The Oxygen Fugacity Structure of the Lithosphere/Upper Asthenosphere Beneath Hawai‘i

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Introduction

The oxygen fugacity (\(f_O^2\)) of the Earth’s mantle, as recorded by variations in Fe\(^{2+}/\)Fe\(^{3+}\) in MORB glasses, spinel and garnet peridotites indicates it is heterogeneous with at least 5 log units variation with respect to the fayalite-magnetite-quartz (FMQ) buffer (+1.5 to -4.5 \(\Delta FMQ\)). This study employs the ferric iron contents of lherzolitic spinels and pyroxenitic garnet-clinopyroxene pairs measured by \(^{57}\)Fe Mössbauer spectroscopy and experimentally derived oxybarometers to quantify \(f_O^2\) variations of the mantle beneath O‘ahu, Hawai‘i. Samples analyzed are from the Pali, Kaau and Salt Lake Crater rejuvenated stage vent in the Koolau shield that forms the eastern portion of the island of O‘ahu.

Results and Discussion

Oxygen fugacity is calculated using the oxybarometers of [1&2] based on the equilibria \(6\text{Fe}_2\text{SiO}_4+\text{O}_2=3\text{Fe}_2\text{SiO}_6+2\text{Fe}_3\text{O}_4\) (olivine-orthopyroxene-spinel) and \(2\text{Fe}_3\text{Si}_2\text{O}_6+2\text{FeSiO}_3+\text{O}_2\) (garnet-olivine-orthopyroxene) for spinel and garnet assemblages, respectively. \(\text{Fe}^{3+}/\Sigma\text{Fe}\) of spinels range from 0.038 to 0.394, resulting in relatively oxidizing conditions, \(\Delta\log f_O^2\) of +0.3 to +1.0 \(\Delta FMQ\) with exception of one sample at -2.9 \(\Delta FMQ\). These values are 1 to 2 log units more oxidized than the sub-ridge mantle, as sampled by abyssal peridotites (-0.9±0.7 \(\Delta FMQ\))[1] and MORBs (-0.4±0.4 \(\Delta FMQ\))[3]. The O‘ahu peridotites record similar degrees of depletion (Cr\(^{#}_{sp}\) 0.1-0.3) as abyssal peridotites, indicating a decoupling between \(f_O^2\) and degree of depletion in the oceanic mantle. Elevated Na contents and LREE enrichments with convex upwards REE patterns also suggest that the O‘ahu peridotites are not simple residues of MORB melting, but have been metasomatized subsequent to melting at the ridge by passing melts [4].

The discovery of nano-diamonds in O‘ahu pyroxenites [5] and spinel-cored garnets recently explored in phase relation studies in tholeiitic and slightly silica-poor portion of the CMAS system [6] suggests these cumulates may have crystallized under more reducing conditions in the asthenosphere (~110-150km) and allow comparison between the \(f_O^2\) of the shallower (T\(\text{BK}\)1175-1350K) depleted lithospheric peridotites and deeper lithologies (T\(\text{EG}\)1260-1560K). \(\text{Fe}^{3+}/\Sigma\text{Fe}\) of the pyroxenitic garnets range from 0.061 to 0.074 and their coexisting clinopyroxenes from 0.279 to 0.340. In the absence of orthopyroxene, oxygen fugacities are calculated assuming a pressure of 4GPa resulting in \(\Delta\log f_O^2\) values of -2.9 to -3.8 \(\Delta FMQ\).

Conclusions

Differences of 3 log units \(f_O^2\) between the spinel peridotites and garnet pyroxenites sampled in O‘ahu point to stratification of oxygen fugacity with depth in the oceanic upper mantle, at least on the localized vent scale, reminiscent of observed trends in the South African craton [7]. The highly reduced nature of the O‘ahu pyroxenites relative to both the overlying, metasomatically overprinted, oxidized spinel peridotites and plume-derived lavas (-0.55±1.0 \(\Delta FMQ\))[8] confirm observations from trace element and isotopic compositions that the pyroxenites are unrelated to the shield stage plume magmatism.

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References