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Calibrating Forsterite Content as a Measure of Melting Degree in Residual Peridotites

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The extent to which the mantle can melt depends on temperature, extent of decompression, and volatile content. Reconstructing the typical extent of mantle melting from ancient primitive magmas or residual mantle peridotites can thus provide insights into the thermal and dynamic state of the Earth's interior back in time. Conventional methods for reconstructing melting degrees are usually based on bulk rock chemistries of magmas or peridotites. In the case of peridotites, which are sampled as exhumed peridotites or xenoliths, bulk rock compositions can be modified by weathering, metasomatism, or contamination from host basalt. Forsterite content (Fo) of relict unaltered olivines has thus been used as a proxy for melt fraction, but because of the complicating effects of water, temperature and oxygen fugacity on the relationship between melting degree and forsterite content, the proxy has not been fully calibrated. Here, we show that the dominant control of Forsterite content is melting degree with a moderate effect of temperature. The effects of oxygen fugacity on the forsterite content of peridotitic olivines is small (but large for olivine phenocrysts crystallized from a magma), and the effect of water can be mostly accounted for by temperature.

We applied this new calibration to olivines from abyssal peridotites, ophiolites, and mantle xenoliths. Representing Phanerozoic conditions, abyssal peridotites and ophiolites record average melt fractions of 0.20 and 0.22 with the maximum 10% of samples melting by 0.38 and 0.43, respectively. Archean cratonic peridotites reflect average melting degrees of 0.30 with the maximum 10% recording melting degrees of 0.56. Proterozoic residues exhibit lower melt fractions, averaging 0.24 with the maximum 10% recording 0.51. Our findings suggest a decreasing secular trend in mantle melting degree, consistent with previous studies. However, ophiolites associated with arcs show elevated melt fractions compared to abyssal peridotites, perhaps due to water enhancing melting in arc environments. Average melting degrees of the top 50% in arc peridotites (0.31) resemble that of Archean cratonic peridotites, begging the question of whether the most depleted arc peridotites could be the building blocks of cratonic mantle.