sorting or flow orientation. Broken olivine crystals are common in parts. Although, in general, the groundmasses appear relatively well crystallised, they do not display typical hypabyssal kimberlite textures, because in some areas incipient to well-developed juvenile lapilli are present (Fig. 5b). These are defined by the presence of partial magmatic selvages on some coarser-grained constituents or subround magmatic bodies without kernels. In both cases, the lapilli-like structures have diffuse margins and consist of similar, but usually finer-grained, components as the surrounding uniform to pseudo-segregationary textured groundmass in which they occur. In places, the lapilli-like structures are better developed within nonuniform carbonate- and/or serpentine-rich matrices, and thus resemble pyroclastic juvenile lapilli. Rare narrow intersections of the 'HK' contain concentrations of small carbonate- and/or serpentine-filled vesicles.

The variable, but overall low proportion ($<15\%$) of country rock xenoliths within the 'HK' is dominated by pale limestone. Minor altered basement granite and diabase also occur and a number of phases also contain common conspicuous green siltstone clasts. Some of the xenoliths display zonal alteration or alteration halos in the host rock. Increases in xenolithic content define localised breccia units. Rare units display a gradational and subtle increase in xenolith size and abundance with depth. Clustering of xenolith types is observed, but not common. Xenoliths are generally less than 5 cm in size, with minor clasts ranging up to 30 cm. Rare 1–8 m thick intersections of limestone presumably represent large blocks. These display in situ brecciation in parts, with or without minor kimberlitic matrix. The combined presence of atypical hypabyssal kimberlite textures, incipient to well-developed juvenile lapilli, vesicular textures and country rock xenolith clusters suggests that the hypabyssal-like kimberlite formed by extrusive rather than deep-seated intrusive processes. The textures of these rocks are complex and require further investigation. Individual phases of 'HK' may grade with depth into narrow juvenile lapilli tuff horizons.

4.1.3. Juvenile lapilli tuffs

Narrow (3–20 m) juvenile lapilli tuff horizons are present in some drill holes between thick intersections of the hypabyssal-like kimberlite described above (Fig. 6). They usually display sharp lower and gradational upper contacts. Clast-supported, fine- to medium-grained, discrete carbonatised olivine macrocrysts and phenocrysts, common subround to irregular, generally vesicular juvenile lapilli (Fig. 5c) and rare armoured lapilli are set in a fine-grained interclast matrix composed of fine ash-sized juvenile and xenolithic constituents and abundant granular carbonate. The country rock xenolith content is variable, but generally higher than in the hypabyssal-like kimberlite, and dominated by limestone, with lesser siltstone. Normal graded planar bedding is defined by variations in olivine and xenolith clast size and abundance. The nature of these rocks, particularly the presence of vesicular lapilli, strongly suggests that they formed by extrusive pyroclastic processes.

4.1.4. Discussion

The features mentioned above suggest that the northwestern part of Victor North was an open crater subsequently infilled by a number of contrasting rock types. The presence of overlying and underlying sedimentary rock breccias, together with the atypical textural characteristics of the hypabyssal-like kimberlite, presence of numerous phases of kimberlite and close association of these with clearly extrusive rocks, supports a nonintrusive origin for the hypabyssal-like kimberlite. Kong et al. (1999) considered whether the hypabyssal-like kimberlite intersected in certain other Attawapiskat kimberlite pipes could be magmatic kimberlite that either intruded earlier-deposited pyroclastic kimberlite or formed subaerial lavas during pipe infilling. Existing evidence does not negate the potential for lavas having formed at some stage during the infilling of the northwestern crater of Victor North. The variable and apparently oscillating uniform to unusual lapilli-like textures of the hypabyssal-like kimberlite and occasional gradation to pyroclastic juvenile lapilli tuff horizons suggests that the kimberlite deposits in the northwestern crater may have formed by a range of possible processes, including effusive lava flows, low-energy lava spatter producing clastogenic lavas (agglutinated lapilli) and more explosive fire-fountaining. The sedimentary rock breccias appear to represent pipe wall collapse and avalanche deposits that formed directly after or during initial crater excavation in the case of the marginal breccias, during quiescent periods, as well as during active volcanism, as suggested by their association with graded volcaniclastic kimberlite units.

The contact between the northwestern and main parts of Victor North (Fig. 2) coincides with a distinct contrast in geophysical signature. In drill core, the contact between the hypabyssal-like kimberlite in the northwest and the pyroclastic kimberlites in the rest of the pipe is sharp. Three-dimensional geological modeling of the contact shows that it is steep and dips slightly to the southeast. The contact appears to curve at the margins of the pipe, defining a concave boundary, which suggests that the northwestern part represents a separate, earlier phase of emplacement in Victor North. The remaining area of Victor North must therefore have formed by a later eruption event that excavated a second crater cross-cutting the original crater. The second crater was infilled with pyroclastic kimberlite, the detailed nature of which is discussed below.

4.2. Victor North: main crater

The pyroclastic kimberlite (PK, Fig. 7a) that dominates the main part of Victor North is different from the PK in the northwestern part of Victor North. The main Victor North PK (VNPK) is composed predominantly of poorly sorted, clast-supported discrete and commonly fresh grains of olivine (macrocrysts and lesser phenocrysts) and subround (Fig. 7b) to curvilinear shaped, rarely vesicular juvenile lapilli. The latter are mostly less than 1 cm in size and are composed of mantle-derived olivine macrocrysts and primary olivine phenocrysts set in a groundmass of carbonate laths, spinel and interstitial cryptocrystalline carbonate. The PK also contains variable, but overall low, proportions of angular country rock xenoliths (Table 1; Fig. 7a) dominated by limestone, with lesser altered basement granitoid, diabase and siltstone. Mantle-derived xenocrysts, megacrysts and mantle xenoliths are also present. These constituents are set in an interclast matrix dominated by serpentine, with lesser carbonate. Subtle variations in the nature, proportion and size of the juvenile and lithic clasts throughout the PK intersections are typical and suggest sorting and/or change in phase of kimberlite. Diffuse stratification and normal graded bedding (1–3 m thick) is discernible in parts. The PK is typically fine- to coarse-grained (terminology after Field and Scott Smith, 1998), although some bedded very fine- (ash-rich) and very coarse-grained intersections also occur. Recent investigations support the original interpretation (Kong et al., 1999) of the Victor pyroclastic kimberlite as partly bedded, juvenile lapilli-bearing olivine tuffs that appear to have formed by subaerial fire-fountaining and primary airfall processes.

4.2.1. Macrodiamond data

The Victor North pyroclastic kimberlite (Figs. 2 and 7a) was initially considered to display limited noteworthy internal variations. The overall macroscopic consistency in texture and principal constitutents of the pyroclastic kimberlite in the drill cores (Table 1), coupled with the absence of sharp internal contacts, suggested that the pyroclastic kimberlite represented one single overall phase of kimberlite emplacement. The subtle variations in nature, proportion and size of juvenile and lithic clasts typically observed in the drill cores did not obviously define readily mapable or recognisable changes in phase of kimberlite. However, the results of a bulk sampling programme conducted in 2000–2001 indicate significant macrodiamond sample grade variations within the Victor North pyroclastic kimberlite (Fig. 8). Sample grades obtained from the short-interval (12 m) bulk sampling of the large-diameter drill holes shown in Fig. 8 vary from zero to >100 carats/100 tonnes, showing that the diamond

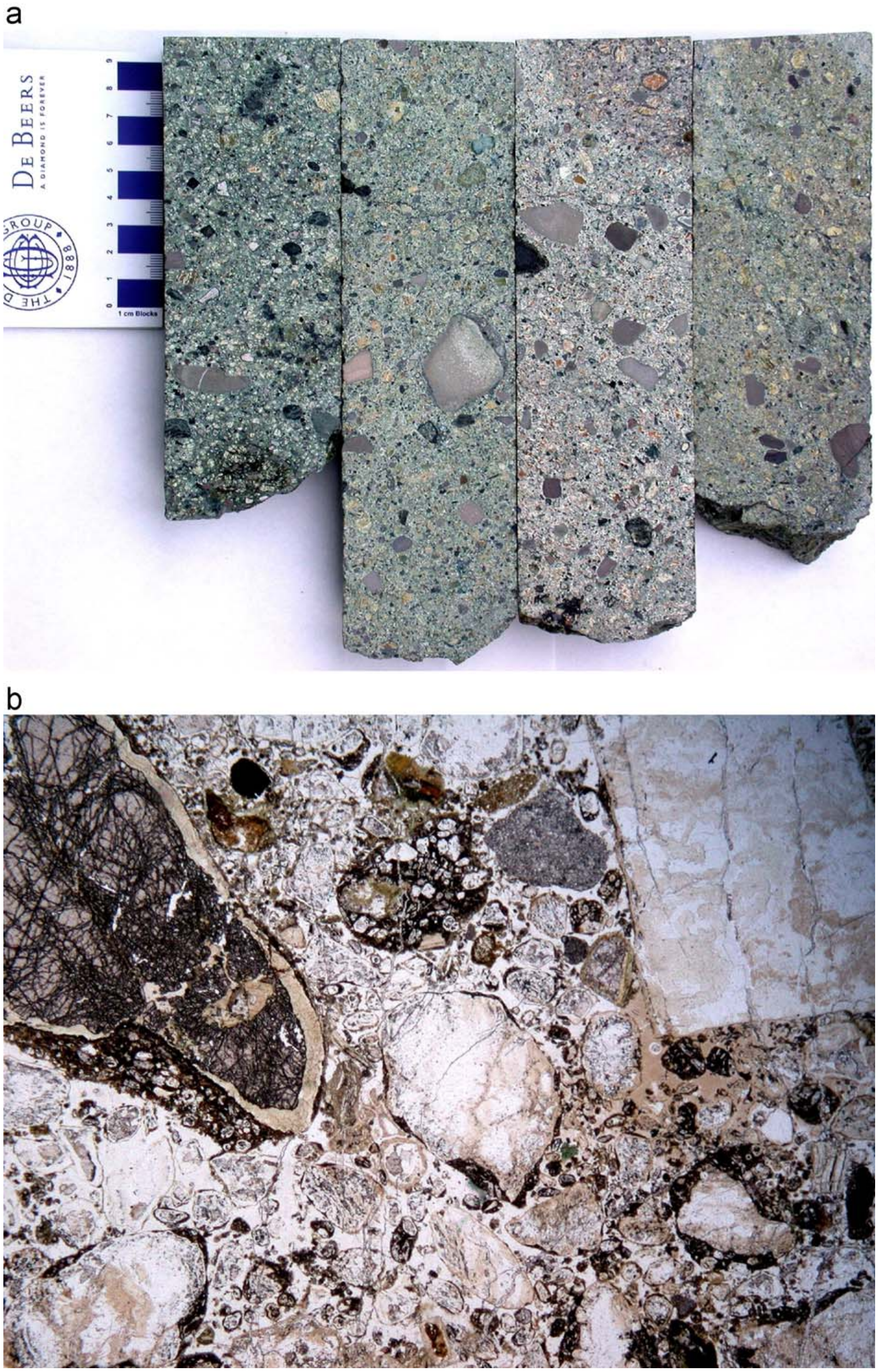


Fig. 7. Typical appearance of Victor pyroclastic kimberlite shown in (a) polished drill core and (b) thin section. The photomicrograph shows abundant clast-supported, discrete fresh and pseudomorphed macrocrystal and phenocrystal olivine and lesser subround juvenile lapilli set in a serpentine-rich matrix. PPL. FOV = 8 mm.

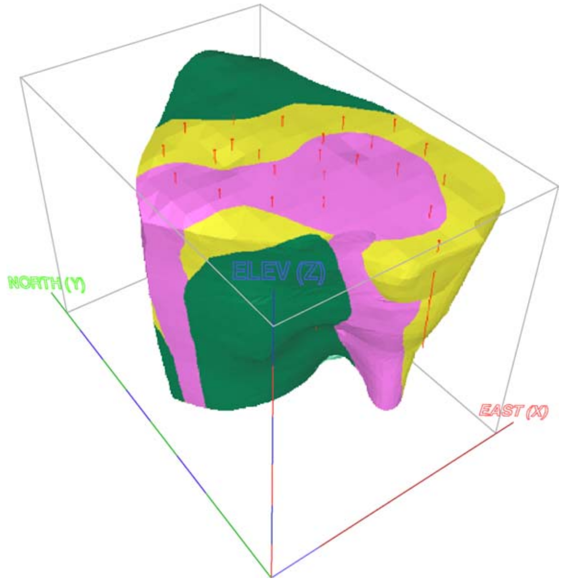


Fig. 8. Macrodiamond sample grade distribution in Victor North pyroclastic kimberlite (2001–2002 bulk sampling programme), courtesy of the Victor Project. Pink = high-grade, yellow = moderate grade, green=low-grade. Intervals on the vertical axis are 50 m. Markers indicate large-diameter drill holes.

distribution is complex. This led to a more detailed and ongoing investigation of the pyroclastic kimberlites and internal geology of this area of Victor North. Detailed petrography indicates that the Victor North pyroclastic kimberlite (VNPK) can be subdivided into two main phases of kimberlite that appear to correlate with the low and high macrodiamond sample results.

4.2.2. Petrographic subdivision of VNPK

The two petrographically identified pyroclastic kimberlites in Victor North are distinguished on the basis of the relative modal abundance, size and habit of the *olivine phenocrysts* that occur both as primary phases within juvenile lapilli and as discrete crystals derived from disruption of the magma during explosive volcanism (Fig. 9a,b). The two VNPK phases have been

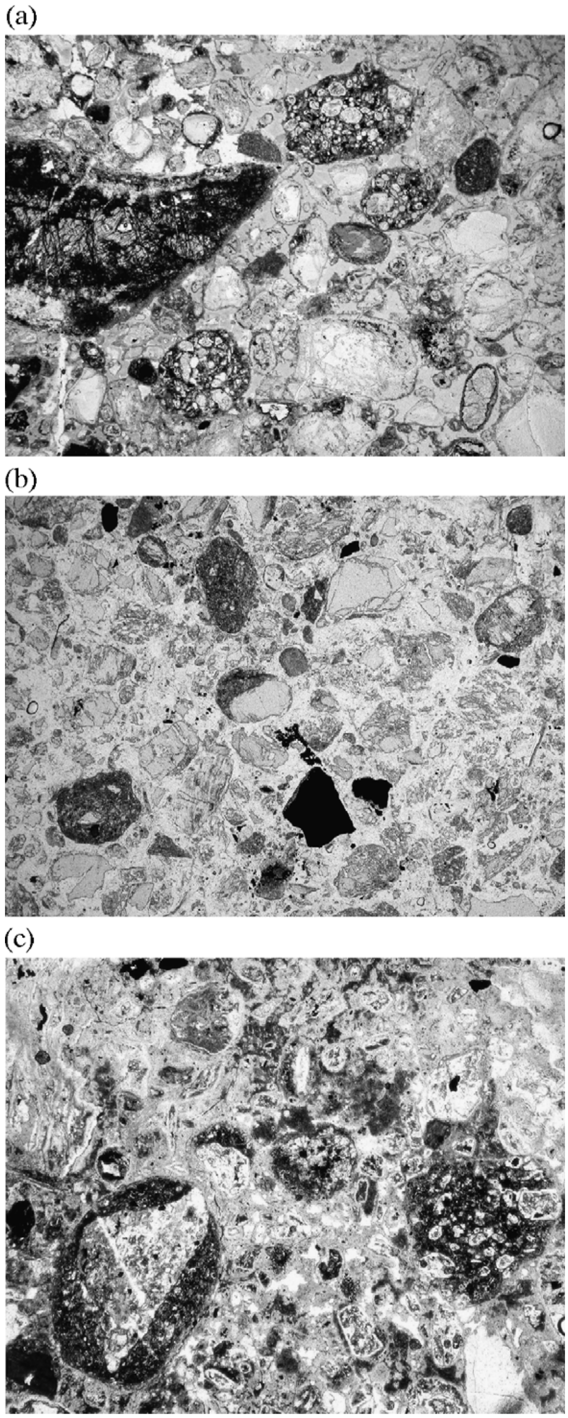


Fig. 9. The three petrographically distinct pyroclastic kimberlite types in Victor North. Photomicrographs (a) VNhoPK and (b) VNloPK show the contrasting modal abundance, size and habit of the primary olivine phenocrysts within the juvenile lapilli of these phases of kimberlite. The VNmoPK sample shown in c contains juvenile lapilli typical of both the VNhoPK and VNloPK. PPL. FOV=(a) 8 mm, (b) 7 mm, (c) 8 mm.

termed VNhoPK and VNloPK (ho = high, lo = low olivine phenocryst content). The comparison of the distribution of these kimberlite phases, as represented in the drill cores, with the corresponding modeled macrodiamond sample grade zones (Fig. 8), shows that the VNhoPK and VNloPK correlate with the low and high sample grades, respectively.

Modal analysis by pointcounting was conducted on thin sections of six VNhoPK and six VNloPK samples (Table 1). These 12 drill core samples were selected from three vertical drill holes (Fig. 3), each of which occurs immediately adjacent to a large-diameter drill hole with sample grades that clearly define the contrasting grade zones shown in Fig. 8. Fig. 10 shows that the modal proportions of the main constituents of the VNhoPK and VNloPK are similar. The principal constituents of both phases are discrete olivine (macrocrysts and phenocrysts), juvenile lapilli (olivine macrocrysts and phenocrysts and groundmass) and interclast matrix. The juvenile lapilli represent discrete bodies of magma formed during eruption and at Victor they may comprise either juvenile or xenolithic clasts with partial or complete magmatic selvages or magmatic bodies without kernels. Discrete cognate grains of olivines without selvages are not termed juvenile lapilli. They are formed by complete separation from the magma during explosive volcanism.

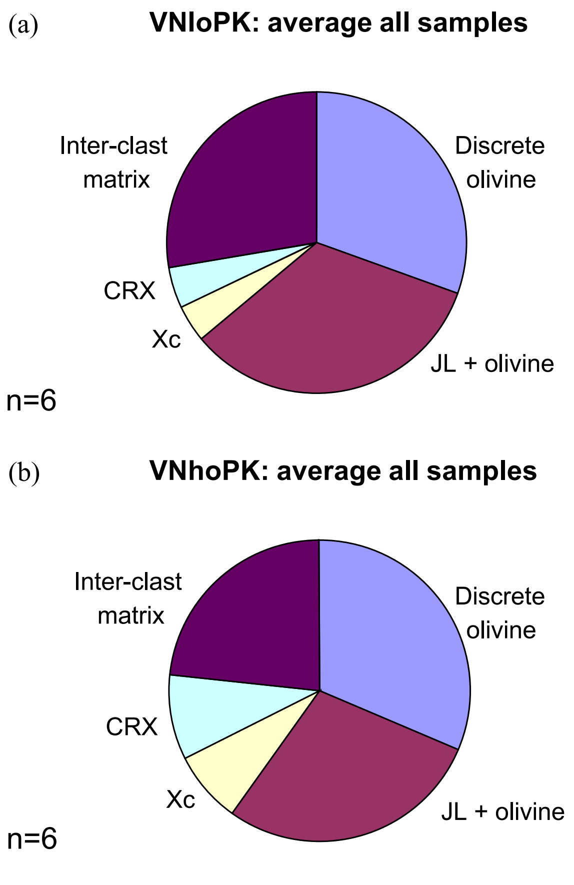


Fig. 10. Average modal abundances of the main constituents of the two principal pyroclastic kimberlites (VNhoPK, VNloPK) in Victor North (data from Table 1).

The individual modal abundances of all the constituents within the juvenile lapilli (olivine macrocrysts, olivine phenocrysts, groundmass material) were initially normalised to 100% to calculate the relative proportions of each component within the typical undisrupted magma of each kimberlite phase. The results of this procedure (Fig. 11) quantify the visually estimated differences in the relative proportions of primary phenocrystal olivine within the VNhoPK and VNloPK. Whereas the VNhoPK magma typically contains an average of 28% olivine phenocrysts, the VNloPK magma is characterised by only ~ 8% olivine phenocrysts. Archetypal or classic kimberlite magmas typically comprise 25% mantle-derived olivine (macrocrysts), 25% primary olivine (phenocrysts) and 50% groundmass (Scott Smith, 1996). When the modal proportions of these components in the VNhoPK and VNloPK are compared with the standard values for kimberlites elsewhere, it seems reasonable that the VNhoPK may be termed ‘olivine phenocryst-rich’ and the VNloPK ‘olivine phenocryst-poor’.

The olivine phenocrysts in the VNhoPK are relatively coarse-grained (average size 0.25 mm), typically serpentinised and display euhedral to subhedral, commonly complex crystal habits (Fig. 9a). The VNloPK, in contrast, is characterised by finer-grained (average size 0.15 mm), dominantly simple subhedral and partly fresh olivine phenocrysts (Fig. 9b). The contrasting modal proportions, grain size and habit of the primary olivine phenocrysts shows that the VNhoPK and VNloPK derive from different pulses, or phases, of kimberlite and thus separate eruptions.

The calculation described above also showed that the proportion of juvenile groundmass material in the ‘reconstructed’ or undisrupted VNhoPK and VNloPK magmas is overall similar (~ 30–40%). This observation permits a direct comparison between the modal

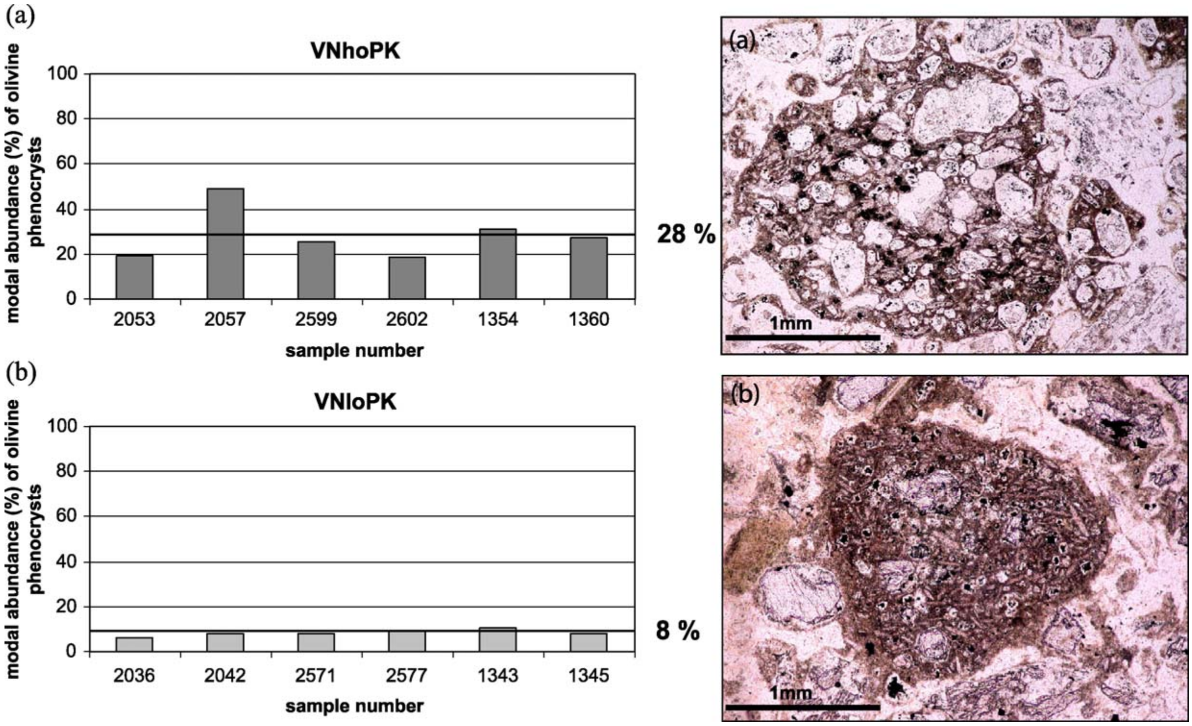


Fig. 11. Comparison of the modal proportion of primary phenocrystal olivine within the typical undisrupted (a) VNhoPK and (b) VNloPK magmas, as represented by the juvenile lapilli in the 12 samples analysed (the individual modal abundances of the olivine macrocrysts, olivine phenocrysts and groundmass material constituting the juvenile lapilli in each kimberlite phase were normalised to 100%). The mean value in each case is indicated on the histograms: 28% in the VNhoPK and 8% in the VNloPK.

abundances of olivine macrocrysts and phenocrysts within juvenile lapilli (i.e., olivine as constituents of the original magma before eruption; Fig. 12), and the modal abundance of discrete olivine macrocrysts and phenocrysts (Fig. 13) of each sample, of each kimberlite type (in both cases the components were normalised to 100% of each sample). The purpose of this calculation was twofold: (i) to determine the relative proportion or ratio of mantle-derived olivine macrocrysts to primary olivine phenocrysts in each phase of kimberlite, and (ii) to compare these data with the ratio of discrete olivine macrocrysts to discrete olivine phenocrysts in each phase of kimberlite, and in so doing establish the degree of retention or loss of olivine during magma fragmentation and primary air-fall deposition processes associated with the volcanic eruption.

Fig. 12 shows that the olivine phenocryst-rich VNhoPK contains a lower proportion of mantle-derived olivine macrocrysts within the juvenile lapilli (and therefore inherently within the erupting magma) compared to the olivine phenocryst-poor VNloPK. The high primary olivine phenocryst content (within lapilli) of the VNhoPK (Fig. 12) is matched by a high discrete olivine phenocryst content (Fig. 13), suggesting minimal loss of discrete olivine grains during eruption. The same applies to the VNloPK (Fig. 13), which is characterised by low proportions of both primary and discrete olivine phenocrysts. The low proportion of discrete olivine phenocrysts in the VNloPK does not imply loss during eruption, but rather reflects the original low modal abundance of primary olivine in this kimberlite magma (Fig. 12). In contrast, both the VNhoPK and VNloPK contain low proportions of magmatic groundmass material (as juvenile lapilli groundmass): 9–16% compared to ~30–40% in the original undisrupted magmas (Table 1). This suggests that (i) at least half of the juvenile groundmass material of the original magmas was fragmented to grain sizes finer than the olivine and

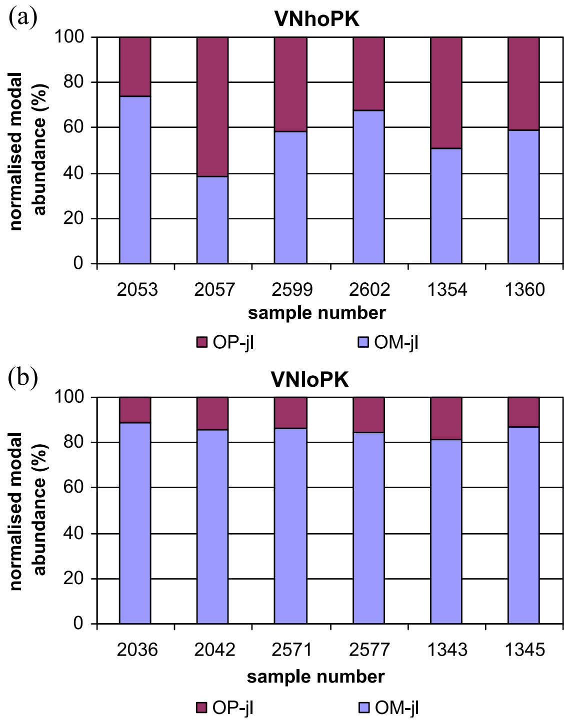


Fig. 12. Normalised modal abundance of olivine macrocrysts and phenocrysts within juvenile lapilli (OM-jl; OP-jl, respectively) of the (a) VNhoPK samples and (b) VNloPK samples.

sufficiently fine to remain airborne within the eruption column and (ii) this finely comminuted juvenile material was subsequently dispersed and lost through winnowing. The general paucity of fine juvenile ash constituents in the VNhoPK and VNloPK supports this.

The modeled moderate macrodiamond sample grade zone (Fig. 8) consists of pyroclastic kimberlite that contains both olivine phenocryst-rich and olivine phenocryst-poor juvenile lapilli (Fig. 9c), which are similar to VNhoPK and VNloPK, respectively, further indicating that the latter are the products of two separate eruption events. The PK that correlates with the moderate sample grades is also characterised by common discrete olivine phenocrysts that are similar to those in the VNhoPK. These features suggest that the moderate-grade PK does not represent a third separate phase of kimberlite, but instead consists of a mixture between the other two phases of juvenile lapilli-bearing olivine tuffs. This kimberlite is thus termed VNmoPK (mo = mixed olivine phenocryst content).

The three pyroclastic kimberlite types described above can only confidently be distinguished petrographically. Although certain macroscopic features do vary between them (e.g., the VNhoPK tends to contain a higher proportion of Cr-diopside xenocrysts and granitic basement xenoliths and more extensive olivine pseudomorphism compared to the VNloPK), these features are not exclusive to each phase of kimberlite and are thus not reliable discriminators.

4.2.3. Emplacement model

The VNhoPK, VNloPK and VNmoPK not only appear to correlate with the macrodiamond sample grades, but also occur as spatially coherent zones within the pipe (Figs. 8 and 14). The low-grade kimberlite (olivine phenocryst-rich or ‘high olivine’ VNhoPK) forms an irregular, but overall bowl-shaped unit in a discontinuous zone adjacent to the pipe wall around most of the Victor North main crater and is considered to have been the first phase of kimberlite to

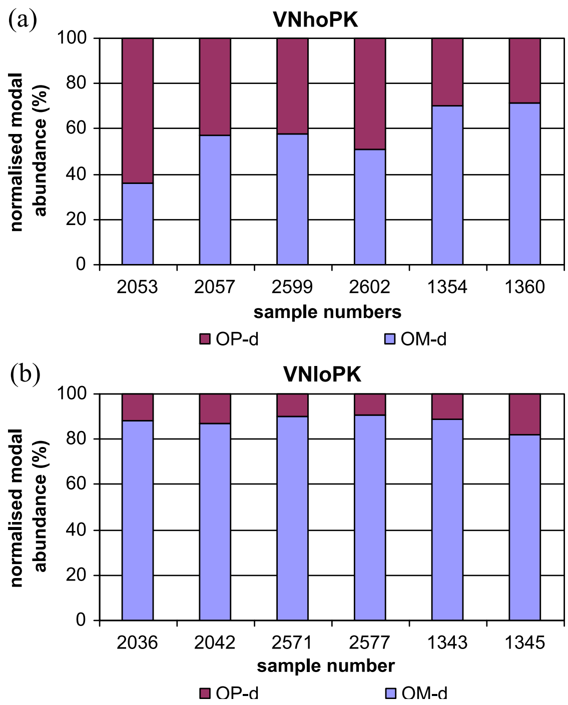
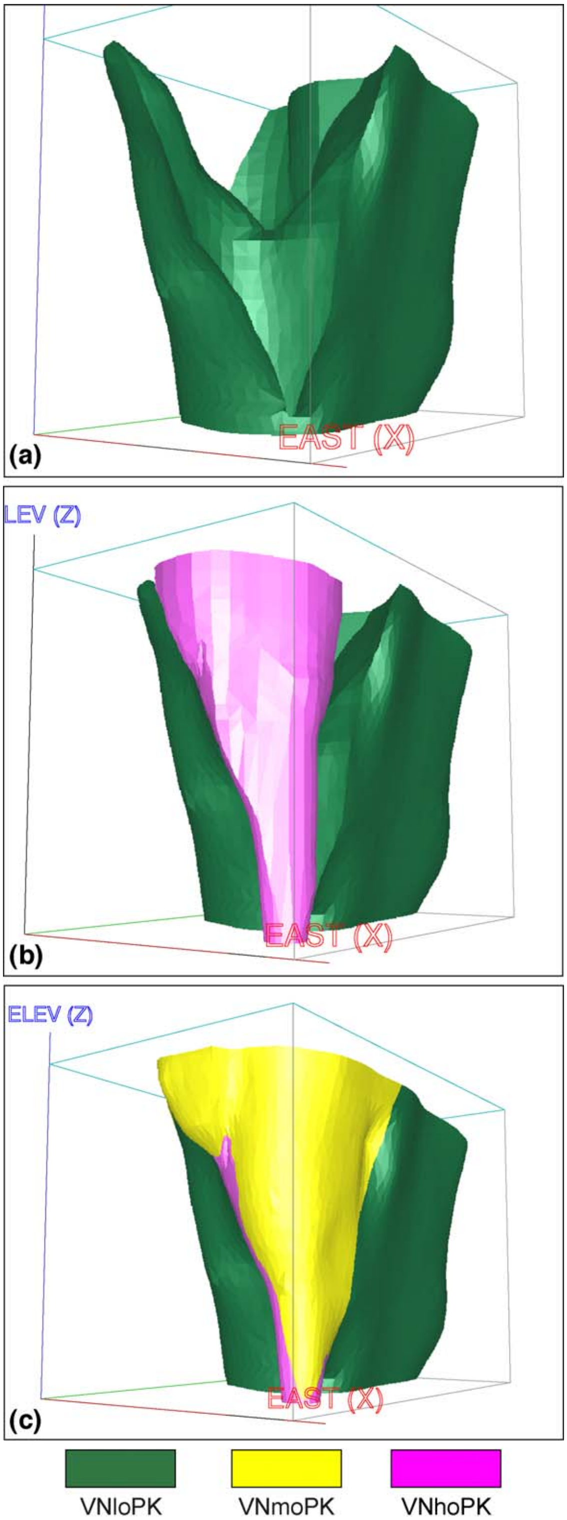


Fig. 13. Normalised modal abundance of olivine macrocrysts and phenocrysts occurring as discrete grains (OM-d; OP-d, respectively) in the (a) VNhoPK samples and (b) VNloPK samples.



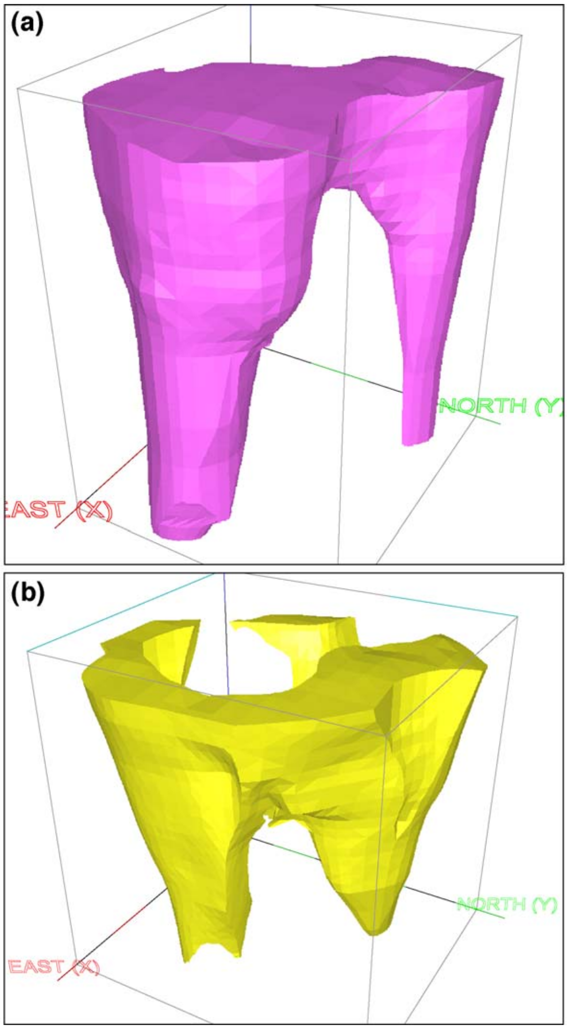


Fig. 15. Distribution of Victor North high- (VNloPK) and moderate- (VNmoPK) grade pyroclastic kimberlites. View from southeast. The similar morphology of the (a) high-grade and (b) moderate-grade zones supports emplacement of the high-grade kimberlite as two separate, but probably coalesced, vents that post date the low-grade phase, and suggests that formation of the moderate-grade kimberlite was related to that of the high-grade phase.

Fig. 14. Spatial distribution of the Victor North pyroclastic kimberlites: (a) low-grade VNhoPK, (b) high-grade VNloPK and (c) low-, high- and moderate- (VNmoPK) grade kimberlites. View from southeast. Note that the low-grade phase appears to be absent in the southeast; however, the margins of the pipe have not been adequately sampled in this area.

be emplaced (Fig. 14a). The high-grade kimberlite (olivine phenocryst-poor or 'low olivine' VNloPK) appears to occur as two separate, but possibly coalesced, steep-sided vents, one in the east and the other in the west of the Victor North main crater (Fig. 15a). Both are nested within the original VNhoPK pipe boundary (Fig. 14b). The high-grade kimberlite is considered to have been the second phase of kimberlite to be emplaced, with the two steep vents erupting through the low-grade VNhoPK, leaving only a remnant along the margins of the pipe and possibly blasting through the original pipe walls in the east, thereby expanding the size of the pipe in that area. This would explain the absence of low-grade kimberlite in the southeast (Fig. 14c; based on current drill hole data). The moderate-grade kimberlite (VNmoPK) forms an irregularly shaped zone that in most parts of the pipe lies between the high-grade (VNloPK) and low-grade (VNhoPK) kimberlite zones (Fig. 14c). The overall shape of the VNmoPK zone mirrors that of the VNloPK (two steep-sided vents) suggesting that the formation of the VNmoPK is related to that of the VNloPK (Fig. 15a,b). The original Victor emplacement model shown in Fig. 4 has been developed further for the Victor North PK (Fig. 16) to cater for this internal geology as follows:

Stage 1: Based on comparison with the adjacent Victor South pipe (Fig. 4), the initial VNhoPK crater appears to have formed by a two-stage process of (i) crater excavation (possibly by phreatomagmatic eruption processes) and (ii) subsequent crater infilling by subaerial fire-fountaining processes. Fig. 16A schematically depicts the eruption of the low-grade VNhoPK into the excavated crater to produce the initial VNhoPK infill (Fig. 16B). There may have been a hiatus between crater excavation and infilling, but not of sufficient length for the development of soils and sedimentary interlayers, neither of which have been identified in the VNPK. There is limited evidence for crater wall collapse.

Stage 2: The high-grade VNloPK erupts through the earlier-formed VNhoPK pipe infill as two steep-sided vents nested within the original VNhoPK pipe boundary. Fig. 16C depicts eruption of the high-grade VNloPK with simultaneous formation of the moderate-grade VNmoPK (Stage 3). Note that only one VNloPK vent is shown for simplicity. The extent of the time period between stages 1 and 2 is uncertain, but it could not have been significant enough for complete consolidation of the VNhoPK (see stage 3).

Stage 3: The moderate-grade VNmoPK formed during eruption of the high-grade VNloPK through the original low-grade VNhoPK crater infill, by sloughing and mixing of the earlier-formed VNhoPK with the erupting VNloPK (Fig. 16C). The VNhoPK could not have been entirely consolidated at the time of the VNloPK eruption. Petrographic evidence supports this model (Section 4.2). Fig. 16D shows the three geological/grade zones of the final Victor North main crater infill. A schematic animation of this eruption model is provided in the online version of this article.

Based on this model, any volume of VNmoPK, which consists of a mixture of VNhoPK and VNloPK, could comprise either: (i) a coherent batch of high-grade VNloPK, (ii) a coherent batch of low-grade VNhoPK or (iii) a physical mixture of pyroclasts and constituents from each main phase. Comparison of petrographic drill core data (5–15 m intervals) with the modeled macrodiamond sample grade zones shows that whereas there is a consistent occurrence of VNhoPK and VNloPK in the modeled low- and high-grade zones, respectively, the modeled moderate-grade zone comprises samples of VNmoPK, as well as a small proportion of individual samples that classify as VNloPK (Table 2). Samples within the modeled moderate-grade zones that classify as VNhoPK are less common and are usually only present close to the modeled boundary between the moderate- and low-grade zones. The rare occurrence of unmixed VNhoPK within the moderate-grade zone suggests that (i) the mixing of VNhoPK with the erupting VNloPK to produce the VNmoPK involved mostly physical mixing of components at clast or granule scale, (ii) the contribution of the erupting high-grade VNloPK in the mixing zone was greater than that of the low-grade VNhoPK, and (iii) the VNhoPK represents the undisturbed earlier-formed crater fill and the outer limit of the mixing zone.

These observations, particularly the intercalation of VNmoPK (mixed) with typical VNloPK (unmixed) in some places (Table 2), together with the absence of

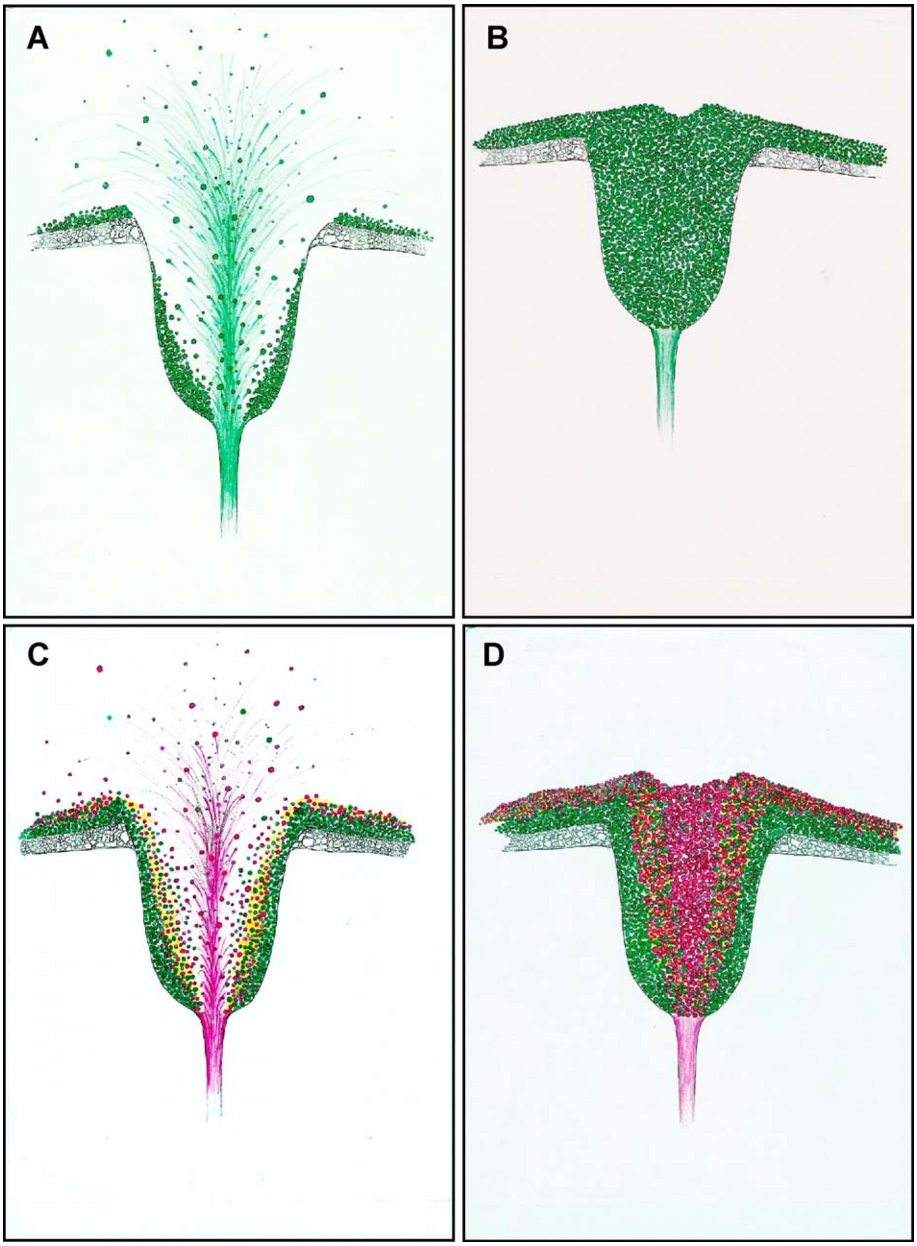


Fig. 16. Schematic representation of the emplacement of the low- (green), high- (pink) and moderate- (yellow) grade pyroclastic kimberlites in the main part of Victor North: (A) initial crater excavation and subsequent eruption of phase (i), a low-grade olivine phenocryst-rich pyroclastic kimberlite; (B) low-grade pipe infill; (C) eruption of phase (ii), a high-grade olivine phenocryst-poor pyroclastic kimberlite through the earlier-formed low-grade pipe infill; sloughing and mixing of the unconsolidated low-grade tephra with the erupting high-grade pyroclastic kimberlite along the margins of the central eruption vent results in an intermediate zone of mixed composition and moderate grade; (D) the three geological/grade zones of the final pipe infill (see the online version of this article for animated emplacement sequence).

Table 2
Comparison of petrographic rock type and modeled macrodiamond sample grade zones

Drillcore 88			LDDH 142	
Sample no.	Depth (m)	Petrographic rock type	Depth (m)	Sample grade
348	26.97	VNloPK	6.95–130.38	Moderate
351	33.38	VNloPK	130.38–203.75	Low
355	45.11	VNmoPK		
359	54.25	VNloPK		
363	67.36	VNloPK		
368	82.30	VNmoPK		
370	86.87	VNmoPK		
372	92.81	VNmoPK		
373	97.08	VNmoPK		
376	106.22	VNloPK		
384	123.75	VNmoPK		
386	126.19	VNmoPK		
387	126.34	VNmoPK		
388	128.78	VNmoPK		
389	132.28	VNmoPK		
394	145.54	VNhoPK		
400	159.87	VNhoPK		
404	169.62	VNhoPK		
411	183.34	VNhoPK		
416	197.51	VNhoPK		
421	207.11	VNhoPK		
424	213.97	VNhoPK		
430	224.64	VNhoPK		
437	242.32	VNhoPK		

sharp contacts and the scarcity or lack of autoliths, lend additional support to the proposed emplacement model for the Victor North pyroclastic kimberlites described above.

5. Discussion

Based on recent discoveries in Canada and advances in understanding of the complex geology of kimberlites, Field and Scott Smith (1999) highlighted the fact that not all kimberlite pipes conform to published models. A comprehensive review of kimberlite models, emplacement mechanisms and the geology of many kimberlites in southern Africa and Canada by these authors showed that kimberlites in different areas have contrasting pipe shapes and internal geology. Three main types of pipes were identified: (i) deep, steep-sided pipes that comprise three distinctive zones (crater, diatreme, root) that are infilled by different textural types of kimberlite (extrusive kimberlite, tuffisitic kimberlite breccia and hypabyssal kimberlite, respectively); (ii) shallow pipes that comprise only the crater zone and are infilled exclusively with volcaniclastic kimberlite (mainly pyroclastic kimberlite, which is different to that in the crater zone of type (i) pipes); and (iii) small, steep-sided pipes without diatremes (sensu Field and Scott Smith, 1999) infilled predominantly with volcaniclastic kimberlite that includes abundant resedimented material or, in less common instances, magmatic kimberlite. Field and Scott Smith (1999) further indicated that there appears to be a correlation between the type of pipe and the near-surface geological setting.

Kimberlite geology in Canada is diverse across varied geological and tectonic settings, including several Archean cratons. The range of kimberlite pipes includes examples of the three main types of kimberlite pipes described by Field and Scott Smith (1999). Fig. 17 schematically summarises the pipe shapes, pipe infill and geological setting for many kimberlites across Canada, including Victor. The Victor North and South kimberlite pipes are medium-sized (< 10 ha), steep-sided and relatively deep (500–600 m original vertical extent). In these respects, they bear similarities to the Lac de Gras kimberlites. However, whereas the Lac de Gras kimberlites are predominantly infilled with resedimented volcaniclastic kimberlite, the dominant pipe infill of the Victor pipes is primary pyroclastic kimberlite. The overall two-stage emplacement of the Victor kimberlite pipes (Sections 3 and 4) is comparable to that proposed for the commonly large, shallower Fort a la Corne kimberlites, which are similarly infilled with primary pyroclastic kimberlite (Scott Smith et al., 1998; Berryman et al., 2004). The emplacement of the Victor pipes into a thick sequence of indurated carbonates and other sedimentary rocks overlying the Precambrian basement contrasts with the geological setting of both the Lac de Gras and Fort a la Corne kimberlites (Graham et al., 1999; Scott Smith et al., 1998).

The occurrence of cross-cutting craters and multiple volcanic centers, as seen at Victor, is not uncommon or unique to kimberlites. However, in Victor North, the eruption of two separate vents nested within an earlier-formed and infilled crater and concomitant formation

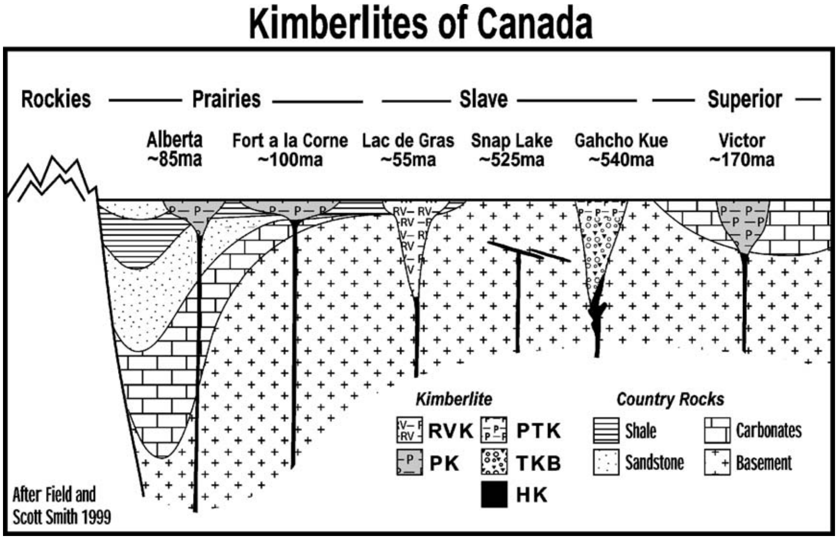


Fig. 17. Schematic overview of the contrasting pipe shapes, kimberlite infills and country rock geological settings of kimberlites in Canada (modified from Field and Scott Smith, 1999), reconstructed to the time of kimberlite emplacement.

of a surrounding zone of mixing resulted in three virtually concentric geological (and macrodiamond grade) zones within a single pipe, a feature seldom described in kimberlites elsewhere. Only through the combination of extensive core drilling, bulk sampling and detailed petrographic investigations has the complex internal geology of this pipe been revealed. Current understanding of the northwestern part of Victor North suggests that it comprises a crater subsequently infilled with a range of extrusive rocks, including possible kimberlite lavas. Although kimberlite lavas have not been confidently identified at Victor, or elsewhere, the unusual textures of the hypabyssal-like kimberlites and their association with clearly extrusive kimberlites and country rock breccias reflects varied volcanic eruption and deposition processes during formation and filling of this crater. The possibility that the apparently magmatic rocks represent subaerial lavas cannot be discounted, and thus these rocks deserve further attention.

6. Conclusions

The Victor kimberlite pipes appear to have formed by several eruptive events resulting in adjacent, cross-cutting and nested craters infilled by two contrasting textural types of kimberlites. Victor South and much of Victor North are composed of similar pyroclastic juvenile lapilli-bearing olivine tuffs. The northwestern part of Victor North contrasts in that it is dominated by rocks resembling hypabyssal kimberlites. The latter are texturally unusual and, because of the association with juvenile lapilli tuffs and country rock breccias ± volcaniclastic kimberlite, they are now interpreted as being of probable extrusive origin. The larger and more complex Victor North pipe, therefore, is proposed to have formed by a number of eruptive events: (1) the crater excavation and infilling of the northwestern part of the pipe; (2) the excavation of a cross-cutting crater that was infilled with low-grade olivine phenocryst-rich pyroclastic kimberlite; and (3) the eruption of high-grade olivine phenocryst-poor pyroclastic kimberlite from two vents nested within crater (2). The two phases of pyroclastic kimberlite are macroscopically similar, but have contrasting macrodiamond sample grades and microscopic characteristics. The second eruption was accompanied by the formation of an intermediate mixed zone, through sloughing and mixing of the unconsolidated tephra from the low-grade phase with the erupting high-grade phase along the margins of the eruption vents. This study highlights the meaningful role of kimberlite petrography in the evaluation of diamond deposits and provides further insight into the emplacement and volcanic processes occurring in kimberlites.

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