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Timescale of emplacement of the Panzhihua gabbroic layered intrusion recorded in giant plagioclase at Sichuan Province, SW China

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ABSTRACT

Giant plagioclase crystals carried into the Panzhihua gabbroic layered intrusion from a deeper magma chamber can help constrain the timescales of emplacement of the Panzhihua intrusion in the Emeishan large igneous province (LIP). In this study, we present the petrographic textures and chemical compositions of giant plagioclase and fine-grained gabbro samples along a ~50 m horizontal outcrop of the low zone of the Panzhihua deposit. The giant plagioclase gabbro (GPG) dykes mostly intrude into the fine-grained gabbros without significant contact. Both types of gabbros have the similar bulk-rock major and trace element compositions. However, the mineral composition shows that most of the plagioclase megacrysts contain less An than the plagioclase in fine-grained gabbro samples. In situ analyses of Sr isotopes from core-to-rim transects of plagioclase megacrysts are constant, indicating that there are no recycled crystals. The textural characteristics of samples combined with petrological modeling using MELTS suggest that the plagioclase megacrysts should crystallize and grow in a deeper magma chamber. Textual studies of the GPG indicate that these plagioclase megacrysts mostly plot as straight lines on a classic crystal size distribution (CSD) diagram. For a plagioclase growth range of 10^{-11}–10^{-10} mm/s, the plagioclase should have a growth time of 530–8118 years. In a 100 km^3 magma chamber releasing thermal energy at a rate of 1000 MW, the Panzhihua intrusion should reach 50% crystallization after ~2400 years. The growth time recorded by the megacrysts in the GPG and numerical modeling may indicate that the emplacement and crystallization of the Panzhihua intrusion may have taken place in thousands of years. In the Emeishan LIP, therefore the combination of large volumes of Fe-rich magma flux and efficient metal precipitation led to the formation of a giant Fe–Ti–V oxide deposit in a short period.

1. Introduction

Layered mafic–ultramafic intrusions represent some of the most complex magmatic systems in the world and they preserve physiochemical processes within magma chambers (Shellnutt and Jahn, 2010). Some layered intrusions host giant deposits of precious metals such as Ni, Cu, Fe, Ti and V (e.g., Irvine, 1975; Parsons, 1987; Wager and Brown, 1967). Southwest China has several large mafic-layered intrusions that host world-class Fe–Ti–V oxide deposits, such as the Panzhihua deposit. The Panzhihua Fe–Ti–V oxide mine makes China a major producer of V and Ti, accounting for 6.7% and 35.2% of the total world production of V and Ti, respectively (Zhou et al., 2005). Several models have been proposed for the formation of the Panzhihua deposit that are related to the Emeishan large igneous province (LIP): (1) the Panzhihua ore bodies developed concentrations of Fe and Ti through the fractional crystallization of ferrobasaltic or ferropicritic magmas, followed by separation into silicate magma and Fe-rich oxide ore melt (Zhou et al., 2005); (2) early crystallization of Fe–Ti oxides from a parent magma with 1.5 wt.% H_2O and oxide accumulated through crystal setting at the base of the intrusion (Pang et al., 2008a,b); and (3) an increase in magma fO_2 related to the CO_2-degassing of the footwall carbonates resulted in the accumulation of Fe–Ti oxides (Ganino et al., 2008). Pang et al. (2008a,b) and Ganino et al. (2008) suggested that the Fe–Ti oxides had crystallized at an early stage of the solidification of the Panzhihua intrusion, in consideration of an effective accumulation of titanomagnetite in the Panzhihua intrusion. However, neither the timescale of the emplacement and solidification of the Panzhihua intrusion nor the timescale of titanomagnetite accumulation has been estimated. The timescales of the magma processes can help clarify these dynamics as well as the formation of the Panzhihua intrusion within the Emeishan LIP. These magma processes might occur on short timescales (hundreds to thousands of years), but this information is inaccessible using current isotopic methods over geological timescales (e.g., Cashman and Marsh, 1988; Costa et al., 2003; Higgins and Chandrasekharam, 2007; Morgan and Jerram, 2006; Zellmer et al., 1999). The theory developed for crystal size distributions (CSDs) (e.g., Cashman and Marsh, 1988; Higgins, 1996, 1998; Marsh, 1988, 1998) is used to document the magma processes and provides a method for determining short timescales. Plagioclase is usually used to determine the timescale in a CSD analysis for two reasons: (1) it is one

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of the most common minerals in igneous rocks; and (2) the growth rate range of plagioclase has been determined. Gabbros in some dykes in the lower zone of the Panzhihua deposit contain giant plagioclase crystals that are up to 50 mm long (giant plagioclase gabbros, or GPGs), which may record the magma processes of the Panzhihua intrusion.

In this study, observations were made of the field geology, petrology, mineralogy, and isotopic microanalysis and were then combined with whole-rock geochemical analyses and quantitative textural analyses of the Panzhihua gabbros. The relationships between dykes and gabbros in the low zones of the Panzhihua were determined, and the timescale of emplacement of the Panzhihua layered intrusion estimated.

2. Geological background

2.1. Emeishan large igneous province

The Emeishan LIP is located on the western margin of the Yangtze craton in southwest China, with an estimated area of $>2.5 \times 10^5$ km^2 and a total volume of $>0.3 \times 10^6$ km^3 (Ali et al., 2005; Chung et al., 1998; Xu et al., 2001). The Emeishan volcanism coincided with the Middle–Late Permian boundary and the end-Guadalupian (~260 Ma) mass extinction (He et al., 2007; Zhou et al., 2002). The Emeishan volcanic successions uncomfortably overlie a late-Middle Permian carbonate formation (the Maokou limestone) and are, in turn, covered by the uppermost Permian in the east and Middle Triassic sediments in the west (Xu et al., 2001). The mafic–ultramafic intrusions occur in the Emeishan LIP, which hosts world-class Fe–Ti–V oxide and Ni–Cu–PGE sulfide deposits (Wang et al., 2012; Zhou et al., 2005). They are exposed in several north–south-trending faults in the Panxi (Panzhihua–Xichang) district along the western margin of the Yangtze Block (Fig. 1). These bodies, such as the Xinjie (Dong et al., 2013; Zhong et al., 2011), Baima (Shellnutt et al., 2009; Wang et al., 2006), Limahe (Tao et al., 2008) and the Panzhihua intrusions and the Miyi syenite complex, have been dated to ~259–263 Ma (Wang et al., 2007, 2012; Zhou et al., 2005, 2013). The ore-bearing mafic–ultramafic rock bodies extend from Mianning in the north, through Xichang, Miyi and Panzhihua in Sichuan Province, to Mouding in Yunnan Province (Fig. 1). The three largest Fe–Ti–V oxide ore deposits are Panzhihua (1333 Mt ore reserves), Baima (1497 Mt ore reserves) and Hongge (4572 Mt ore reserves) (Ma et al., 2003).

2.2. Panzhihua gabbroic intrusion

The Panzhihua intrusion is a ~19 km-long and ~2 km-thick, layered gabbroic sill that intruded the Late Neoproterozoic limestone (Dengying Formation), which was metamorphosed into forsterite and diopside marbles along the contact and formed the footwall of the intrusion. A general description of the intrusion is provided by Pang et al. (2008a) and Zhou et al. (2005). The Panzhihua intrusion is transected by steeply dipping, north-trending faults that cut the ore horizons into several blocks and are currently being quarried, including within the Zhujiabaobao, Lanjian, Damakan, Gongshan and Nalaqing mines (Fig. 1). The Marginal zone is at the base, followed upward by the Lower, Middle, and Upper zones (Zhou et al., 2005). The Marginal zone is 0–40 m thick and very heterogeneous and consists of fine-grained, hornblende-bearing and olivine gabbros, with abundant marble xenoliths derived from the footwall. The Lower zone ranges from 0 to 110 m in thickness and is composed of layered, fine-grained gabbro, with major oxide layers (the ore bodies) reaching

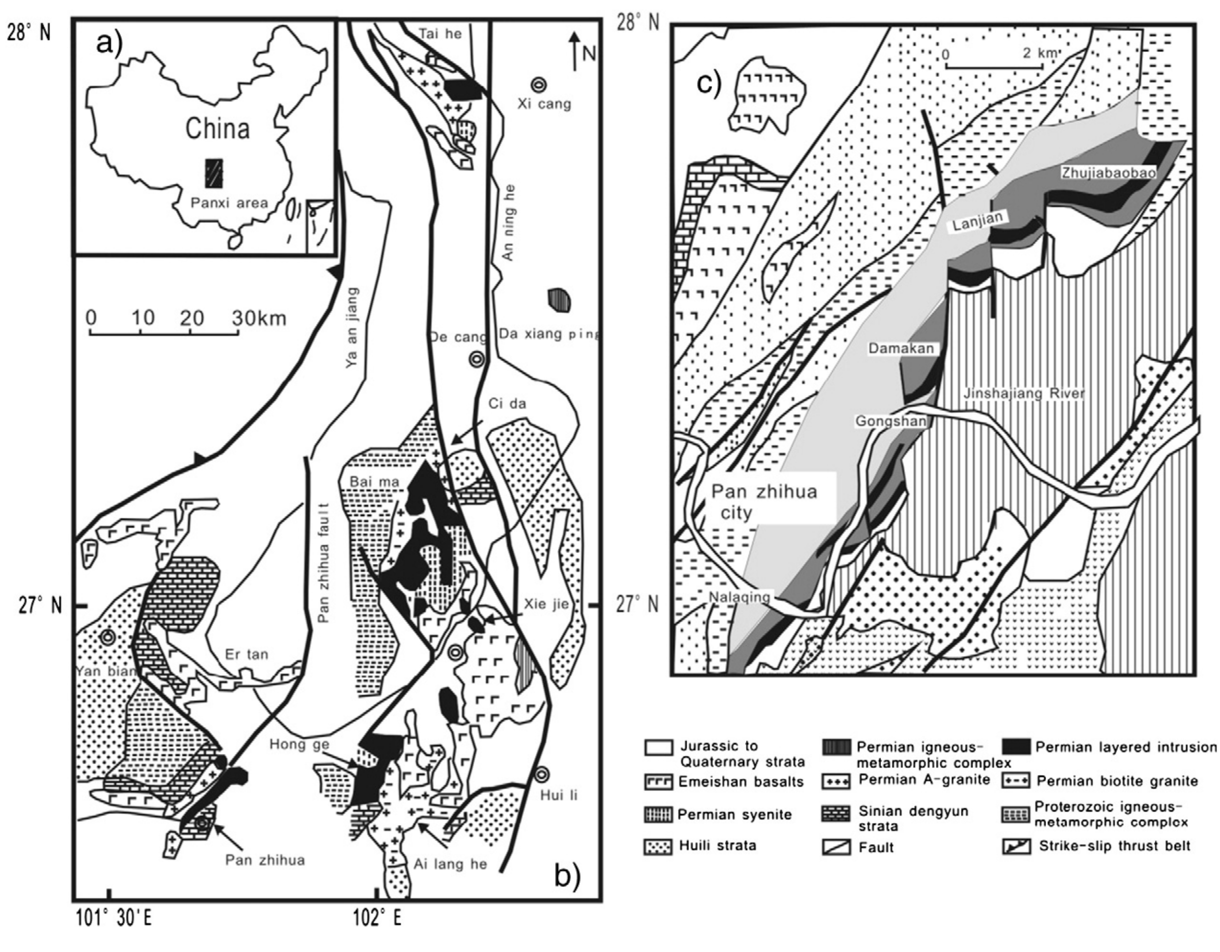

Fig. 1. (a) Map showing principal outcrops of the Emeishan flood basalts in SW China; (b) Related mafic–ultramafic intrusion in the Panxi district, Sichuan Province, SW China; (c) Geological map of the Panzhihua intrusion, SW China (after Zhou et al., 2005). The samples used in this study were collected along a profile in Zhujiabaobao.