A preliminary assessment of the application of Sr, Nd, Pb, He and N isotope analysis to fluid inclusions in kimberlite olivine: A new approach to trace deep-mantle sources

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Kimberlites are the deepest melts that reach Earth’s surface and, therefore, can provide unique insights into the composition and evolution of the convective mantle through time. Application of isotope geochemistry to trace the composition of kimberlite sources has thus far been hindered by the ubiquitous alteration and incorporation of xenocrystic material in kimberlite rocks. Bulk-kimberlite analyses are typically considered reliable for Nd and Hf isotopes due to their overwhelmingly higher concentrations in kimberlite melts compared to common mantle and crustal contaminants. Conversely, Sr and Pb isotope compositions of bulk kimberlite samples are seldom considered representative of their parental melts thus requiring analysis of robust magmatic phases, primarily perovskite. Addressing the primary (i.e. magmatic) isotopic composition of volatile elements, such as N and noble gases, requires analyses of volatile-rich phases, and fluid inclusions in olivine represent a typical primary target in mantle-derived magmas. However, fluid inclusions in kimberlitic olivine are dominantly secondary in origin. Secondary inclusions can form at any time after crystallisation of their mineral host, which requires assessment of the origin of trapped fluids (i.e. pristine magmatic fluids, crustal fluids of external derivation, or combination thereof) before their isotopic composition can be used to make inferences about kimberlite mantle sources.

Here we present trace-element and Sr-Nd-Pb-He-N isotopic compositions of multiple olivine aliquots representing two different magmatic units of the ~88 Ma Wesselton kimberlite (Kimberley, South Africa). The Sr and Nd isotopic composition of olivine analysed by isotope-dilution (ID) TIMS are within the narrow range of perovskite \(^{87}\text{Sr}/^{86}\text{Sr} (0.7043-0.7046)\) and whole-rock \(^{143}\text{Nd}/^{144}\text{Nd} (\text{eNd}\_\text{i} = 0.4-2.2)\) for the Kimberley kimberlites. These results indicate that the secondary fluid inclusions, which dominate the incompatible trace-element budget of olivine separates, have a pristine magmatic origin devoid of crustal contribution.
Helium isotope compositions were measured by laser heating of 1.6 to 9.8 mg of olivine using an ultrahigh-sensitivity compressor-source noble gas mass spectrometer. $^{3}$He/$^{4}$He ratios are between 1.6 $R_A$ and 3.7 $R_A$ (where $R_A$ indicates the atmospheric $^{3}$He/$^{4}$He ratio), values more radiogenic than MORBs but comparable to HIMU OIBs. These results indicate a high time-integrated (U+Th)/He ratio in the source of the Kimberley kimberlites, which is consistent with the moderately high (i.e. HIMU-like) time-integrated U/Pb ratio implied by elevated initial $^{206}$Pb/$^{204}$Pb in Wesselton olivine (19.1-19.5), Kimberley kimberlites (up to 19.9) and megacrysts in southern African Cretaceous kimberlites (up to 20.5). The combination of low $^{3}$He/$^{4}$He, moderately radiogenic $^{87}$Sr/$^{86}$Sr, and negative $d^{34}$S values (-2.6‰ to -5.7‰) require a contribution from subducted recycled material in the source of the Kimberley kimberlites. Conversely, a preliminary N isotope analysis of Wesselton olivine by in-vacuo crushing using a noble gas mass spectrometer returned a mantle-like $d^{15}$N of -2.9‰, which might suggest limited recycling of surface N ($d^{15}$N >0‰) in the source of these kimberlites. We conclude that the combination of Sr-Nd-Pb and He-N isotope tracing of fluid inclusions in olivine can provide a robust new approach to address the composition of kimberlite sources and, therefore, the evolution of the deep mantle through time.