Paper Number: 1299

The timing of mantle metasomatism revealed by diffusion profiles in zoned garnet crystals – a nanoSIMS study

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Relict diffusion profiles in natural crystals have the capability to yield information about the duration of geologically very short processes (as short as hours to years) occurring in the deep geological past (millions or hundreds of millions of years ago). Garnet from a peridotite xenolith from the Wesselton kimberlite, South Africa displays distinct growth zones, with a large core that formed in a depleted peridotite and a rim formed during mantle metasomatism at around 1120°C and 4.5 GPa. Due to the compositional contrast between these two garnet domains, concentration profiles were formed by solid-state diffusion that can yield constraints on timescales between metasomatism of the mantle and eruption of the xenolith.

Linear compositional profiles have been quantified between core and rim using electron microprobe (Na, Al, Mg, Ca, Cr, Fe, Mn and Ti) and Nano-Secondary Ion Mass Spectrometry (Na, Ca, Cr, Fe, Mn, Ti and Y) analyses. The profile lengths are <10 µm and thus the high spatial resolution (800 nm spot size) of the NanoSIMS was necessary to adequately measure the profiles. The profiles were modelled as a diffusive process by fitting to a solution of the diffusion equation using published diffusivity values for Ca, Fe and Mn. Estimates of the time taken to yield the diffusion profiles were 2 – 10 years based on Ca, and <100 days based on Mn and Fe. Such timescales are too long to be produced by the interaction of the mantle xenolith with the host kimberlite magma. Therefore we suggest that an episode of mantle metasomatism occurred only a few years before the extraction of the xenolith by the kimberlite 86-90 Ma ago.

From the measured profiles it was also possible to determine the diffusivity of Na, Ti, Cr, and Y in peridotitic garnet relative to Ca. These elements fell into three groups based upon their relative diffusivities: Mn (log D = Ca +0.53 m^2s^{-1}) and Fe (Ca +0.61 m^2s^{-1}) diffused significantly faster than Ca; Na (Ca +0.11 m^2s^{-1}) and Cr (Ca +0.05 m^2s^{-1}) diffuse at a similar rate; whilst Ti (Ca -0.26 m^2s^{-1}) and Y (Ca -0.17 m^2s^{-1}) diffuse slower than Ca. Therefore, some trace element zoning in peridotite garnets will survive longer than major element zoning, which could provide a tool to investigate marginally longer timescales for mantle metasomatism.