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Review

Dating mantle peridotites using Re-Os isotopes: The complex message from whole rocks, base metal sulfides, and platinum group minerals

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Abstract

The Re-Os isotopic system is largely considered the geochronometer of choice to date partial melting of terrestrial peridotites and in constraining the evolution of Earth's dynamics from the mantle viewpoint. While whole-rock peridotite Re-Os isotopic signatures are the core of such investigations, the Re-Os dating of individual peridotite minerals—base metal sulfides (BMS) and platinum group minerals (PGM)—that are the main hosts for Re and Os in the mantle peridotites came into play two decades ago.

These nanometric-micrometric BMS and PGM display an extreme complexity and heterogeneity in their $^{187}Os/^{188}Os$ and $^{187}Re/^{188}Os$ signatures that result from the origin of the BMS±PGM grains (residual vs. metasomatic), the nature of the metasomatic agents, the transport/precipitation mechanisms, BMS±PGM mineralogy, and subsequent Re/Os fractionation. Corresponding whole-rock host peridotites, typically plot within the $^{187}Os/^{188}Os$ and $^{187}Re/^{188}Os$ ranges defined by the BMS±PGM, clearly demonstrating that their Re-Os signatures represent the average of the different BMS±PGM populations. The difference between the $^{187}Os/^{188}Os$ ratios of the least radiogenic BMS±PGM and the respective host peridotite increases with the fertility of the peridotite reflecting the increasing contribution of metasomatic BMS±PGM to the whole-rock mass balance of Re and Os concentrations and Os isotope compositions. Corollaries to these observations are that (1) BMS may provide a record of much older partial melting event, pushing back in time the age of the lithospheric mantle stabilization, (2) if only whole-rock peridotite Re-Os isotopic measurements are possible, then the best targets for constraining the timing of lithospheric stabilization are BMS-free/BMS-poor ultra-refractory spinel-bearing peridotites with very minimal metasomatic overprint, as their $^{187}Os/^{188}Os$ signatures may be geologically meaningful, (3) while lherzolites are "fertile" in terms of their geochemical composition, they do not have a "primitive," unmodified composition, certainly in terms of their highly siderophile elements (HSE) and Re-Os isotopic systematics, and (4) the combined Re-Os isotopic investigations of BMS and whole-rock in BMS-rich mantle peridotites would provide a complementary view on the timing and nature of the petrological events responsible for the chemical and isotopic evolution and destruction of the lithospheric mantle.

In addition, the $^{187}Os/^{188}Os$ composition of the BMS±PGM (both residual and metasomatic) within any single peridotite may define several age clusters—in contrast to the single whole-rock value—and thus provide a more accurate picture of the complex petrogenetic history of the lithospheric mantle. When coupled with a detailed BMS±PGM petrographical study and whole-rock lithophile and HSE systematics, these BMS age clusters highlight the timing and nature of the petrological events contributing to the formation and chemical and isotopic evolution of the lithospheric mantle. These BMS±PGM age clusters may match regional or the local crustal ages, suggesting that the formation and evolution of the lithospheric mantle and its overlying crust are linked, providing mirror records of their geological and chemical history. This is, however, not a rule of thumb as clear evidence of crust-mantle age decoupling also exist.

Although the BMS±PGM Re-Os model ages push back in time the stabilization of lithospheric mantle, the dichotomy between Archean cratonic and circum-cratonic peridotites, and post-Archean non-cratonic peridotites and tectonites is preserved. This ability of BMS±PGM to preserve older ages than their host peridotite also underscores their survival for billions of years without being reset or reequilibrated despite the complex petrogenetic processes recorded by their host mantle peridotites. As such, they are the mantle equivalents of crustal zircons. Preservation of such old signatures in "young" oceanic peridotites ultimately rules out the use of the Re-Os signatures in both oceanic peridotites and their BMS to estimate the timescales of isotopic homogenization of the convecting mantle.

Keywords: Re-Os isotopic system, mantle peridotites, base metal sulfides, platinum group minerals; Planetary Processes as Revealed by Sulfides and Chalcophile Elements

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