The effect of oxidation on the mineralogy and magnetic properties of olivine

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ABSTRACT

Although nucleation of magnetite and/or hematite along dislocations upon oxidation of olivine has been observed by many workers, the effect of oxidation on the magnetic properties of the sample with specific mineralogical alterations has not been studied. Therefore, we investigate this problem using a set of time series 1 bar oxidation experiments at 600 and 900 °C. Results show rapid olivine oxidation and alteration at both 600 and 900 °C, forming magnetite and hematite associated with a change from paramagnetic to ferromagnetic behavior after oxidation. Magnetite and hematite nucleate along dislocations and impurities in the crystal structure, along with surface coatings and within cracks in the crystals.

Fresh, unaltered mantle xenoliths containing magnetite have been interpreted as having formed in cold tectonic regimes in the mantle, rather than through oxidation during or after ascent. Mantle xenoliths rapidly ascend through the mantle with estimates of the ascent of up to 90 km/h (3 GPa/h) based on the diffusion profile of water in mantle olivine. The rates correspond to xenoliths ascending through the mantle over hours and not days or weeks. Our results show that olivine oxidation and alteration can occur in days to weeks at 600 °C and within minutes at 900 °C. Therefore, if the xenolithic material is transported to the surface in a cold magma (at temperatures ≤600 °C), then the timescale of ascent is likely not long enough for oxidation to cause magnetite formation or a ferromagnetic signature to occur. However, if the material is transported in a hot oxidized basaltic magma (with temperatures ≥900 °C), then oxidation can cause magnetite formation and a ferromagnetic signature.

Keywords: Olivine, oxidation, hematite, magnetite, magnetic properties, xenoliths

INTRODUCTION

Olivine is typically the first mineral to crystallize from mafic and ultramafic magmas and is also the first mineral to be modified in a typical alteration and oxidation sequence (e.g., Bowen 1928; Goldich 1938; Hausrath et al. 2008). Consequently, its degradation state in a rock can be used as proxy for the length of time of alteration and oxidation (Hausrath et al. 2008). Olivine typically alters to magnetite or hematite under oxidizing conditions (though laihunite may also form), and iron oxyhydroxides, such as goethite, under hydrous conditions (e.g., Goode 1974; Eggleton et al. 1987; Khisina et al. 1998; Oze and Sharma 2005; Syverson et al. 2017). In a seminal paper, Kohlstedt et al. (1976) showed that magnetite and/or hematite could nucleate along dislocations upon oxidation of olivine (so-called “olivine decoration” experiments). However, this work did not investigate how oxidation affects changes in the magnetic properties of the sample with specific mineralogical alterations. Therefore, we here investigate the effect of oxidation on the magnetic properties of olivine. The main motivation for combining oxidation experiments with magnetic measurements arises from the recent work by Ferré et al. (2013, 2014) and Friedman et al. (2014), which showed that fresh, unaltered mantle xenoliths contain magnetite that is interpreted as having formed in cold tectonic regimes in the mantle, as opposed to having formed through oxidation during or after ascent. Therefore, this work seeks to constrain both the rates of magnetite formation during oxidation and how this oxidation affects magnetic properties to assess if oxidation during or after ascent can account for the magnetic properties of mantle xenoliths.

Olivine dislocation decoration experiments, originally used to investigate rates of creep along dislocation as a mechanism for modeling mantle flow patterns, have also led to important insights in magnetite formation from olivine oxidation (Kohlstedt et al. 1976). These experiments were performed at atmospheric conditions (pressure and oxygen fugacity) and a mantle-like temperature of 900 °C for 1 h. The results showed that oxidized phases formed along lattice dislocations and produced reddish-