Magnetite exsolution in ilmenite from the Fe-Ti oxide gabbro in the Xinjie intrusion (SW China) and sources of unusually strong remnant magnetization

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ABSTRACT

This study investigates magnetite exsolution in ilmenite from Fe-Ti oxide gabbro in the Xinjie intrusion, SW China. Exsolved magnetite lamellae in ilmenite contain nearly pure Fe3O4 with ~1 wt% TiO2. EBSD-based analyses indicate that the magnetite lamellae have close-packed oxygen planes and directions parallel to those in the host ilmenite with [111]Mag/(0001)Ilm and <110>Mag/<10T0>Ilm. The Fe2+ in the magnetite lamellae is probably derived from adjacent titanomagnetite by sub-solidus inter-oxide cation re-partitioning of Fe2++Ti4+=2Fe3+ during cooling. It is thus suggested that only Fe3+ cations in the magnetite lamellae should be included into the composition of the Ilm-Hemm precursor for the Fe-Ti oxide oxy-thermometer. The existence of magnetite exsolution in ilmenite also provides an alternative explanation for unusually strong natural remnant magnetization in natural ilmenite.

Keywords: Magnetite exsolution, ilmenite, electron backscatter diffraction (EBSD), crystallographic relationship, sub-solidus cation re-partitioning

INTRODUCTION

Ilmenite-hematite solid solution (Ilm-Hemm) forms in a wide range of temperature and oxygen fugacity due to the hetero-valent isomorphous substitution of 2Fe3+→Ti3++Fe2+ (Buddington and Lindsley 1964; Evans et al. 2006; Lindsley 1991; Lattard et al. 2005; Sauerzapf et al. 2008). Ilm-Hemm plays an important role in the acquisition of natural remanent magnetization (NRM) in different types of rocks containing Ilm-Hemm (Brownlee et al. 2010; Feinberg et al. 2005; Ferré et al. 2013; Harrison et al. 2000; McEnroe et al. 2001, 2002). The composition of Ilm-Hemm, and coexisting titanomagnetite can also be used as a thermometer/ox-barometer to estimate the formation temperature/oxygen fugacity of host rocks (Andersen and Lindsley 1988; Buddington and Lindsley 1964). As temperature decreases, Ilm-Hemm commonly separates into hematite-rich and ilmenite-rich end-member phases due to a miscibility gap at 600–700 °C (Harrison et al. 2000), resulting in formation of an intergrowth composed of oriented hematite lamellae in host ilmenite (Fe2+TiO3), a common feature in mafic-ultramafic intrusions (Bolle et al. 2014; Harrison et al. 2000; Lindsley 1991; Morisset et al. 2010).

Natural ilmenite also contains magnetite exsolution (Buddington and Lindsley 1964; Lattard 1995; Mücke 2003; Wang et al. 2008). Magnetite (Fe2+Fe3+O4) contains both Fe2+ and Fe3+, whereas hematite (Fe3+O3) only contains Fe3+. Exsolved magnetite lamellae in ilmenite thus plays a key role in the Fe2+/Fe3+ ratio of the composition of Ilm-Hemm precursor, which can be reconstructed by integrating and averaging the chemistry of the exsolved phases and host ilmenite, and it is crucial to the Fe-Ti oxide oxy-thermometer. Magnetite is considered to control magnetic anomalies of rocks (Frost 1991), magnetite exsolution in ilmenite may thus explain the unusually strong NRM of ilmenite in some metamorphic and igneous rocks (McEnroe et al. 2002; Robinson et al. 2002, 2004).

Several mineralogical and geophysical studies have dealt with Fe-Ti oxide exsolution in silicate minerals such as pyroxene, plagioclase, and olivine (Dobrzhinetskaya et al. 1996; Feinberg et al. 2004; Fleet et al. 1980; Hwang et al. 2008; Prior et al. 1999; Wenk et al. 2011). However, magnetite exsolution in ilmenite is more or less neglected compared with hematite exsolution in ilmenite and magnetite exsolution in silicates. This is probably because the magnetite lamellae in ilmenite are not easily distinguished from hematite lamellae in terms of morphology, optical color and BSE images (Bolle et al. 2014; Haggerty 1991; Morisset et al. 2013; Wang et al. 2008). Nevertheless, the origin of magnetite exsolution in ilmenite remains controversial, and has been ascribed to three mechanisms: direct exsolution from Fe3O4-FeTiO3 precursors (Mücke 2003), sub-solidus reduction of Fe3O4 in Ilm-Hemm (Brownlee et al. 2010; Buddington and Lindsley 1964; Haggerty 1991), or sub-solidus cation re-partitioning between coexisting Fe-Ti oxides (Lattard 1995).

In this study, magnetite exsolution is observed and confirmed in ilmenite from the Fe-Ti oxide gabbro in the Xinjie intrusion (SW China) using Raman spectroscopy and electron microprobe analysis (EMPA). The crystallographic relationship between the crystal lattices of the magnetite lamellae and host ilmenite was revealed by electron backscatter diffraction analysis (EBSD). This study has important implications for understanding the mechanism of magnetite exsolution in ilmenite and the major controls on the complex sub-solidus Fe-Ti oxide re-equilibration.