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Fractional crystallization and the formation of thick Fe–Ti–V oxide layers in the Baima layered intrusion, SW China

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ABSTRACT

The Baima layered intrusion is located in the central part of the Emeishan Large Igneous Province (ELIP). The N–S striking intrusion is ~24 km long and ~2 km thick and dips to the west. Based on variations in modal proportions and cumulus mineral assemblages, the intrusion from the base to the top is simply subdivided into a lower zone (LZ) with most of the economic magnetite layers, and an upper zone (UZ) with apatite-bearing troctolite and gabbro. The rock textures suggest crystallization of the Fe–Ti oxide slightly later than plagioclase (An_{67-54}) but relatively earlier than olivine (Fo_{74-55}), followed by clinopyroxene and finally apatite.

Relatively low olivine forsterite content and abundant ilmenite exsolution lamellae in clinopyroxene indicate that the Baima parental magma is a highly evolved Fe–Ti-rich magma. Via MELTS model, it demonstrates that under a closed oxygen system, extensive silicate mineral fractionation of a picritic magma might lead to Fe and Ti enrichment and oxygen fugacity elevation in the residual magma. When such Fe–Ti-rich magma ascends to the shallower Baima intrusion, the Fe–Ti oxides may become an early liquidus phase. Well-matched olivine and plagioclase microprobe data with the results of MELTS calculation, combined with relatively low CaO content in olivine (0.02–0.08 wt.%) indicate that wall-rock contamination probably plays a weak role on oxygen fugacity elevation and the early crystallization of Fe–Ti oxides. Several reversals in whole-rock chromium and plagioclase anorthite contents illustrate that multiple recharges of such Fe–Ti-rich magma mainly occurred along the lower part of the Baima magma chamber. Frequent Fe–Ti-rich magma replenishment and gravitational sorting and settling are crucial for the development of thick Fe–Ti oxide layers at the base of the Baima layered intrusion.

1. Introduction

The study of layered intrusions has provided valuable insights into the processes of igneous differentiation, crystallization and the formation of magmatic ore deposits (Cawthorn, 1996; Wager and Brown, 1968 and references therein). Geochemistry and petrogenesis studies in the past few years have improved our understanding on the origin of the mafic–ultramafic layered intrusions and their hosting Fe–Ti oxide ores in the Emeishan Large Igneous Province (ELIP), SW China. For example, recent zircon U–Pb dating indicated that these layered intrusions were formed in the Late Permian (~260 Ma) and were related to the Emeishan mantle plume (Zhong and Zhu, 2006; Zhong et al., 2011; Zhou et al., 2002, 2005, 2008). Geochemistry studies suggested that the Fe–Ti-oxide-bearing layered intrusions are genetically linked with high-Ti Emeishan continental flood basalts, which were generated by the partial melting of a mantle plume head with a minor sub-continental lithospheric mantle overprint (Qi and Zhou 2008; Song et al., 2009; Zhou et al., 2008).

Despite the former investigations, no consensus has been reached on the formation mechanism of thick Fe–Ti oxide layers in these intrusions and related magma chamber processes, such as why the thick Fe–Ti oxide ore layers usually present in the lower parts of the layered intrusions when compared with the Skaergaard intrusion and the Bushveld Complex (Eales and Cawthorn, 1996; McBirney, 1996; Wager and Brown, 1968)? Whether the thick oxide stratiforms were formed by fractional crystallization (Wager and Brown, 1968), liquid immiscibility (Philpotts, 1982; Reynolds, 1985) or by magma mixing (Cawthorn and McCarthy, 1981; Harney et al., 1990) is still debated.

The Baima intrusion is one of the largest layered intrusions in the ELIP. Detailed petrology, mineralogy and chemical studies indicate that the formation of the lithologic sequences in this intrusion was

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constrained by fractional crystallization. This paper uses MELTS algorithm (Ghiorso and Sack, 1995) to model the fractional crystallization processes and formation of the thick Fe–Ti oxide layers in the Baima intrusion. The results lead us to maintain that fractional crystallization in a magma system closed to oxygen at depth will increase iron and titanium contents and fO_2 condition in the residual magma. Frequent recharges of such Fe–Ti enriched fractionated magma and early fractional crystallization of Fe–Ti oxides are the key factors forming the thick Fe–Ti oxide deposit at the base of the Baima layered intrusion.

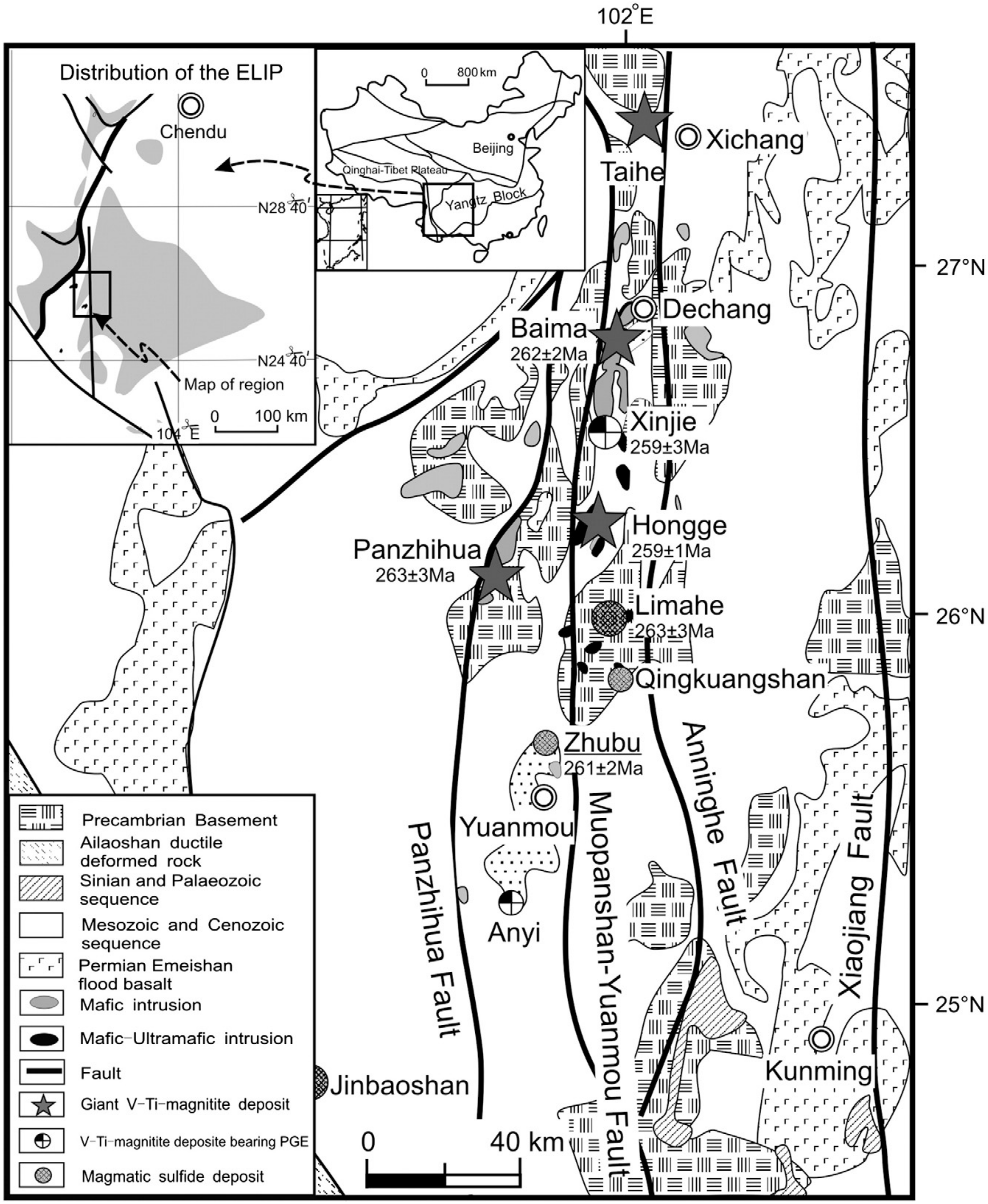

Fig. 1. Regional geological map of the central ELIP, showing the distribution of layered mafic–ultramafic intrusions that host giant Fe–Ti–V oxide deposits (modified after Song et al., 2009).