New insights into the age, composition and evolution of the lithospheric mantle using in-situ isotopic analysis

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The development of the multi-collector ICP-MS has provided a wider range of isotopic systems (e.g. Li, Mg, Fe, Cu, Hf, Os, Tl) that can used to place constraints on the timing of depletion and metasomatic events in the mantle and to better characterize the processes that modify the composition of the lithospheric mantle. Associated with the application of these isotopic systems has been the parallel development of in-situ isotope analysis using a laser ablation microprobe attached to the mass spectrometer. The in-situ capabilities allow for the first time the investigation of the scale of isotopic variation due to metasomatism and raises questions over the validity of whole-rock measurements. In-situ analysis also allows the isotopic data to be interpreted within a microstructural context and in the framework of geochemical data from other microanalytical techniques.

In-situ Re-Os isotope analysis of mantle sulfides has enabled the in-situ dating of the lithospheric mantle. Apart from dating the depletion events that formed the volume of lithosphere the sulfides provide constraints on a range of processes that might modify the mantle such as the addition of metasomatic fluids during lithosphere reworking. The isotopic data indicate that there are multiple generations of sulfides in most mantle peridotites and whole-rock Re-Os ages thus reflect a mix of these different sulfide populations: in many samples the in-situ data yield older ages for original lithospheric mantle stabilization. Superimposed on the record obtained from enclosed residual primary sulfides is the post-stabilisation history preserved in mainly interstitial sulfides. This has significant implications for linking crust-mantle evolution and identifying mantle terranes with different histories.

A study of the Mg isotopic composition of mantle olivines shows a significant heterogeneity in the lithospheric mantle: δ^{26}Mg ranges from –3.01 to +1.03 per mil and δ^{25}Mg from –1.59 to +0.51 per mil. Samples with petrographic evidence of refertilisation (including modal metasomatism) show large ranges in δMg values within samples. Sheared peridotite xenoliths from the Kaapvaal and Slave cratons show a shift to higher δMg associated with the introduction of fluids with an 'asthenospheric' signature. Olivine in the least metasomatised peridotites from SE Australia has isotopically light Mg, whereas olivine in cryptically and modally metasomatised peridotites (amphibole±apatite–bearing) becomes progressively heavier, both absolutely and relative to pyroxene and amphibole, with increasing degrees of metasomatism. The heterogeneity measured in individual samples suggests that Mg isotopic fractionations produced by processes of mantle metasomatism are preserved on the intra-grain scale, and the magnitude of the observed fractionations indicates that diffusion-related (kinetic) processes are important in controlling isotope fractionation at high temperatures.

The Lu-Hf isotopic system has been applied to solving the problem of origin of the MARID xenoliths by in-situ analysis of rutile and zircon. The rutiles are isotopically very heterogeneous, both within and between grains, with an overall range in ^{176}Hf/^{177}Hf from 0.2812-0.2858. The lowest values represent Hf that has been isolated from the Depleted Mantle since 3 Ga, whereas the highest values are well above the mean value for the present-day Depleted Mantle. This Hf must have resided in a high Lu/Hf phase for a long time, such as eclogitic or peridotitic garnet. A model to explain the Hf isotope results is that the MARID rocks initially formed by interaction of asthenospheric melt with ancient harzburgitic mantle, which dominated their Hf budget and gave the low Hf isotopic signatures. Later metasomatism by a fluid/melt with highly radiogenic Hf derived from the breakdown of the garnet, produced the range to high Hf isotopic signatures.