Journal of Volcanology and Geothermal Research 199 (2011) 85–95

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

journal homepage: www.elsevier.com/locate/jvolgeores

Origin of Late Permian Emeishan basaltic rocks from the Panxi region (SW China): Implications for the Ti-classification and spatial–compositional distribution of the Emeishan flood basalts

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ARTICLE INFO

Article history:
Received 2 July 2010
Accepted 15 October 2010
Available online 29 October 2010

Keywords:
Late Permian
Emeishan large igneous province
SW China
SHRIMP
high- and low-Ti flood basalts

ABSTRACT

Basalts and a mafic dyke collected from the city of Panzhihua show characteristics of high-Ti and low-Ti Emeishan basalts respectively. The dyke yielded a SHRIMP zircon U–Pb mean age of 261 ± 5 Ma making it contemporaneous with the eruption of Emeishan basalts. The basalts have I_{Sr} ranging from 0.7059 to 0.7062 with $\varepsilon Nd_{(T)}$ ranging from −1.1 to +0.7 whereas the dyke has I_{Sr} ranging from 0.7056 to 0.7064 with $\varepsilon Nd_{(T)}$ ranging from +0.3 to +0.5. Trace element modeling shows that the two rock types can be generated by different degrees of partial melting from the same garnet-bearing source. Assimilation of crustal material is required in order to produce the depletion of some trace elements (e.g. Nb and Ta) of the dyke however crustal assimilation is not required to produce the basalts. Trace element modeling and isotopic data of the Emeishan basalts suggest that, in general, the high- and low-Ti basaltic rocks are likely derived from the same source and represent different degrees of partial melting with or without crustal assimilation. The location and geological relationships of the 'high-Ti' basalts indicate they erupted relatively early and within the central part of the ELIP, casting doubt on the previous spatial–compositional distribution of the Emeishan basalts.

1. Introduction

Flood basalts are the signature feature of continental large igneous provinces (LIP) (Coffin and Eldholm, 1994; Jerram and Widdowson, 2005). The compositional diversity of the volcanic and plutonic rocks of a particular LIP is unique. Although similar tectonomagmatic characteristics may be recognized (i.e. plume versus non-plume) amongst different LIPs, the precise conditions (e.g. degree and depth of partial melting and initial source material) for each are inherently different thus giving rise to diverse compositions. The recognition of high- and low-Ti flood basalts in continental settings is a well documented phenomenon. The Triassic–Jurassic (~200 Ma) flood basalts of Eastern North America were amongst the first to be distinguished using Ti. The Ti-classification scheme was subsequently modified and adopted to distinguish basaltic rocks from other continental large igneous provinces such as Parana–Etendeka, Karoo, Siberian Traps and Emeishan (Wiegand and Ragland, 1970; Cox, 1988; Peate et al., 1992; Lightfoot et al., 1993; Xu et al., 2001). The use of Ti/HFSE (high field strength elements) ratios usually provides better discrimination between the two types of basalts rather than just TiO_2 (wt.%) (Cummins et al., 1992; Peate et al., 1992). The implications of the 'Ti-classification' system are the recognition of distinct petrological processes, source heterogeneity or source contamination of basaltic rocks within the same temporal, spatial and geological setting. However there is no consensus as to the compositional divisions between high- and low-Ti basalt and it is possible that high-Ti basalt in one LIP may be considered low-Ti basalt in another (c.f. Peate et al., 1992; Xiao et al., 2004; Qi et al., 2010). There are some problems with the use of 'Ti-based' discrimination of basalts because alkaline basalts have higher average TiO_2 wt.% than tholeiitic basalts and thus one must be careful to distinguish 'higher than average-Ti' tholeiitic basalts from alkaline basalts because their origins are distinct (Middlemost, 1975; Winchester and Floyd, 1977; Takahashi and Kushiro, 1983; Cummins et al., 1992).

The Late Permian (~260 Ma) Emeishan large igneous province (ELIP) consists of mostly basaltic rocks which have been subdivided into high- and low-Ti groups (Xu et al., 2001; Xiao et al., 2004; Wang et al., 2007; Song et al., 2008). The Emeishan 'high-Ti' basalts are generally accepted as originating by a small amount (<8%) of partial melting and fractional crystallization of mantle plume-derived (i.e. enriched mantle source) mafic or ultramafic magmas whereas the 'low-Ti' basalts are considered to be derived from either the sub-continental lithospheric mantle or picritic magmas which have assimilated upper crust (Xiao et al., 2004; Wang et al., 2007; Fan et al., 2008; Zhou et al., 2008).

Furthermore, the ELIP is subdivided into three roughly concentric zones (i.e. inner, intermediate and outer) which correspond to crustal

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doi:10.1016/j.jvolgeores.2010.10.009

thickness estimates (Xu et al., 2004). The centre of the ELIP is known as the inner zone and has the thickest crust, with the intermediate and outer zones having progressively thinner crust. The flood basalt compositions are seemingly correlative to the concentric zones where the 'low-Ti' basalts are more abundant within the inner zone than the 'high-Ti' basalts. The spatial distribution as well geological observations have indicated that 'high-Ti' basalts represent the waning stages of ELIP volcanism (Xu et al., 2001, 2004). Yet, there is contradictory evidence which suggests the 'high-Ti' basalts may have erupted during the initial stages of ELIP magmatism. For example, the Fe–Ti oxide bearing gabbroic intrusions are concentrated within the centre of the inner zone and are considered to be derived by factional crystallization of 'high-Ti' basalt (Zhou et al., 2008, Shellnutt et al., 2009a, 2009b; Shellnutt and Jahn, 2010). We present new major, trace and isotopic data of high-Ti and low-Ti basaltic rocks from the Panxi region (inner zone) in order to examine their possible origins and assess their relationship to the timing and spatial–compositional distribution of the Emeishan basalts.

2. Geologic background

The Emeishan large igneous province (ELIP) covers an area of 0.3×10^6 km^2 within southwestern China and northern Vietnam and consists of flood basalts, spatially associated felsic plutons and layered mafic–ultramafic intrusions, some of which host giant Fe–Ti–V oxide deposits or Ni–Cu sulphide deposits (Fig. 1) (Chung and Jahn, 1995; Ali et al., 2005; Wang et al., 2007; Zhou et al., 2008). The ELIP is located along the western edge of the Proterozoic Yangtze Block near the boundary with the Early Triassic Songpan–Ganze terrane and was subsequently dismembered during the Mesozoic and Cenozoic by post-emplacement faulting associated with the collision of the North China Block and South China Block and the Indo-Eurasian collision

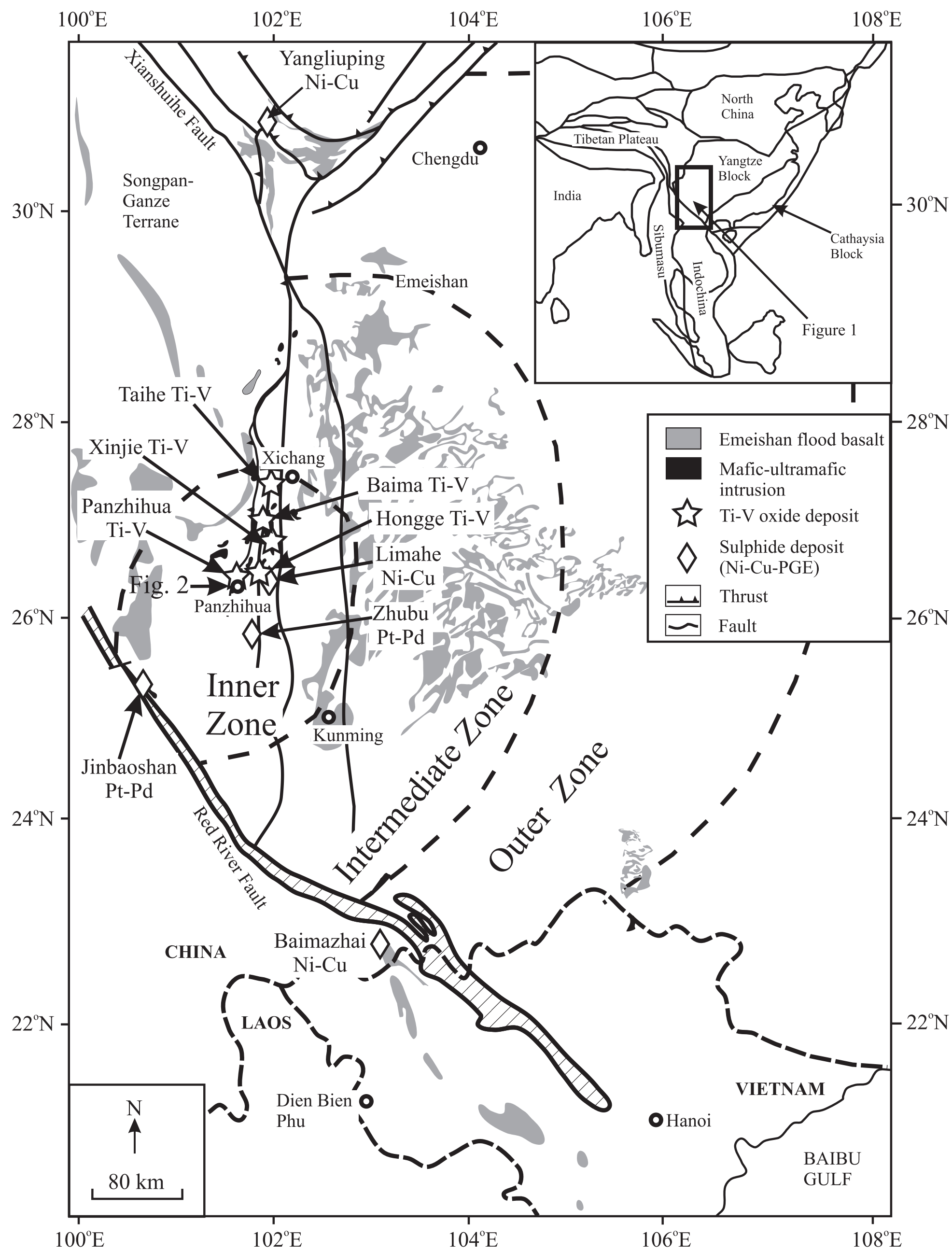

Fig. 1. Regional distribution of the Emeishan large igneous province showing the concentric zones of the ELIP and location of Ti–V oxide and Ni–Cu–PGE sulphide deposits (modified from Tao et al., 2010).