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Petrogenesis of Late Permian silicic rocks of Tu Le basin and Phan Si Pan uplift (NW Vietnam) and their association with the Emeishan large igneous province

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ABSTRACT

Major and trace elements and whole rock Sr–Nd isotope data of Late Permian silicic plutonic and volcanic rocks from the Phan Si Pan–Tu Le region in NW Vietnam were collected in order to establish their petrogenetic relationship with the magmatic rocks of the Song Da zone (NW Vietnam) and the alkaline silicic rocks of the Panxi area of the Emeishan large igneous province (ELIP) in SW China. The granites and rhyolites have geochemical characteristics of anorogenic granites (e.g. high Fe# and high Ga/Al) and are further subdivided based on mineralogy. The Phu Sa Phin and Muong Hum granites contain sodic to sodic–calcic amphiboles and sodic pyroxene, while the Phan Si Pan granite does not. The Phu Sa Phin and Muong Hum granites occasionally show peralkaline to metaluminous compositions, while the Phan Si Pan granites and the Tu Le rhyolites have metaluminous to peraluminous compositions. The chondrite-normalized REE patterns [$(La/Yb)_N$ = 3.6–51.3, $(Gd/Yb)_N$ = 1.4–3.4] and the primitive mantle-normalized spidergrams (enrichment in high field strength elements) are similar to those of the Song Da silicic rocks and the Panzhihua and Taihe granites in the Panxi area. Rhyolite-MELTS modeling suggest that the silicic magmas were likely generated by fractionation of the Song Da high-Ti basalts. The $\varepsilon Nd(t)$ values range from weakly negative to moderately positive values (−2.2 to +2.2), suggesting the silicic rocks may be assimilated by basement rocks during magma emplacement. Permian magmatic rocks in the Phan Si Pan–Tu Le region are petrologically, geochemically and geochronologically comparable to those of the inner zone of ELIP. Although Permian lithospheric mantle and lower crustal structure of the Phan Si Pan–Tu Le region may be destroyed by a lithospheric removal in response to Cenozoic India–Eurasia collision, our results along with recent geophysical analyses in NW Vietnam suggest that the upper to middle crust of Phan Si Pan–Tu Le region represent a remnant upper to middle crust of inner zone of ELIP.

1. Introduction

Mantle plumes and the formation of large igneous provinces play an important role in the formation and recycling of continental crust (Stein and Hofmann, 1994; Nance et al., 1988; Coffin and Eldholm, 1994). The Late Permian Emeishan large igneous province (ELIP, Fig. 1) in SW China has been extensively studied and is considered to be one of the best examples of a Phanerozoic mantle plume-derived large igneous province (Chung and Jahn, 1995; Xu et al., 2001, 2004; Ali et al., 2005; Zhang et al., 2006, 2008; Shellnutt, 2014). The ELIP covers an area of ~0.3×10^6 km^2 of the western Yangzte block and consists of voluminous flood basalts, ultramafic and silicic volcanic rocks as well as their intrusive equivalents (e.g. Chung and Jahn, 1995; Xu et al., 2001). The ELIP is divided into three zones (i.e. inner, intermediate and outer zones, Fig. 1), based on the erosion extent of the Maokou limestone underneath the Emeishan basalts (He et al., 2003). The zonation also corresponds to a decrease of crustal thickness from the center to the margin (Xu et al., 2004). The inner zone is characterized by the thickest crust but also contains ultramafic volcanic rocks, ore-bearing mafic–ultramafic layered intrusions and is interpreted

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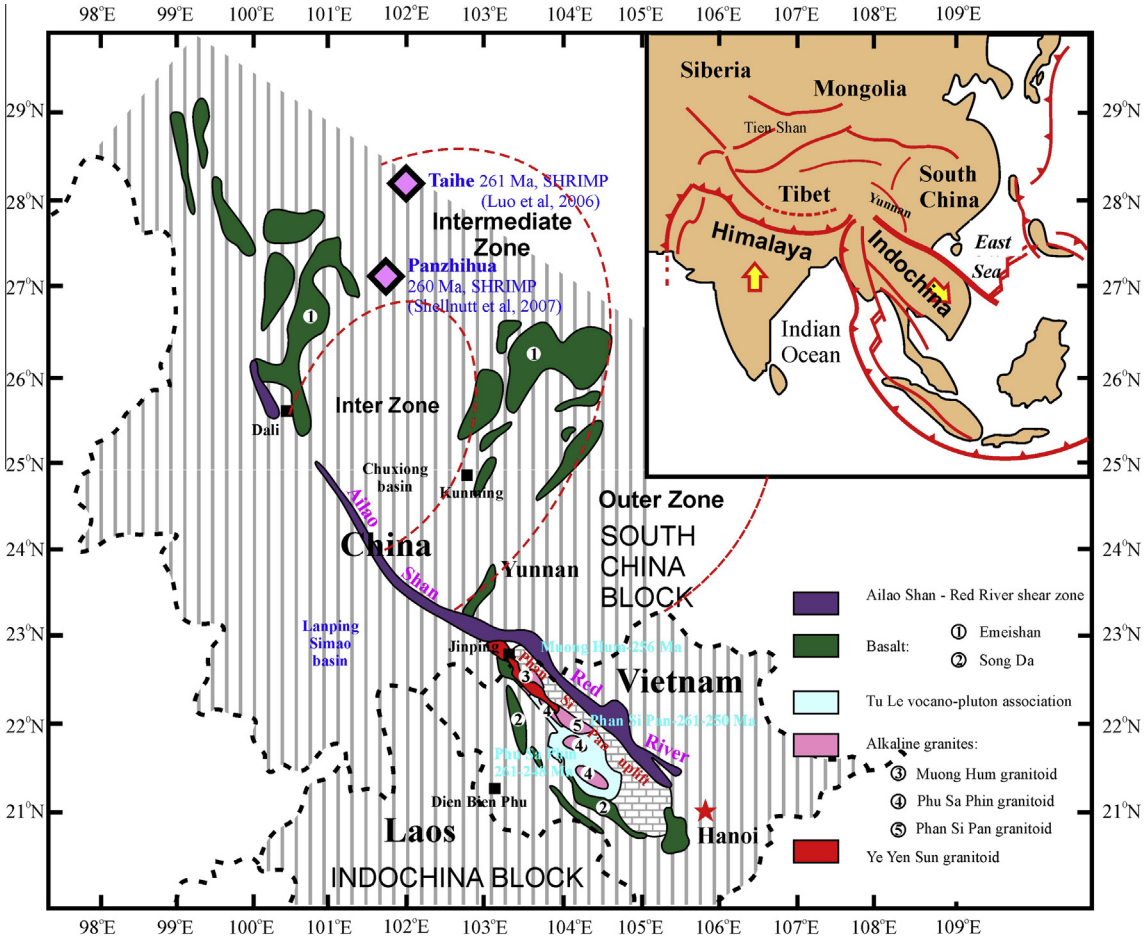

Fig. 1. Distribution of Permian magmatic rocks of the Song Da–Tu Le rift system, the Phan Si Pan uplift and the Emeishan basalts and their silicic differentiates (modified after Lan et al., 2000). Red broken lines indicate the zone boundaries of inner, intermediate and outer zones of the Emeishan Large Igneous Province (He et al., 2003). Inset indicates continental blocks in the SE Asia. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

to be the location of the plume axis (Chung and Jahn, 1995; Xu et al., 2001, 2004; He et al., 2010).

The western part of the ELIP was bisected along the Ailaoshan-Red River (ASRR) shear zone (Fig. 1) during the Paleogene and now has displaced portions located in NW Vietnam (Tapponnier et al., 1990; Leloup et al., 1995; Chung et al., 1997; Xiao et al., 2003; Usuki et al., 2015). During the last decade, picrites, flood basalts and mafic–ultramafic intrusion of the Song Da belt in NW Vietnam (Fig. 1) were revealed to have a genetic relation with the ELIP-related rocks, specifically rocks within the inner zone (Chung et al., 1997; Wang et al., 2007; Anh et al., 2011). However there are comparatively few studies focusing on the silicic volcanic and plutonic rocks from NW Vietnam. Although the silicic rocks of the Phan Si Pan–Tu Le region (Fig. 1), located between the ASRR shear zone and the Song Da belt, were initially interpreted to be Late Mesozoic in age (140–87 Ma based on K–Ar or Ar–Ar isotopic dating; Dovjikov, 1965; Tri, 1977; Luong and Bao, 1988; Anh et al., 2004), recent geochronological studies of these rocks (250–261 Ma, Hieu et al., 2013; Usuki et al., 2015) revealed that they are contemporaneous with the mafic rocks from the Song Da belt and probably represent a structural continuation of the ELIP inner zone (Hoa and Anh, 2011; Usuki et al., 2015). However, there are no detailed geochemical and isotope studies on the silicic volcanic and plutonic rocks and their precise relationship to the ELIP inner zone is uncertain.

The silicic magmatic rocks of the ELIP provide important information regarding the diversity of magmas produced from different sources (i.e. mantle vs. crust) but also the role of mantle plumes in the recycling of old crust and formation of juvenile crust (Shellnutt, 2014). For example, there are granitic plutons which are derived from fractionation of mantle-derived mafic magmas, and partial melting of crust and mixing between mantle-derived and crust-derived melts (Xu et al., 2008, 2010; Zhong et al., 2007, 2009, 2011; Shellnutt and Zhou, 2007, 2008; Shellnutt et al., 2009a,b, 2011a,b, 2012; Shellnutt and Jahn, 2010; Shellnutt and Iizuka, 2011, 2012; Anh et al., 2011; Luo et al., 2013). Furthermore, the ELIP peralkaline silicic plutonic rocks are suggested to be petrogenetically related to the Fe–Ti–V oxide ore-bearing mafic layered intrusions (Shellnutt et al., 2009a, 2011b; Shellnutt and Jahn, 2010).

We report the petrography and geochemical and isotopic data of the granitoids from the Phan Si Pan uplift and rhyolites from the Tu Le basin in order to examine a genetic relationship of the granites, rhyolites, and Song Da mafic rocks, and compare with the alkaline granites of the ELIP inner zone. We also examine fractional crystallization of high-Ti basalts for petrogenesis of the silicic rocks using the program Rhyolite-MELTS (Gualda et al., 2012). Finally we discuss implications to lithospheric structure of NW Vietnam.

2. Geological background

2.1. Geological situation of NW Vietnam

Northern Vietnam belongs to Sino-Vietnam composite terrane (i.e. Yangtze terrane) of the South China block, which is separated