

# NEW PETROLOGICAL-GEODYNAMIC MODEL FOR THE ORIGIN OF KIMBERLITES AND DIAMOND

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On the basis of published experimental and petrological data and his own method (Shkodzinsky, 1985), the author has calculated quantitative models for the evolution of kimberlite magmas during rise and solidification and for the formation of their source substrates and diamond. The models have revealed some so far unknown phenomena in kimberlite magmas and shed new light on processes of kimberlite and diamond generation.

The calculated phase PT diagram demonstrates that under high pressure the solid phase content of kimberlite magmas (like other magmas) strongly increases (lines A, Б, Figure) and in zones of their origin they turn into identical in composition, primarily solid-phase substrates. Therefore, these magmas result from remelting of such substrates with frictional heating-up in deep tectonic shear faults (areas 1-3 on line Д) and decompression during rise (areas 4 and 5). That is, kimberlite magmas have a decompressional-frictional origin. This is confirmed by subsolidus (usually 900-1200° C) rather than subliquidus (1500-1700° C) temperatures of deep mineral equilibrium in kimberlites and diamond; the presence, in kimberlites, of high-density inclusions that failed to settle in viscous, predominantly solid-phase magmas at depth; the presence of inverse zoning in some deep-seated minerals of kimberlites, caused by the path of melting processes during magma rise; the presence of carbonate inclusions and incompatible-component rich minerals in diamond due to its generation in kimberlitic substrates.

The origin of kimberlite magmas in relation to frictional heating-up explains the relationship of kimberlite magmatism with periods of tectonic deformation of ancient platforms, linear tectonic zones, rift and syncline margins. It appears that the high-temperature parts of the geotherms with a kink obtained from peridotite xenoliths reflect frictional heating-up with origination of kimberlite magmas in zones of underthrusting of lower lithosphere blocks as a result of spreading out asthenosphere plumes. This is evidenced by a direct relationship between the degree of tectonic deformation of xenoliths and the temperature of mineral equilibrium in them and between the depth of these equilibrium and the diamond grade of the enclosing kimberlites (Shkodzinsky, 1995).

With decompressional-frictional origin of magmas, the composition of kimberlites was mainly determined by processes of formation of their parent substrates at an early stage of the Earth's history. According to the calculated model, substrates of kimberlitic composition resulted from late, synaccretional fractionation of deeper, peridotite-picrite parts of a global magma ocean that appeared from impact heat release during the Earth's formation. These fractionation processes are responsible for high concentrations of light rare earth elements in kimberlites. Precipitation of high-temperature (highly magnesian) and, sometimes, low-temperature (of hydrated carbonaceous chondrite-type) condensates from a protoplanet cloud during these processes is responsible for abundance of magnesium and volatiles in kimberlites. The restriction of diamondiferous kimberlites to ancient platforms can only be explained by preservation of kimberlitic substrates in the almost undisturbed ancient mantle lithosphere. Diffusional exchange of components between peridotitic cumulates and alcaic residues of fractionation of the magma ocean is responsible for mantle metasomatism processes. Diffusion of radiogenic isotopes from kimberlitic substrates into the enclosing peridotites caused the relatively little dependence of "primary" radiogenic/non-radiogenic isotope ratios on compositional characteristics of kimberlites.

During rise to shallow depths, kimberlite magmas experienced rapid decompressional vitrification (area 6 on line Д). With increasing magma viscosity, narrow, dike-like conduits changed into isometric to start the formation of kimberlite pipes; in contact zones, tear-off of layers occurred. Further rise witnessed sealing of high internal pressure of a fluid phase by decompressional solidification, increase in difference between this and falling external pressure, and a resulting explosive desintegration of the upper





(following their origination from global magma fractionation) at the expense of graphite with decreasing temperature (segment 0 on line D). This lends explanation for the frequent presence of graphite inclusions in diamond nuclei (Bulanova et al., 1993).

Melting during kimberlite magma generation was accompanied by strong decrease in water fugacity due to its dissolution in a melt. In Le Chatellier's principle, this forced water to be formed at the expense of other components, particularly by reducing CO<sub>2</sub> and CO from a fluid by methane and hydrogen dissolved in sulphides, with the released carbon crystallizing as diamond. This is illustrated by a schematic reaction:



where F, S, L and D stand for fluid, sulphides, melt and diamond.

The validity of this reaction of diamond formation with melting is confirmed by a well-known reverse reaction of diamond resorption under the effect of water released from crystallization of kimberlite magmas, as well as abundant sulphide inclusions in diamond versus the low sulphide content of the kimberlites. Along with diamond formation, reduction of some other oxides took place, which explains the presence of native metal and carbide inclusions in diamond.

The short period of earthquakes evidences that frictional melting in deep tectonic zones occurred in pulses. Rapid release of CH<sub>4</sub> and H<sub>2</sub> from molten (during these pulses) sulphides led to the appearance, along the periphery of sulphide grains, of zones with a very low oxidizing potential. This accounts for the nature of a much lower oxidizing potential during origin of many central inclusions in diamond (wustite-iron buffer, Bulanova et al., 1993) compared to the rock-forming minerals of kimberlites (fayalite-magnetite-quartz buffer, Ryabchikov et al., 1981).

Central areas of zoned diamond crystals formed in predominantly solid-phase substrates (area 2) under conditions of severe deformation with pulses of frictional melting and carbon oversaturation of a melt. This explains a frequently irregular shape of the diamond's central zone, abundance of inclusions and indications of plastic deformations in it and a highly imperfect structure of its substance (Beskrovanov, 1992). The diamond's peripheral zone crystallized from already liquid magmas (area 4) in a carbon-depleted medium; hence its idiomorphic shape, rare inclusions and perfect structure.

Temperature fluctuations during magma generation and compositional heterogeneity of kimberlitic substrates are responsible for significant variations in diamond morphology even within a single pipe. Poorer solubility of carbon dioxide and nitrogen in a melt relative to water caused their increased concentration in all phases during melting and a higher average concentration of CO<sub>2</sub> and H<sub>2</sub> in higher-temperature octahedral crystals relative to cubic ones.

Inclusions of eclogitic paragenesis resulted mainly from melt solidification products in-between frictional melting pulses in the most readily fusible areas of kimberlitic substrates, which lends support for a high incompatible element content of their minerals. Inclusions of peridotitic paragenesis mainly consist of refractory relict minerals of kimberlitic substrates, which explains their high magnesium and chromium contents and older average absolute ages. However, these ages appear to be exaggerated since they fail to consider the kimberlitic rather than peridotitic composition of the diamond generation environment.

Diamonds of deep-seated xenoliths differ in origin from those formed in kimberlite magmas, but a little amount of them should be present in kimberlites due to partial destruction of xenoliths.

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