Association of cumulus apatite with compositionally unusual olivine and plagioclase in the Taihe Fe-Ti oxide ore-bearing layered mafic-ultramafic intrusion: Petrogenetic significance and implications for ore genesis

ZHONG-JIE BAI1, HONG ZHONG1,*, CHUSI LI2, WEI-GUANG ZHU1, AND WEN-JUN HU1,3

1State Key Laboratory of Ore Deposit Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang 550081, China
2Department of Geological Sciences, Indiana University, Indiana 47405, U.S.A.
3University of Chinese Academy of Sciences, Beijing 100049, China

ABSTRACT

In many large, layered, mafic-ultramafic intrusions worldwide cumulus apatite commonly occurs in the highly fractionated Fe-Ti oxide-rich lithological units at the top of the intrusions and the associated plagioclase and olivine, if present, have An content <50 mol% and Fo content <40 mol%. These are not true for several Fe-Ti oxide ore-bearing mafic-mafic intrusions in the Emeishan large igneous province, SW China. A good example is the Taihe intrusion, which is described in this paper. In this intrusion the associated olivine and plagioclase are significantly more primitive, containing 69 mol% Fo and 59 mol% An, respectively. MELTS simulation reveals that such unusual association is the result of previous cotectic crystallization of Fe-Ti oxides with silicate minerals during magma evolution under oxidizing condition close to that of nickel–nickel oxide buffer. Supports for this new model include the observed upward decrease in plagioclase An contents coupled by lack of significant change in original olivine Fo contents in the Fe-Ti oxide ore-bearing sequence below the apatite-rich horizon, which is in turn supported by the facts that Fe-Ti oxide crystallization has a counter effect on MgO/FeO, but no effect on CaO/NaO in the residual magma and that the addition of Fe-Ti oxides in the cumulus assemblage expedites the arrival of apatite on the liquidus. Our new findings support the interpretation that the oxide ores in the Taihe intrusion formed by gravitational accumulation of Fe-Ti oxides crystallizing from a basaltic magma, not a Fe-Ti-P-rich immiscible liquid segregated from such magma.

Keywords: Cumulus apatite, Fe-Ti oxides, olivine, plagioclase, magma differentiation, layered intrusion

INTRODUCTION

Phosphorus is an incompatible element during fractional crystallization of silicate minerals from basaltic magma. The content of phosphorus in apatite-saturated magma is mainly a function of temperature and SiO2 concentration in the magma, but almost insensitive to pressure according to the experiments of Watson (1979) and Tollari et al. (2006, 2008). These experiments show that the maximum solubility of phosphorus at apatite saturation in basaltic magma increases with temperature and decreases with SiO2 content. The content of SiO2 in a basaltic magma commonly increases during the crystallization of silicate minerals plus minor spinel from the magma on cooling. As a result, fractional crystallization not only increases the abundance of phosphorus in the residual liquid but also decreases the maximum solubility of phosphorus in the magma, thereby inducing apatite crystallization eventually. In natural basaltic systems this takes place most commonly when the residual liquid is also saturated with Fe-Ti oxides. The best examples worldwide are the Bushveld, Skaergaard, Kiglapait, and Sonju Lake layered mafic-ultramafic intrusions in which the cumulus apatite horizons also contain abundant Fe-Ti oxides. The apatite-oxide layers occur at the top of these intrusions and the associated plagioclase and olivine have An content <50 mol% and Fo content <40 mol%, which are thought to have formed from highly evolved basaltic-andesitic melt after extensive fractional crystallization (Morse 1979; Mc Birney 1996; Park et al. 2004; Tegner et al. 2006). An exception has been found in several mafic-ultramafic layered intrusions of the Emeishan large igneous province in SW China, such as the Panzhuhua (Zhou et al. 2005; Pang et al. 2008a, 2008b, 2009; Song et al. 2013), Hongge (Bai et al. 2012, 2014; Luan et al. 2014), and Taihe (Shellnutt et al. 2011; Hou et al. 2012; She et al. 2014) intrusions. In these intrusions cumulus apatite horizons occur above several massive Fe-Ti oxide layers (Fig. 1). In addition, the associated olivine and plagioclase are much more primitive in these intrusions than those occur elsewhere in the world (Table 1 and Fig. 2). The reasons for these differences and their implications will be discussed in this paper.

GEOLOGICAL SETTING

The Emeishan large igneous province is composed of picrites, flood basalts, rhyolitic/trachytic volcanic rocks, mafic–ultramafic