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Tracing the metasomatic and magmatic evolution of continental mantle roots: A case study of high $^{238}U/^{204}Pb$ and $^{232}Th/^{204}Pb$ clinopyroxenes from Middle Atlas (Morocco) peridotite xenoliths

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Although comprising only 2% of Earth's mantle, lithospheric peridotites and pyroxenites, especially those from beneath the continental blocks, feature strongly in the literature as deplete analogues for the entire upper mantle. This frequent usage stems from its availability at Earth surface as xenoliths sampled by volcanic rocks, as obducted orogenic bodies marking (paleo-) suture zones and also as samples from the current oceanic basins (abyssal peridotites). On the other hand lithospheric mantle records ubiquitous metasomatic enrichment (modal and cryptic) due to interaction with various fluid phases and both, extreme depletion and metasomatic enrichment may render Earth lithospheric mantle an important geochemical reservoir that could be distinct from the convecting mantle.

We wish to particularly address the potential of SCLM (sub-continental lithospheric mantle) as potential source of the intraplate volcanism and, importantly, whether SCLM has unique lithophile (Rb/Sr, Sm/Nd, Lu/Hf, U/Pb, Th/Pb) and siderophile (Re/Os) isotope features that would allow the discrimination of SCLM from the convecting mantle at a given time. We will focus on off-cratonic spinel-facies peridotite xenoliths sampled by the Quaternary intra-plate volcanism of the Middle Atlas (Morocco) and highlight clinopyroxenes with unusually high $^{238}U/^{204}Pb$ and $^{232}Th/^{204}Pb$ that are coupled with homogeneous radiogenic Pb isotopes.

The Moroccan U, Th and Pb abundances in the clinopyroxenes generally exceed estimates of primitive mantle clinopyroxene. Pb isotope compositions of these clinopyroxenes are unusually radiogenic relative to literature data of SCLM minerals and vary between $^{206}Pb/^{204}Pb$ = 19.93 – 20.25, $^{207}Pb/^{204}Pb$ = 15.63 – 15.66 and $^{208}Pb/^{204}Pb$ = 39.72 – 40.23. These Pb isotope systematics are associated with the Pb isotope signature of the convecting mantle. Nevertheless, these samples have negative $\Delta 7/4$ but positive $\Delta 8/4$; setting them distinctly apart from typical HIMU. $^{238}U/^{204}Pb$ and $^{232}Th/^{204}Pb$ of these clinopyroxenes, which range from 26 to 81 and 136 to 399, respectively, more are extreme than estimates of MORB- and HIMU-source mantle. This high-quality U-Pb and Th-Pb data and Pb isotopes allows us to determine that the age of the metasomatic enrichment is very young ($>$ 20 Ma) and associated with the Quaternary intra-plate volcanism in this region although, importantly, Pb isotopes of host volcanic rocks and SCLM clinopyroxenes do not overlap.

When literature data for Pb isotopes in mantle minerals are considered, the Pb isotope range of Archean, Proterozoic and Phanerozoic continental mantle roots is remarkable in that they are similar to the convecting mantle. This observation does not support the existence of SCLM with high $^{238}U/^{204}Pb$ and $^{232}Th/^{204}Pb$, which has been recorded from numerous localities, for long periods of time. Consequently, the narrow range of Pb isotopes in SCLM worldwide suggests that only the youngest metasomatic events are recorded by incompatible elements such as U, Th and Pb and that such metasomatism frequently effects continental SCLM throughout Earth's evolution.

Numerical modelling of putative magmas from the Middle Atlas SCLM generated by fractional, non-modal melting calculations yield extremely high $^{238}U/^{204}Pb$ and $^{232}Th/^{204}Pb$ ratios that do not seem to be realized in terrestrial basaltic rocks. For example, the most extreme SCLM melt generated yields $^{232}Th/^{204}Pb$ of 2250 relative to $^{232}Th/^{204}Pb$ of 200 for the host volcanic rocks from the Middle Atlas.

Relative to the elevated $^{238}U/^{204}Pb$ and $^{232}Th/^{204}Pb$ ratios that are found in many peridotite clinopyroxenes available from the literature, Rb/Sr, Sm/Nd and Lu/Hf data of most of these samples are unremarkable and remain associated with values of the convecting mantle, i.e. this data is unsuitable in tracing the age of the metasomatism, the separation of the SCLM from the convecting mantle or the melting of SCLM. Therefore we propose extreme U/Pb and Th/Pb could be used to tracing lithospheric melting, yet neither extreme Pb isotope nor extreme $^{238}U/^{204}Pb$ and $^{232}Th/^{204}Pb$ have been found in terrestrial volcanism rendering frequent SCLM melting/recycling undetectable or insignificant.