Vanadium micro-XANES determination of oxygen fugacity in olivine-hosted glass inclusion and groundmass glasses of martian primitive shergottite Yamato 980459

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Abstract

The redox condition of magma determines the stability and composition of crystallizing and volatile phases in martian meteorites, reflecting the evolution of the martian interior. In the current study, direct analyses on the oxidation states of V, Cr, and Fe were performed based on the X-ray absorption near-edge structure (XANES) measurements equipped with a micro-sized X-ray beam. We first applied the micro-XANES (μ-XANES) technique to the olivine-hosted glass inclusion and groundmass glass of martian meteorite Yamato 980459 (Y98), which is interpreted as representing a primary melt composition. Mass-balance calculations and XANES spectra comparisons indicated that, while chromite and pyroxene affected Cr and Fe K-edge XANES spectra, the contribution of these minerals was minimal for V. The pre-edge peak intensity of V K-edge XANES enabled the estimation of the oxygen fugacity for inclusion and groundmass glasses. The calculated oxygen fugacity ($f_{O_2}$) of the glass inclusions was near the Iron-Wüstitie (IW) buffer ($IW-0.07 \pm 0.32$) for the glass inclusion, whereas it was 0.9 log units more oxidized ($IW+0.93 \pm 0.56$) for the groundmass glasses. This result suggests that the redox condition of the parent magma of Y98 evolved during magma ascent and emplacement. Since Y98 is interpreted to have evolved in a closed system, our finding suggests that fractional crystallization and/or ascent of magma potentially induces the $f_{O_2}$ increase. This study shows that the μ-XANES technique enables us to determine the $f_{O_2}$ by only measuring a single phase of glassy compounds, and thus, it is useful to discuss the redox condition of volcanic rocks even if they do not crystallize out several equilibrium phases of minerals.

Keywords: μ-XANES, oxidation states, oxygen fugacity, Yamato 980459, shergottite

Introduction

The magmatic oxygen fugacity ($f_{O_2}$) controls the stability and composition of crystallizing and fluid phases in magma. The oxygen fugacity also provides information on the genesis, differentiation, and source regions of the mantle and can be used to investigate the evolution of the martian interior. This information is acquired by redox analysis of martian meteorite. The mineralogical oxybarometers, such as Fe-Ti oxides, have been conventionally applied to the estimation of $f_{O_2}$ of martian magma (e.g., Stolper and McSween 1979; Steele and Smith 1982; McSween et al. 1996; Ghosal et al. 1998; Herd et al. 2001). The olivine-pyroxene-spinel oxybarometer has also been used for better estimation of the magmatic $f_{O_2}$ (e.g., Herd et al. 2002; Goodrich et al. 2003; Herd 2003; Peslier et al. 2010; Castle and Herd 2017). Partitioning of redox-sensitive elements such as Eu (Wadhwa 2001; Herd et al. 2002; McCanta et al. 2009) and transition metals including V, Cr, and Fe (Shearer et al. 2006; Karner et al. 2007a, 2007b, 2008; Papike et al. 2013) have been used to evaluate $f_{O_2}$ more recently, in combination with laboratory experiments. Nowadays, in addition to these methods, the direct analysis of the oxidation states of an element of interest using X-ray absorption near edge structure (XANES) analysis has become an additional method for estimating the $f_{O_2}$ of martian magma (Bell et al. 2014; Satake et al. 2014). These previous studies showed that $f_{O_2}$ range of martian magma was mostly from −1 to +2 relative to iron-wüstite (IW) buffer, which is more reducing than Earth’s basals (IW+2 to IW+6), but slightly more oxidized than lunar basalts (IW-2 to IW±0) (Papike et al. 2004). When oxidized groundmasses are included, the $f_{O_2}$ of martian basaltic lithology is up to IW±4 (Castle and Herd 2017).

These previous studies, which estimated the $f_{O_2}$ of martian magma based on several of the approaches described above, did not pay much attention to glassy compounds. For instance, olivine-hosted glass inclusion and groundmass glasses generally crystallize at the earliest and latest stages of the formation of basaltic rocks, respectively. This fact means that the investigation of these contrasting glass phases have the potential to provide information on the transition or evolution of the $f_{O_2}$ from...