

Multiple Origins for Mantle Pyroxenites: Subducted Ocean Crust and/or Cumulates from Asthenospheric Magmas

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Pyroxenites are the second most common ultramafic rock-type in the shallow continental lithospheric mantle (SCLM) after the spinel lherzolite-harzburgerite series. Judging from their abundances in mantle xenolith suites and ultramafic massifs, approximately 1% of the SCLM is composed of pyroxenite. Ultramafic massifs provide field relations between pyroxenites and their host peridotites and show that they form layers that have been interpreted as originally forming dykes that have been rotated into the foliation plane of the surrounding peridotite. Thick pyroxenite layers often contain a garnet pyroxenite core and spinel pyroxenite margins, indicating a long history of re-equilibration with their host peridotite. There are two schools of thought concerning the origin of mantle pyroxenites. (i) They are formed by passage of asthenosphere-derived silicate magmas through the lithosphere. This is a particularly common interpretation of spinel-pyroxenites and amphibole-pyroxenites that occur in most spinel peridotite xenolith suites, but has also been suggested as the origin of garnet- and spinel-pyroxenite layers in ultramafic massifs. This view is supported by the common similarity between the Sr–Nd isotopic composition of the pyroxenites and that of alkaline and tholeiitic continental basalts. (ii) They are remnants of oceanic crust, subducted into the asthenosphere and then streaked out by mantle convection until they were incorporated into the lithosphere, together with their host peridotites. This view is supported by the apparent antiquity of garnet pyroxenite layers in ultramafic massifs, the presence of graphite in such layers and the carbon isotope composition of the graphite, anomalous oxygen isotope compositions of the silicate minerals, and anomalous Os and Hf isotope compositions. Here I present a review of relevant data available for mantle pyroxenites and present new isotope and trace element results on pyroxenites from xenolith suites and massifs, including rare garnet pyroxenite xenoliths. From this review, it is clear that there are multiple origins for pyroxenites in the upper mantle.

In terms of major elements, pyroxenites have lower Mg contents and variable but generally higher concentrations of Al,

Ca and Ti, compared with mantle peridotites. Their compositions reflect (a) the nature of the magma from which they were formed, and (b) the abundances of their constituent cumulate minerals. Pyroxenites show a wide range of $\text{CaO}/\text{Al}_2\text{O}_3$ ratios from 0.5 to 4.5. This could be due either to accumulation from mafic magma, in which Ca-rich clinopyroxene and/or Ca-rich plagioclase were cumulus phases, or from sea-water alteration of oceanic gabbros. Layered pyroxenites in peridotite massifs tend to show bulk rock LREE-depletion; this may be due to the original chemistry of the magma that formed the pyroxenite (e.g. streaked out layers of MORB-type oceanic crust) or because of subsequent equilibration with the surrounding LREE-depleted peridotites. However, positive and negative Eu anomalies are not observed in their bulk rock compositions, as would be expected if fractionation or accumulation of plagioclase had occurred in oceanic crustal magma chambers. Clinopyroxenes from mantle pyroxenites often have REE patterns that are very similar to those from LREE-depleted peridotites. This may be due to their original ocean crustal composition or due to re-equilibration with LREE-depleted host peridotite mantle. However, clinopyroxenes from many pyroxenite xenoliths are LREE-enriched; magmas in equilibrium with these pyroxenites must also have been LREE-enriched, which argues against an origin as MORB-like oceanic crust. Wide variations in $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ isotopic compositions are present in clinopyroxenes from mantle pyroxenites. In the Pyrenees massifs, some pyroxenites are identical to their host peridotites in isotope compositions, but others show both much higher and much lower $^{143}\text{Nd}/^{144}\text{Nd}$ ratios, and a tendency to higher $^{87}\text{Sr}/^{86}\text{Sr}$. Radiogenic ingrowth contributes to some of the observed isotope heterogeneity. The Hf isotope composition of pyroxenites from the Beni Bousera are likewise very variable. Thus, if pyroxenite layers represent oceanic crust, they must be very ancient in order to have produced such isotopic heterogeneity in response to relatively minor fractionation of Sm/Nd ratios and Lu/Hf ratios. Os-isotope evidence also points to the great antiquity of pyroxenites in ultramafic massifs.