New Identity of the Kimberlite Melt: Constraints from Unaltered Diamondiferous Udachnaya-East Pipe Kimberlite, Siberia, Russia

by

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Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any tertiary institution, and to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

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Abstract

This study aims at understanding parental melt compositions and evolutionary history of mantle-derived kimberlitic magmas, using unaltered Udachnaya-East kimberlite as an example.

Recent advances in theoretical, experimental and melt inclusion research strongly suggest that the mantle is highly heterogeneous on a small scale, but this heterogeneity is effectively obscured by the blended nature of most erupted magmas. Thus, the original compositions of individual mantle-derived melt batches that supposedly reflect their respective mantle sources are in fact averaged, owing to mixing of melts en route to the surface. The exception may be occasional low degree partial melts that erupt with little or no mixing with subsequent melt fractions. However, such melts are particularly prone to reaction with country rocks along the pathways to ascent, and are also very rare among erupted rocks.

Among all known erupted mantle-derived magmas, kimberlites offer the deepest probes into the convecting subcontinental mantle, derived from the lowest degrees of melting. Such origins make kimberlites most suitable for characterising primitive (undepleted by previous melting) mantle assemblages with their likely enrichment in the volatile elements, and thus with the lowest solidus temperatures. On the other hand, the large amount of lithospheric and crustal xenoliths in kimberlites and their typically high degree of alteration, can significantly affect interpretations that can be drawn from bulk rock analyses.

This study attempts to overcome such problems related to alteration of kimberlites and presents detailed petrographic, mineralogical, chemical, and isotope data on exceptionally fresh kimberlite samples from the diamondiferous Udachnaya-East pipe (Daldyn-Alakit region, Siberia). I demonstrate that the Udachnaya-East rocks have radiogenic isotopic compositions, petrographic features and major and trace element geochemistry typical of group-I kimberlites. However, unlike common kimberlites, the studied samples show no primary or secondary serpentine, and thus are essentially anhydrous (< 0.5 wt% H$_2$O), but CO$_2$-rich (10-11 wt%). In contrast with
other kimberlites worldwide, the Udachnaya-East samples are uniquely enriched in chlorine and alkalies (2.3-3.2 wt% Cl, 2.6-3.7 wt% Na, and 1.6-2.0 wt% K).

Enrichment in CO$_2$, Cl and alkalies is expressed in the essentially alkali-carbonate (shortite, zemkorite) and alkali-chloride (halite, sylvite) composition of the kimberlite groundmass. These minerals cement olivine phenocrysts and form round segregations (“nodules”). Radiogenic isotope compositions (Nd, Sr, and Pb) of the chloride, chloride-alkali carbonate, carbonate and oxide-silicate constituents in the groundmass of the Udachnaya-East kimberlite effectively show the coexistence of these phases in the closed system since kimberlite emplacement $\approx$347 Ma. Complementary to insights into radiogenic isotope composition of the parental mantle source of the Udachnaya-East kimberlite, my study explores stable isotope compositions of the kimberlite groundmass (O, C and S isotopes), chloride-carbonate nodules (O and C isotopes) and two populations of olivine (O isotopes).

Detailed study of zoning and composition of the groundmass olivine-II demonstrates very complex fractionation of the ultramafic primary kimberlite melt. Additional constraints are provided by olivine-hosted inclusions of cogenetic minerals, fluid and melt. The wide compositional interval shown by the cores of olivine-II (Fo$_{86-93}$) reflects either crystallisation from different melt batches, or re-equilibration (in terms of Fe-Mg) with different mantle lithologies. I report the discovery of previously unknown inclusions of high-Ca pyroxene in the olivine-II cores. They formed in the diamond stability field (45-50 kb) at temperatures of 900-1100$^\circ$C, from a melt with a trace element composition resembling that of the kimberlite groundmass. The inferred P-T conditions correspond to the lower part of lithosphere beneath the Siberian craton.

I consider that a prolonged evolution of the kimberlite magma by olivine crystallisation was responsible for a build-up of abundances of alkalies, chloride, carbonate, and sulphate components. As a result, the residual kimberlite magma acquires an essentially non-silicate composition, but high in CO$_2$, Cl, and alkalies. This magma crystallises at low temperatures ($<650$-750$^\circ$C), and undergoes chloride-carbonate liquid immiscibility at $\sim$600$^\circ$C.
I propose that significant amounts of alkali chlorides and carbonates in the Udachnaya-East kimberlite are pristine magmatic components inherited from the kimberlite parental/primary magma. This enrichment may be responsible for the kimberlite low liquidus temperatures, low viscosities, and rapid ascent.
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