Goldschmidt 2025 Abstract
https://doi.org/10.7185/gold2025.28750

Time-constrained Mantle Metasomatism Leading to Kimberlite Genesis

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Kimberlite magmatism is preceded by metasomatism of the depleted cratonic mantle by proto-kimberlitic melts enriched in volatiles and incompatible elements. Validating theoretical models of proto-kimberlite metasomatism requires time constraints on various stages of metasomatism. This has nevertheless proven challenging due to limitations in chronometric techniques that have so far been used on mantle xenoliths (e.g., Re-Os, Sm-Nd geochronology). Garnet Lu-Hf geochronology now provides a robust method for constraining the ages of garnet in individual xenoliths, thereby enabling the dating of metasomatic garnet growth.

In this study, we analyzed garnet from kimberlite-hosted pyroxenites and peridotites with sheared and coarse textures from the Slave, Kaapvaal and Siberian cratons. Low-dispersion internal Lu-Hf isochrons for individual xenoliths yielded ages ranging from Archean to Phanerozoic. Garnets in orthopyroxenite and harzburgite samples are G10 - G9 with strong depletion in Y, Zr, Ti, and Na. These exclusively yielded Archean age (3.0-2.7 Ga). Carbonatitic metasomatism introduced Ca in some of the samples, resulting in the formation of clinopyroxene and garnet. Garnet in these assemblages (Lu-Hf ages of 1.89-0.75 Ga) exhibits G9 lherzolitic compositions, reflecting Cr-Ca equilibration with clinopyroxene during progressive carbonatitic metasomatism. Beginning ~150 My before kimberlite eruption, a new generation of garnet was introduced characterized by Cr-poor G1 compositions with elevated Ti, Na, and Y at constant Ca-Cr concentrations. This garnet is restricted to sheared peridotites, which are strained by hydrous weakening. It thus may reflect hydrous rather than carbonatitic metasomatism.

The above evolution appears to capture a common refertilization cycle in the mantle of kimberlite provinces. The Lu-Hf internal isochron ages show drastic differences in the timescales of these various processes, with carbonatitic metasomatism recurring over billions of years, whereas proto-kimberlite hydrous Ti-metasomatism and associated shearing occurred for 150 Myr or less before kimberlite magmatism. Systematic global trends in garnet chemistry across cratons suggest that carbonatitic metasomatism may be a necessary precursor to Ti metasomatism. These observed metasomatic processes likely reflect localized mantle evolution beneath kimberlite provinces rather than the global-scale compositional changes in the subcontinental lithospheric mantle over time.