CONSTRAINTS ON THE OXYGEN FUGACITY OF THE SUB-OCEANIC LITHOSPHERE BENEATH HAWAII

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Introduction
The oxidation state of the Earth’s mantle dictates the stability of different mineral phases, the nature of volatile species degassing through volcanism, electrical conductivity, diffusivity and mechanical behavior [1]. Additionally, changes in the redox history of the Earth’s mantle through time have implications for the development of the atmosphere and evolution of the biosphere [2]. It remains a question as to whether the oxygen fugacity ($f_{O_2}$) of the mantle is an intrinsic function of its bulk chemical composition, pressure and temperature or whether it is imposed externally through processes such as metasomatism. Here we present the first direct determination of the oxygen fugacity of plume-related spinel peridotite xenoliths from Hawaii, based on Fe$^{3+}$/ΣFe Mossbauer determinations of spinel. These xenoliths are thought to be fragments of the oceanic lithosphere that formed at mid-oceanic ridges some 80-100 Ma ago and are brought to the surface by the Hawaiian rejuvenated stage volcanism [3]. Resulting $f_{O_2}$s are then compared to that of abyssal peridotites (the residues of mid-ocean ridge basalt (MORB) melting) to determine the effect of metasomatism on the oxidation state of plume-affected lithosphere.

Experimental
Six spinel peridotite xenoliths from vents on the island of Oahu, Hawaii, and one from Potrillo Maar, New Mexico were analyzed for major element compositions by Electron Microprobe at, FIU. Trace elements concentrations were determined by Laser-Ablation-ICP-MS at NHMFL-FSU, and ferric iron contents of spinels were determined by $^{57}$Fe Mossbauer spectroscopy at the University of Bayreuth, Germany. Oxygen fugacity is calculated relative to the synthetic fayalite-magnetite-quartz (FMQ) oxygen buffer, using the spinel peridotite oxygen barometer of Bryndzia and Wood [4]:

$$6\text{Fe}_2\text{SiO}_4 + \text{O}_2 \leftrightarrow 3\text{Fe}_2\text{Si}_2\text{O}_6 + 2\text{Fe}_2\text{O}_4$$  [1]

Results and Discussion
The Hawaiian peridotite xenoliths log ($f_{O_2}$) values range from +0.3 to 1.0 $\Delta$FMQ (where $\Delta$FMQ = log ($f_{O_2}$FMQ)$_{P,T}$ – log ($f_{O_2}$Sample)$_{P,T}$). These values are more oxidizing than the sub-ridge mantle, as sampled by abyssal peridotites (-0.9±0.7 $\Delta$FMQ) and MORBs (-1.2±0.63 $\Delta$FMQ) [4], by 1 to 2 log ($f_{O_2}$) units. In contrast, the Potrillo Maar peridotite has an $f_{O_2}$ of -0.6 AFMQ and falls within the range of abyssal peridotites, in agreement with its LREE depleted patterns and the Nd and Sr isotope ratios.

The Hawaiian peridotites record similar degrees of depletion (Cr$^{#}_{\text{spinel}}$=0.1-0.3) as abyssal peridotites, however they are more oxidized than the latter. This indicates 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 Oahu peridotites are not simple residues of MORB melting, but have been metasomatized subsequent to melting at the ridge by melts related to the Hawaiian volcanism [3]. Therefore, our new $f_{O_2}$ data points to a correlation between oxidation and metasomatism in the oceanic mantle lithosphere.

Conclusions
Oxygen fugacity data from Oahu spinel peridotites suggest that metasomatism, and not melt depletion, is the dominant mechanism controlling the oxidation of the oceanic lithosphere. Additional analyses of Hawaiian xenoliths will constrain whether differing degrees of metasomatism result in systematic variations in oxidation state of the oceanic lithosphere.

References