# Mineralogy and Geochemistry of Kimberlites and Related Rocks from Finland

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## Introduction

In January 1997 the Geological Survey of Finland initiated a study of Finnish kimberlitic intrusions discovered by Malmikaivos Oy as a result of their diamond exploration activities (Griffin et al., 1995; Tyni, 1997). These Paleozoic intrusions (two pipes dated by K-Ar gave 590 and 430 Ma) form the Eastern Finland Kimberlite Province which includes the Kaavi and Kuopio clusters. The pipes and dikes intruded into 3.1-2.6 Ga gneiss complexes of the Archean Karelian craton and allochthonous 1.9 - 1.8 Ga metasedimentary cover rocks thrust onto the craton during the Svecofennian orogeny. The intrusions are dominated by textural and mineralogical variants of archetypal kimberlites but also include less common dikes of ultramafic lamprophyre and olivine lamproite. Ranging from purely hypabyssal kimberlite dikes to multiphase pipes of diatreme facies volcaniclastics, the Finnish kimberlites generally contain abundant diamond indicator minerals and almost all contain at least trace amounts of microdiamonds. Of the 24 intrusive bodies discovered, we have drill core samples from 12 (Table 1) from which 30 samples have been analyzed for major and trace elements and 14 for Sr, Nd and Pb isotopic compositions.

## Sample Description and Mineralogy

*Pipe 1* was discovered by Malmikaivos Oy in 1964 (Tyni, 1997) and is the only sample in our collection that may represent a magma composition although cumulate oribicules indicate that some crystal accumulation occurred. It is an aphanitic spinel-rich monticellite kimberlite (Table 1) with a small volume marginal phase of carbonate-rich kimberlite. Containing up to 40% olivine as macrocrysts and phenocrysts in a matrix of monticellite microphenocrysts, perovskite, spectacular atoll spinels zoned from chromite to magnesian ulvöspinel, serpentine and calcite, the main phase of the pipe is mostly massive but about 10% has a carbonate segregation-texture. Cemented into the carbonate matrix (25% by volume) of the marginal phase rocks are globular segregations of aphanitic silicate kimberlite magma and olivine-pseudomorphs surrounded by a thin veneer of silicate magma. *Pipes 2 & 3* occur near each other (within 500m), are both elongate bodies and both contain the same volcaniclastic and hypabyssal rocks with serpentine pseudomorphs after olivine macrocrysts in a matrix of perovskite, serpentine and calcite. Exceptional volcaniclastic breccias from pipe 3 contain abundant xenoliths of quartzite, gneisses and granitoids. *Pipes 4 & 6* are composed exclusively of diatreme facies volcaniclastic breccias, which have been considerably altered to clay minerals. Nevertheless some garnet-bearing peridotite xenoliths have survived the alteration process mostly intact. *Pipe 5* contains serpentinized olivine macrocryst-rich hypabyssal kimberlite and volcaniclastic diatreme facies rocks that vary from breccias to ash-rich sandstones. It is unclear whether the sandstones represent resedimented material from the very top of a diatreme or simply more completely comminuted material. The hypabyssal rocks contain relatively fresh garnet-bearing peridotite xenoliths. *Pipe 9* contains hypabyssal kimberlite rich in olivine and picroilmenite macrocrysts and garnet-bearing peridotites (mostly lherzolite). *Pipe 10* is a multiphase pipe dominated by picroilmenite-rich volcaniclastic breccia studded with about 5% subrounded autoliths of dark gray hypabyssal material that likely represent samples of a magmatic phase. The diatreme rocks contain olivine pseudomorphs, picroilmenite, garnet and Cr-diopside macrocrysts and relatively abundant peridotite and eclogite xenoliths in an opaque-rich, serpentine-calcite matrix. *Pipe 14* contains fresh olivine and picroilmenite macrocrystic hypabyssal kimberlite and kimberlite breccia. The breccia in places is rich in crustal xenoliths, however, other parts have dominant peridotite xenoliths or are crystallinoclastic comprising essentially disaggregated peridotite minerals in minimal kimberlite matrix. Ultramafic lamprophyre *dike 15* is composed mostly of large serpentine pseudomorphs (after olivine?), zoned phlogopite, and carbonate with accessory ilmenite, titanomagnetite, rutile and apatite. Lamproite *dike 16* is composed largely of phlogopite and pseudomorphs of olivine and is intriguing because it appears to have some affinities to Type II kimberlites (orangeites in the terminology of Mitchell, 1995). The sample contains grains of a calcium zirconium silicate (Ca-catapleite?) rather than the lamproite typomorphic mineral wadeite and zoning in micas that follow the extreme Al depletion evolutionary trend diagnostic of orangeite micas. However the mica core compositions have relatively high Ti; within the field demarcated as lamproite by Mitchell (op. cit.) and the major element composition of the sample is nearly exactly equivalent to the average for olivine lamproite calculated by Mitchell and Bergman (1991). *Pipe 23* is composed exclusively of volcaniclastic kimberlite breccia and contains the least altered diatreme material of any of the pipes sampled. This rock has approximately 25% crustal and mantle xenoliths and <5% rounded autoliths contained in a matrix that has a distinctly blue color.

**Table 1. Characteristics of Finnish Kimberlites and Related Rocks**

| Pipe / Dike | Shape | Size (m) | Dominant Rock Type | Mineralogy |
|---|---|---|---|---|
| #1 | oval pipe | 110 x 150 | chrome spinel-rich hypabyssal monticellite kimberlite | olivine, monticellite, spinel, perovskite, serp, cc |
| #2 | elongate pipe | 300 x 20-40 | hypabyssal kimberlite breccia > volcaniclastic kimberlite breccia | serp-ol, cc, serp, perovskite |
| #3 | elongate pipe | 250 x 40 | hypabyssal kimberlite breccia > volcaniclastic kimberlite breccia | serp-ol cc, serp, perovskite |
| #4 | double pipe | 150 x 100 | volcaniclastic kimberlite breccia only | serp-ol, clay-rich in matrix |
| #5 | dike with breccia (blows?) at each end | >500 x 20 | macrocryst-rich hyp kimb>vol kimb, some finely comminuted | olivine, serp, cc, peridotite fragments |
| #6 | irregular elongate pipe | 200 x 70 | volcaniclastic kimberlite breccia >> hypabyssal kimberlite breccia | serp-ol, clay-rich matrix |
| #9 | irregular oblate pipe | 100 x 50 | macrocrystic hypabyssal kimberlite | olivine, Mg-il-rich, serp, cc, peridotite fragments |
| #10 | irregular oblate, hyp kimberlite limited to one end of pipe | 150 x 200 | macrocryst-rich volcaniclastic kimberlite br > macrocryst-rich hypabyssal kimberlite breccia | serp-ol, Mg-il-, pyrope-, Cr-diopside-rich, serp, cc, spinel, peridotite & eclogite fragments |
| #14 | irregular oblate pipe | 100 x 50 | hypabyssal kimberlite > hypabyssal kimberlite breccia | serp-ol, Mg-il-rich, serp, cc, abundant peridotite fragments |
| #15 | dike | 2m wide and roughly 1km long | ultramafic lamprophyre (Aillikite) | serp-ol, phlogopite, carbonate, Mg-Mn ilmenite, Ti-magnetite, rutile, perovskite, apatite |
| #16 | dike | <5m wide, length unknown | olivine lamproite | phlogopite, serp-ol, K-richterite, diopside, perovskite, chromite, apatite, Ca-catapleite |
| #23 | oblate pipe | 80 x 40 | volcaniclastic kimberlite breccia | olivine, serp, cc, peridotite fragments |
| KEY: | | | br = breccia<br>hyp = hypabyssal<br>kimb = kimberlite | serp-ol=serpentinized olivine<br>Mg-il=magnesian ilmenite<br>serp=serpentine, cc=calcite |

## Geochemistry

Major elements of the Finnish kimberlites and related rocks show that the samples vary from being unaltered and uncontaminated (e.g., pipe 1) to highly altered and/or contaminated (e.g., pipes 3, 4 & 6) with contamination index values (C.I.; Clement, 1982) ranging from 1 to 2.4, respectively. Contamination vectors in an $Al_2O_3$ - $SiO_2$ diagram not unexpectedly indicate granitoid as the most significant contaminant. Yet, despite this indication for contamination, the incompatible element abundances in the Finnish kimberlites are not greatly modified relative to the pipe 1 composition (Fig. 1). This remains true even for samples with C.I. indexes as high as 2.4 where the overall effect is dilution for the elements Pb to Nd (except K and Rb, Fig. 1) and enrichment in the elements P to Yb. Isotopic compositions of archetypal kimberlites have Pb-Nd-Sr compositions that appear to reflect sources in the well-mixed asthenospheric mantle and samples from Pipe 1 plot within this field, with $\varepsilon_{Nd}$ of 1.4 to 1.5 and $\varepsilon_{Sr}$ of -4 to -6. Crustal contamination in the remainder of the Finnish kimberlites is manifested not such much in their Nd isotopes ($\varepsilon_{Nd}$=2 to 6) but in their Sr isotopic compositions ($\varepsilon_{Sr}$ 1.5 to 28.5). The lamproite and ultramafic lamprophyre have radiogenic Nd and Sr compositions ($\varepsilon_{Nd}$ of –15 & -3 and $\varepsilon_{Sr}$ of 99 & 84, respectively) calculated at an estimated intrusion age of 450 Ma.

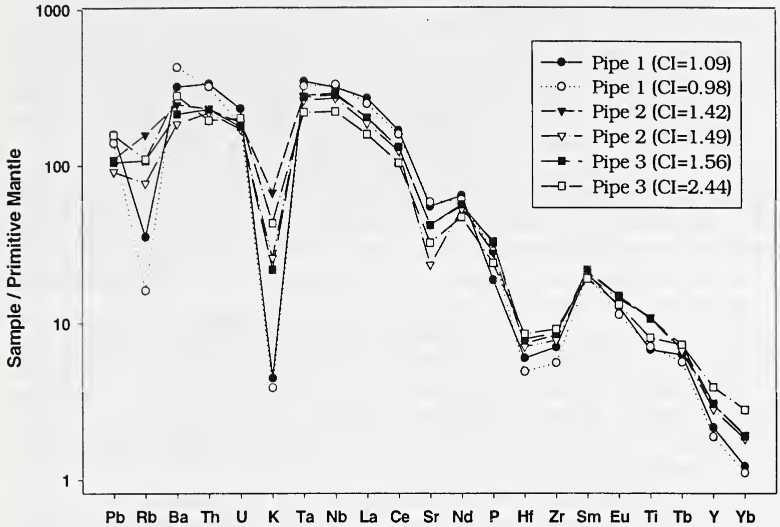


Figure 1. Primitive mantle normalized incompatible element profiles for 3 Finnish kimberlites (CI=Contamination Index).

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