Paper Number: 2332

Phosphorus zoning in olivine from the Fe-Ti oxide-bearing Baima mafic intrusion, SW China: implications for the origin of Fe-Ti oxide ores

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Fe-Ti oxide ores in the mafic-ultramafic layered intrusions are important source of iron, titanium, vanadium and possible phosphorus. Origin of the Fe-Ti oxide ore bodies in the mafic-ultramafic intrusions, however, has long been a matter of debate. Many models have been proposed to illustrate the concentration of Fe-Ti oxides, and the major concern is whether the Fe-Ti oxides are products of normal fractional crystallization of ferrobasaltic magmas [1-3], or crystallized from immiscible Fe-rich melts that separated from the evolved magmas [4-6].

The Baima mafic layered intrusion in the central part of the Emeishan large igneous province (SW China) hosts giant Fe-Ti oxide deposit. The intrusion is divided into the lower and upper zones [7]. The lower zone varies in thickness from 150 to 300 m and mainly composed of troctolite and olivine gabbro with <20 vol.% Fe-Ti oxides. The upper zone is up to 1500 m in thickness and composed of isotropic olivine gabbro, gabbro and apatite-bearing gabbro with <10 vol.% Fe-Ti oxides [7].

The major Fe-Ti oxide ore layers occur in the lower zone. They are mainly composed of net-textured ores with a total thickness of over 100 m. The net-textured ores are composed of 40-60 vol.% Fe-Ti oxides, 20-30 vol.% olivine, <10 vol.% plagioclase and clinopyroxene as well as small amounts of sulfide. Fe-Ti oxides occur as interstitial phases filling the space between silicate minerals. Olivine typically occurs as rounded crystals varying from 0.02 to 2 mm in size. The olivine grains commonly enclose rounded titanomagnetite and crystallized melt inclusions that consist of titanomagnetite, ilmenite, spinel, phlogopite with/without apatite, amphibole and sulfide.

High-resolution phosphorus X-ray mapping for the rounded olivine grains in the net-textured ores shows that they contain complex patterns of phosphorus zoning. The internal part of the olivine appears as highly irregular patches, curved and thick discontinuous phosphorus bands that vary in width from 30 to 500 µm and cross cut by phosphorus-poor olivine section, or small pieces of phosphorus band relicts, strongly indicative of resorption. The rounded titanomagnetite and melt inclusions are mostly trapped in the phosphorus-poor olivine section, which hints that titanomagnetite crystallized later than the primary phosphorus zoning. These textures indicate that the Fe-Ti oxides are not products of normal fractional crystallization, and gravitational settling and accumulation cannot account for their enrichment. Given the common presence of titanomagnetite, ilmenite and phlogopite in the melt inclusions, we suggest that abundant Fe-Ti oxides crystallized from the interstitial immiscible Fe-Ti-H_2O-rich melts. Sustaining diffusion of phosphorus at high temperature partly coarsened the primary phosphorus band and resulted in homogeneity of phosphorus in some olivine grains.

This study has been founded by NSFC grants (41502048 and 41473037).

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