

Iron isotope fractionation in mantle minerals and the effects of partial melting and oxygen fugacity

H.M. Williams¹, C. McCammon², A.H. Peslier³, A.N. Halliday⁴, S. Levasseur⁵, N. Teutsch⁵, J.-P. Burg⁵, S.Y. O'Reilly¹

¹ GEMOC National Key Centre, Macquarie University, NSW 2109 Australia

² Bayerisches Geoinstitut Universität Bayreuth D-95440 Bayreuth Germany

³ Texas Center for Superconductivity University of Houston Houston TX 77204 USA

⁴ Department of Earth Sciences, University of Oxford, Parks Road, Oxford, OX1 3PR, United Kingdom

⁵ Department of Earth Sciences, ETH-Zürich, Sonneggstrasse 5, CH-8092 Switzerland

The oxygen fugacity of the mantle exerts a fundamental influence on mantle melting, volatile speciation and the development of the Earth's atmosphere. Changes in mantle oxidation state are generally reflected in the ferric iron contents of mantle minerals. As equilibrium stable isotope fractionation is driven by changes in the oxidation or coordination state of the element of interest, the iron isotope signatures of mantle rocks should provide information about spatial and secular changes in mantle oxidation state. However, the processes governing iron isotope fractionation in igneous rocks remain poorly understood. We have investigated the relationships between iron isotope fractionation, oxygen fugacity, melting and metasomatism with a combined MC-ICPMS iron isotope and Mössbauer spectroscopy study of spinels and silicate minerals from mantle xenoliths and massif samples originating from different tectonic settings. There are significant variations in the iron isotope compositions ($\delta^{57/54}\text{Fe}$) of mantle rocks (0.9‰) and minerals (olivines 0.6‰, clinopyroxenes 0.9‰ and orthopyroxenes 0.8‰), with spinels showing the greatest total variation of 1.7‰. Positive linear functional relationships with slopes that are, within error, equal to unity are found between the $\delta^{57/54}\text{Fe}$ values of coexisting orthopyroxene, clinopyroxene and olivine, strongly suggesting that the $\delta^{57/54}\text{Fe}$ values of these minerals reflect intra-sample mineral-mineral isotopic equilibrium. Positive correlations between the $\delta^{57/54}\text{Fe}$ values of silicate minerals and spinels also exist, although they are more scattered, which could be caused by late disturbance of mineral-spinel isotopic equilibrium. Bulk-rock, clinopyroxene and spinel $\delta^{57/54}\text{Fe}$ values correlate with chemical indices of both melt extraction and oxidation. Iron isotope fractionation during spinel-facies partial melting is investigated using simple models, which demonstrate that the maximum expected fractionation between melt and residue will be ~0.5‰, with the residue becoming isotopically light relative to the melt and to the initial source region. Hence melt extraction, in combination with significant changes in mantle oxidation state, may be an explanation for Fe isotopic variations in mantle peridotites. Metasomatism of the sub-arc mantle by iron-rich silicate melts originating from the subducting slab may also explain the light bulk-sample $\delta^{57/54}\text{Fe}$ values of some arc peridotites (-0.2 to -0.6‰), but mass-balance calculations require these metasomatic agents to have extreme $\delta^{57/54}\text{Fe}$ values (e.g. -3.0‰) which, on the basis of existing published data, are unrealistic. The large differences in the $\delta^{57/54}\text{Fe}$ values of garnet and spinel facies rocks are likely to be caused by the contrasting behaviour of Fe^{3+} during melting in the spinel and garnet facies. Future work will focus on investigating the behaviour of Fe^{3+} and iron isotopes during partial melting in garnet-facies mantle xenoliths.