The lithospheric mantle beneath the Central Karelia: xenoliths from the Kostomuksha lamproites/kimberlites2

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This job describes a suite of peridotite xenoliths from the lamproite/kimberlite2 bodies of the Kostomuksha L/K2 Proterozoic dike cluster (Fig. 1). The all xenoliths are rounded and quite small, ranging up to 5-7 cm in diameter. The black outer rinds (with up to 3-5 mm width) are common. Some xenoliths are cut by veins up to 2 mm wide of host lamproite containing groundmass phlogopite, apatite, carbonates, chromites and ilmenite. The peridotites are mostly coarse (in Harte terminology 1977) (Fig. 2) garnet and spinel lherzolites. Values for modal analysis were determined with fully automated probe system of mineralogical analysis (QemScan E430, Intellection Pty) by point-counting (with 20 μm of point spacing) over 1.3X1.3 cm area for 12 thin sections (Fig. 3).

Fig. 1 Simplified geological scheme of Kostomuksha open pit mine area. Legend: 1 – aluminous crystalline schists suite; 2 - haelleflintes; 3 – iron ores; 4 – metamorphosed vulcanites; 5 – disintegrated rocks; 6 – lamproite/k2 dikes; 7 – open pit boundaries; 8 – dikes sampled for peridotite xenoliths

In all cases the garnet has been replaced by simplectic assemblage of Al-spinel, Al-rich pyroxenes (CPx+OPx), phyllosilicates after them and carbonates. An extremely Cr-rich chromite was found as inclusions in CPx of primary association (up to 65 wt. % Cr_2O_3 (Fig. 7)). Olivine and orthopyroxene (with rare exception for the last one) are replaced by secondary phyllosilicates.

Fig. 2 Enriched with clinopyroxene peridotite nodule of garnet facies (former) in the Kostomuksha lamproite/kimberlite 2 host rock, field of view 3,2 cm width.

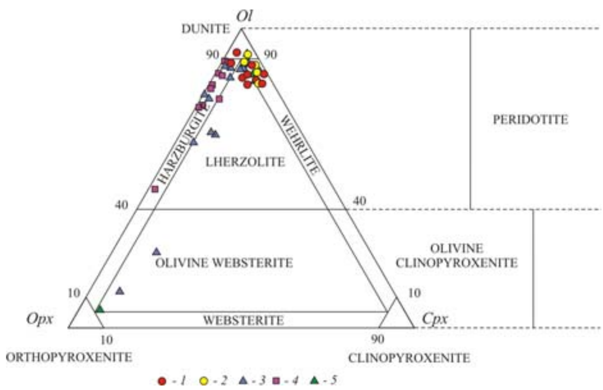

Fig. 3 Classification of the peridotitic upper mantle xenoliths from the Kostomuksha lamproites/k2 dykes. Explanation: 1- garnet facies of Kostomuksha mantle xenoliths suite, 2 – spinel facies from same, 3, 4 and 5 – xenoliths from Finnish kimberlite pipes (Peltonen, 1998).

Clinopyroxene in most xenoliths survived alteration and was analyzed by SEM EDX and LA-ICPMS to constrain the P-T conditions and trace element chemical composition of the upper mantle intruded by kimberlite 2 and lamproite melts during formation of the Kostomuksha dike cluster.

Compositional data were obtained by energy-dispersive (at 20 kV of EHT and 1 nA beam current on Faraday cup) spectrometry using scanning electron microscope. X-ray spectra were acquired for 100 seconds. Spectra were collected and processed with INCA Energy software package. XPP correction was applied to the raw data. The approved natural minerals were used as standards.

Clinopyroxenes grains are fresh and typically 0.5-2 mm, has abundant kink-bands but some are partially damaged with alteration processes (Fig. 4). The CPxs have the wide **#mg** range (91.3-93.7) with Ca/(Ca+Mg) in the range 0.36-0.45 (17.08-21.58 wt. % CaO). They have moderate Cr_2O_3 (0.70-1.76 wt. %), Al_2O_3 (0.78-2.74 wt. %) and Na_2O (0.24-1.94 wt. %) contents. All of the diopsides are very poor in TiO_2 (below or close to detection limits of EDX analysis ~0.1 wt. %).

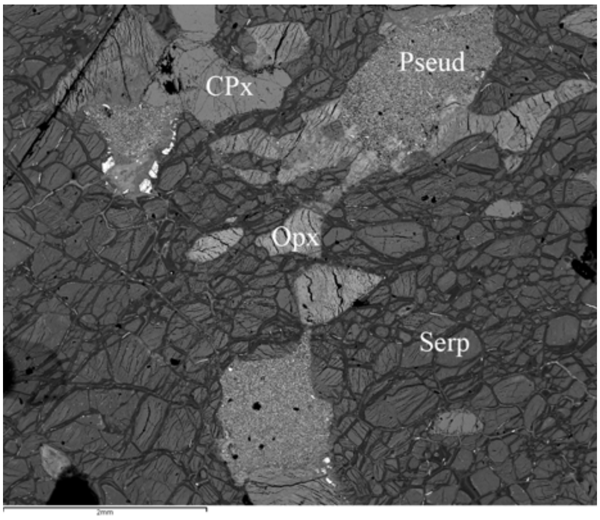

Fig. 4 BSE microphotography of OPx, CPx and former garnet enriched area of Kostomuksha lherzolite module. Explanation: CPx – Cr-diopside, OPx – enstatite, Serp – serpentine, Pseud – former garnet simplectic association.

The reliable enstatite compositional data are impossible to achieve because of the extensive alteration. Orthopyroxenes grains are typically 1-2 mm size, with abundant kink-bands as well (Fig. 4). Though the number of good stoichiometric data no attempts for applying of OPx at PT calculations were made. All data gave extremely ferrous compositions (up to 22 % wt. % FeO) with significant Al_2O_3 (up to 3 wt. %). The principal formula of these orthopyroxenes is $(Mg_{1.3}Ca_{0.1}Fe^{2+}_{0.6})(Si_{1.9}Al_{0.1})O_6$. So, this high iron content is not allowing us to relate these OPxs with primary association.
Olivine (totally replaced with serpentine and talc) grains are up to 6 mm across (typically ~3 mm).

The symplectic assemblages are developed into former garnet margins and consist of different types of spinels, Al-rich CPx and OPx, late phyllosilicates (serpentine and phlogopite), calcite and K-feldspar? (Fig. 5, 6). These intergrowths are composed with very fine fibrous to microcrystalline aggregate which, in some cases, is radially oriented. The rim of the former garnet is marked by comparatively coarse grained (up to 60 μm) subhedral reddish brown Cr-Al spinel with skeletal structure. The spinels show a wide range in Al_2O_3 and Cr_2O_3 contents (Fig. 7) from extremely Al-rich (~50 wt. % Al_2O_3 and 20 wt. % Cr_2O_3) to Cr-rich (10 wt. % Al_2O_3 and 45 wt. % Cr_2O_3).

Fig. 5 Photomicrograph of symplectite of Al-rich spinel and Al-rich pyroxenes formed after garnet.

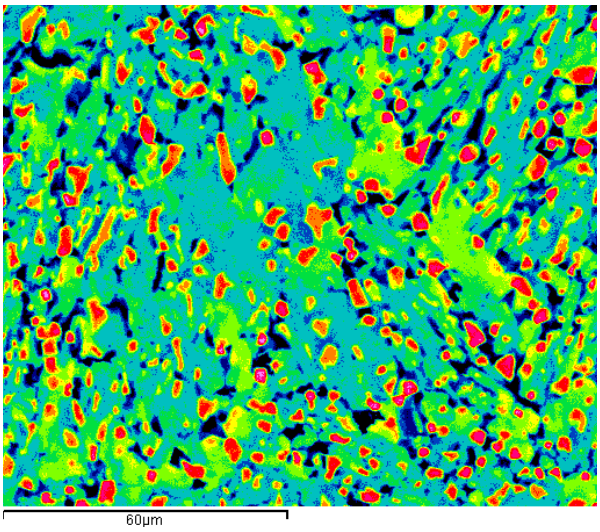

Fig. 6 The fragment of the pseudomorphose after garnet interior (false-colored in BSE mode). Explanation: red – Al-spinel, green – Al-CPx (augite), pale blue – Al-rich OPx, dark blue – phyllosilicates.

Pyroxenes in the symplectic assemblage are enriched in Al_2O_3 with orthopyroxene containing up to 9 wt.% and clinopyroxene up to 12 wt. %. These both pyroxenes are inhomogeneous in composition on a local scale. Na_2O content in the Al-rich clinopyroxenes is very low < 0.5 wt. %.

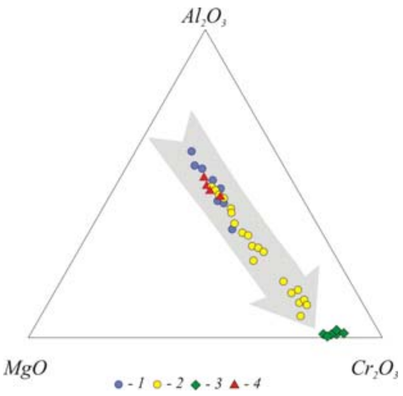

Fig. 7 Diagram showing the compositional variation of symplectic spinels from cores (1) to rims (2) in comparison with symplectic spinels (after garnet) from the peridotite xenoliths of Argyle (AK1) pipe (Jaques et al 1990) (4), and Cr-rich spinel inclusions in primary CPx of former garnet facies (3).

Primary chromite was found in one third of Kostomuksha xenoliths collection (6 nodules of garnet free peridotites). It occurs as subhedral to anhedral grains up to 1.5 mm across, typically with reaction (oxidezed?) rim (Fig. 8). The low-Cr spinel appears red-brown in thin section and contains less than 30 wt. %, 40-42 wt. % Al_2O_3, 9-11 wt. % FeO and 19-20 wt. % MgO.

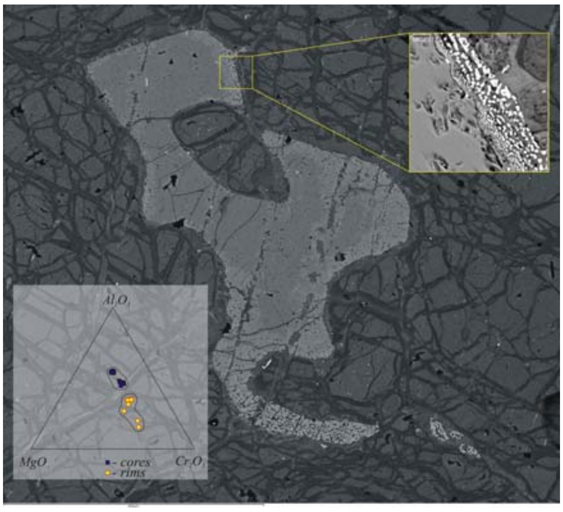

Fig. 8 BSE photomicrograph of spinel grain of primary association with reaction rim with variation diagram of MgO, Al_2O_3 and Cr_2O_3 components for cores and rims

Single-phase geothermobarometers (Nimis, 2000, Ashchepkov, 2001) applied to the primary clinopyroxenes texturally equilibrated with orthopyroxene and garnet yielded P-T estimates ranging from ca. 800 to 1300 ^{o}C at 34-70 kbar, which mostly correspond to the diamond stability field. Clinopyroxenes from the spinel-pyroxene symplectites after garnet yielded lower temperatures (<800 ^{o}C) at pressures unlikely exceeding ca. 20 kbar, given the chemical composition of the associated spinel (Webb, 1986).

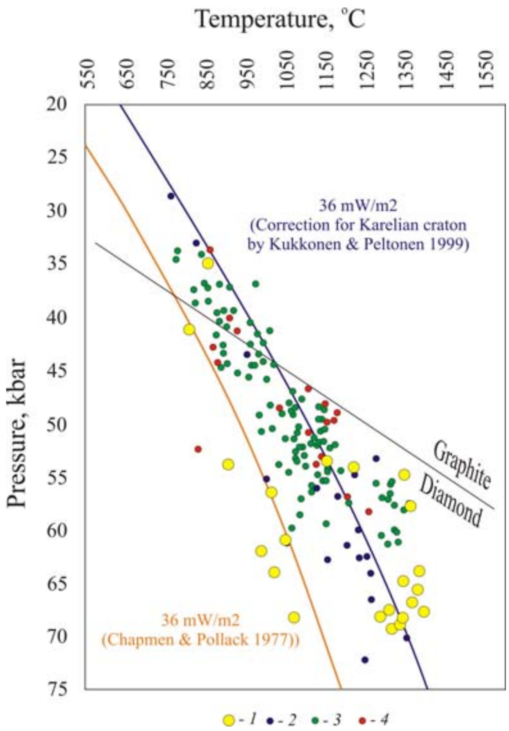

Fig. 9 P-T estimates for Kostomuksha peridotite xenoliths (1) by NT200, 2-4 – peridotite xenoliths from Finnish kimberlite pipes (Lehtonen, 2004)

LA-ICPMS measurements show an enrichment of the primary clinopyroxenes in light REE and Sr and negative anomalies of high field strength elements (Zr, Hf and Ti) and Pb relative to the REE. Together with the complete absence of primary hydrous minerals such as amphibole and phlogopite in the studied xenoliths, this geochemical signature indicates that the xenolith rocks were affected by carbonatite metasomatism at depth preceding their entrapment by the host lamproite/kimberlite 2. We believe that the xenoliths provide a record of transition from carbonatite to lamproite/kimberlite 2 melts in the mantle during progressive partial melting of the source region of the host kimberlite 2. The carbonatite melts were subsequently consumed by reaction with depleted uppermost mantle rocks, while the xenolith-bearing lamproite/kimberlite 2 melts reached the Earth's surface.

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