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Immiscible Fe- and Si-rich silicate melts in plagioclase from the Baima mafic intrusion (SW China): Implications for the origin of bi-modal igneous suites in large igneous provinces

Ping-Ping Liu [a,*], Mei-Fu Zhou [a], Zhongyuan Ren [b], Christina Yan Wang [c], Kun Wang [c]

[a] Department of Earth Sciences, University of Hong Kong, Hong Kong, China
[b] State Key Laboratory of Isotope Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510460, China
[c] Key Laboratory of Mineralogy and Metallogeny, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510460, China

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ABSTRACT

The Emeishan large igneous province (ELIP) in SW China is characterized by voluminous high-Ti and low-Ti basalts and spatially associated Fe-Ti oxide-bearing mafic-ultramafic and syenitic/granitic intrusions. The Baima layered mafic intrusion in the central part of the ELIP is surrounded by syenitic and granitic rocks and contains a Lower Zone of interlayered Fe-Ti oxide ores, troctolites and clinopyroxenites and an Upper Zone of isotropic olivine gabbros and gabbros (UZa) and apatite gabbros and Fe-Ti-P oxide ores (UZb). Polycrystalline mineral inclusions, for the first time, were observed in primocryst plagioclase from the basal part of the UZa through to the top of the UZb and consist mostly of clinopyroxene, plagioclase, magnetite, ilmenite and apatite with minor orthopyroxene, sulfide and hornblende. These minerals are commonly anhedral and form irregular shapes. Daughter plagioclase usually crystallizes on the walls of host primocryst plagioclase and has An contents typically 3–6 An% lower than the host plagioclase. Daughter clinopyroxene has similar Mg# but lower TiO_2 and Al_2O_3 contents than primocryst clinopyroxene. These polycrystalline mineral inclusions are considered to crystallize from melts contemporaneous with host plagioclase. The compositional differences between daughter and primocryst minerals can be attributed to equilibrium crystallization in a closed system of the trapped melt inclusions in contrast to fractional crystallization and possible magma replenishment in an open system typical for primocumulates of large layered intrusions. Heated and homogenized melt inclusions have variable SiO_2 (33–52 wt%), CaO (7–20 wt%), TiO_2 (0.1–12 wt%), FeO_t (5–20 wt%), P_2O_5 (0.2–10 wt%) and K_2O (0–2.2 wt%). The large ranges of melt compositions are interpreted to result from heterogeneous trapping of different proportions of immiscible Si-rich and Fe-Ti-rich silicate liquids, together with entrapment of various microphenocrysts. The separation of micrometer-scale Si-rich melts at least started from the lower part of the Upper Zone. We thus infer that the Baima high-Ti basaltic magmas evolved into the field of immiscible Fe-rich and Si-rich melts. Prolonged fractional crystallization of olivine, plagioclase and clinopyroxene from the Fe-rich melts formed gabbro and olivine gabbro in the UZa, before the melts became saturated in Fe-Ti oxides and apatite and formed apatite-rich Fe-Ti oxide ores in the UZb. Immiscible Si-rich melts migrated upwards and coalesced to form fayalite syenite around the Baima intrusion. Silicate liquid immiscibility may have played an important role in the petrogenesis of Fe-Ti oxide-rich layered mafic intrusions and syenitic rocks in the ELIP and elsewhere. This mechanism may be common and may explain the traditionally thought bi-modal assemblages of large igneous provinces in intra-continental extensional settings.

1. Introduction

The Emeishan large igneous province (ELIP) in SW China contains voluminous flood basalts, mafic-ultramafic intrusions and syenitic and granitic intrusions. These Fe-Ti oxide-bearing mafic-ultramafic intrusions are usually <3 km thick, considerably smaller than typical Fe-Ti oxide-bearing layered intrusions worldwide, but contain tens of meters' thick massive and/or net-textured, conformable lenses or layers of Fe-Ti oxide ores in the lower part (e.g. Zhou et al., 2005, 2013; Pang et al., 2008a,b; Bai et al., 2012; Howarth et al., 2013; Song et al., 2013) and Fe-Ti-P oxide ores in the upper part. Extreme Fe and Ti enrichments in these relatively

* Corresponding author at: Department of Geosciences, National Taiwan University, Taipei, Taiwan.
E-mail address: liupingping11@live.cn (P.-P. Liu).

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small intrusions, absence of intermediate rocks and association of silicic and mafic rocks in the ELIP are not well understood. Eruption of excessive low-FeO_t magmas (Bai et al., 2012) and fractional crystallization for the formation of silicic and mafic units (Shellnutt et al., 2009) have been proposed to account for Fe enrichment of these layered intrusions. However, these models cannot explain the net-textured Fe-Ti-P oxide ores and the Si-rich melt inclusions hosted in cumulus apatite in these Fe-Ti oxide-bearing mafic layered intrusions, which were considered to be important evidence of liquid immiscibility (Zhou et al., 2005, 2013; Wang et al., 2013; Wang and Zhou, 2013; Liu et al., 2014b).

Melt inclusions are melt fossils that contain important information about liquid compositions when the host minerals crystallized, and thus are highly suitable for investigating melt evolution in magma systems (e.g. Sorby, 1858; Roedder, 1979; Luais, 1987; Thomas and Klemm, 1997; Anderson et al., 2000; Thomas et al., 2000; Kamenetsky et al., 2001). Trapped melts may maintain primary compositions of magmas unaffected by fractionation and post-crystallization alteration. Rocks of the oxide-bearing intrusions in Panxi are fresh and are particularly suitable for examination of melt inclusions. Although there are extensive studies about these intrusions, studies of melt inclusions to constrain the evolution of the melts are rare. Wang et al. (2013) presented some results of melt inclusions in apatite from the middle zone of the Panzhihua intrusion. However, apatite commonly appears abundantly in the middle-high levels of the intrusions. The trapped melts in apatite, as a consequence, can only represent magma compositions at a highly evolved stage.

In this study, polycrystalline mineral inclusions in plagioclase from the Upper Zone of the Baima intrusion are identified. We describe the petrography and distribution of these inclusions and report mineral compositions of daughter mineral phases. Bulk compositions of polycrystalline mineral inclusions were obtained after heating and homogenization. Our study demonstrates that the polycrystalline mineral inclusions crystallized from primary melts with Si-rich and Fe-Ti-rich compositions. Large variations

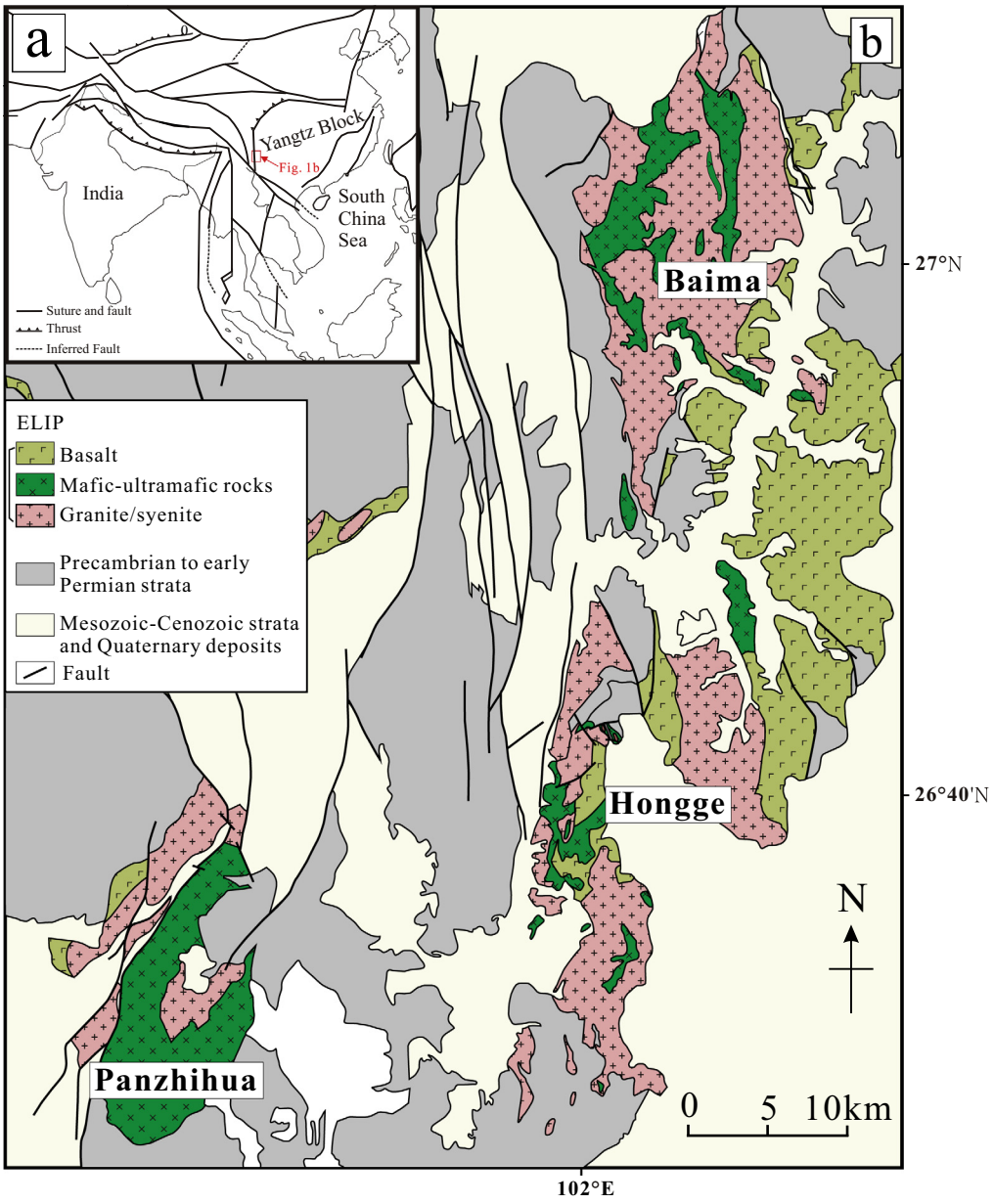

Fig. 1. Simplified regional geology of the Panxi area, Emeishan large igneous province, SW China, showing the distribution of Panzhihua, Hongge and Baima mafic-ultramafic intrusions that host Fe-Ti-(V) oxide ore deposits and associated granitic and syenitic plutons. Modified after Pang et al. (2008b).