Lithos 119 (2010) 47–60

Contents lists available at ScienceDirect

Lithos

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

Silicic magmas from the Emeishan large igneous province, Southwest China: Petrogenesis and their link with the end-Guadalupian biological crisis

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ARTICLE INFO

Article history:
Received 30 September 2009
Accepted 21 April 2010
Available online 29 April 2010

Keywords:
Silicic magmatism
Daly gap
Fractionation
Crustal melting
End-Guadalupian mass extinction
Emeishan large igneous province

ABSTRACT

The Emeishan large igneous province in SW China comprises a bimodal mafic–silicic suite with the silicic rocks occurring at the uppermost part of the thick lava sequence. The silicic rocks have an age of 257–263 Ma, and are thus roughly coeval with the Guadalupian–Loping (G–L) boundary event. Most silicic rocks (trachyte and rhyolite) from the Emeishan province have rather uniform ε_{Nd} values (+1 to +2.9) that are comparable with the uncontaminated high-Ti basalts. This fact and the remarkably narrow ranges of incompatible element ratios (e.g., Zr/Nb) of the basalt–silicic suite indicate a genetic relationship between basalt and silicic members. The significant difference between the Emeishan rocks and the experimental melts of hydrated basaltic crust, suggests the fractional crystallization of basaltic magma, rather than crustal melting, as the major petrogenetic process for the formation of silicic rocks. Indeed, their major and trace element trends can be modeled by fractionation of the observed mineral phases (feldspar, clinopyroxene, Fe–Ti oxide and apatite). In contrast to the virtually closed system differentiation processes associated with trachytes, the rhyolites may have experienced interaction with upper crustal material during ascent. The geochemical characteristics and recent assessment of timing of the Emeishan volcanism suggest the Emeishan rhyolites as the potential source of the widespread clay bed at the G–L boundary in south China. This enhanced the causal link between the Emeishan eruption and the end-Guadalupian biological crisis.

1. Introduction

The Emeishan flood basalts, as parts of the important large igneous province (LIP) in SW China, occurred around the Guadalupian–Loping (G–L) boundary (i.e., middle–late Permian boundary) (Chung and Jahn, 1995; Xu et al., 2004a; Zhou et al., 2002; He et al., 2007). Its possible relationship to the end-Permian mass extinction have attracted a number of recent studies (Courtillot et al., 1999; Boven et al., 2002; Lo et al., 2002; Zhou et al., 2002; Ali et al., 2004; He et al., 2007; Wignall et al., 2009). The generation of massive mantle-derived rocks (250,000 km^2) over a relatively short time span (Chung et al., 1998; Huang and Opdyke, 1998; Lo et al., 2002; He et al., 2007) and inferred high potential mantle temperature (>1550 °C) from the REE inversion on the mafic basalts (Xu et al., 2001) and picrites (Zhang et al., 2006) are consistent with the hypothesis that the Emeishan traps was formed by a mantle plume head (Chung and Jahn, 1995; Chung et al., 1998). The involvement of mantle plumes in the Emeishan volcanism is further supported by the sedimentary evidence for a rapid crustal doming prior to the Emeishan flood volcanism (He et al., 2003) and other collective arguments based on the spatial distribution of different rock-types and available geophysical data (Xu et al., 2004a; Xu and He, 2007).

So far, most of our knowledge about the Emeishan LIP comes from studies on the mafic intrusives and extrusives that are predominant in this province, and the petrogenetic aspect of the Emeishan silicic magmatism has not yet been elucidated in detail. It has been known for a long time that the Emeishan LIP comprises a bimodal suite, especially in the western part of the province (Huang, 1986; Cong, 1988; Zhang et al., 1988; Yunnan, 1990). The presence of silicic member of the Emeishan LIP has also been confirmed through a recent study on the clastic rocks of the Xuanwei Formation, which represent the erosion products of the Emeishan mafic and silicic lavas (He et al., 2007). The importance of the Emeishan silicic rocks is two folds. On one hand, the study of such rocks will contribute to the long-term controversy about the genesis of the bimodal volcanism (basalt–rhyolite association) in an intraplate setting (or the origin of the "Daly gap"), that is whether silicic magmas resulted from crystal fractionation of mafic rocks or from partial melting of basaltic materials in the lower crust or upper mantle (Chayes, 1963; Macdonald et al., 1990; Mungall and Martin, 1995; Gunnarsson et al., 1998; Peccerillo et al., 2003; White et al., 2009). On the other hand, the characterization of the Emeishan silicic rocks is useful to determine whether the widespread clay beds at the end-Permian sequence in South China were derived from a large-scale silicic volcanism (e.g., Zhou and Kyte,

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doi:10.1016/j.lithos.2010.04.013

1988; Chung et al., 1998) or alkaline magmas (Isozaki et al., 2004). This is highly relevant to establish the causal link between the end-Guadalupian catastrophic biomass extinction and boundary clays.

The Emeishan LIP was subjected to severe erosion, which has destroyed the majority of silicic constituents initially sitting in the uppermost part of volcanic successions in the inner zone (He et al., 2003), making the distribution of the remnant silicic rocks rather restricted. In this paper, we present major and trace element and Sr–Nd isotopic analyses of a set of trachyte, rhyolite and granophyre dyke from Binchuan, Ertan and Wuben in western Emeishan LIP. The aims of this study are to determine whether the mafic and silicic rocks represent a cogenetic suite and the extent by which these rocks interacted with continental crust. We will show that trachytes experienced a virtually closed system fractionation from evolved basalts, whereas the formation of rhyolites was associated with an open-system fractionation in which coupled crustal assimilation and fractional crystallization took place. Crustal melting may only have a restricted role in the evolution of the Emeishan silicic rocks. Geochemical comparison and recent assessment of the time sequence of the Emeishan volcanism support the hypothesis that the Emeishan silicic rocks are the potential source of the G–L boundary ash layers in South China, thus favoring the causal link between the Emeishan eruption and the end-Guadalupian biologic crisis.

2. Geological background and geochronology

The Emeishan basalts are generally referred to as the remnants of the Late Permian volcanic successions in the western Yangtze craton, SW China (Fig. 1a). The massive mafic lavas and pyroclastics, in association with a number of intrusive bodies of ultramafic–felsic composition (Zhou et al., 2005; Shellnutt and Zhou, 2007), are exposed in a rhombic area of ~250,000 km^2 (Fig. 1a). The Ailao Shan–Red River fault zone is traditionally considered as its western boundary (e.g., Zhang et al., 1988). However, some basalts and mafic complexes exposed in the Simao basin and Qiangtang terrane are possibly an extension of the Emeishan LIP (Chung et al., 1998). Some Emeishan-type basalts traced in SW Yunnan and northern Vietnam may be related to the mid-Tertiary continental extrusion of Indochina relative to South China along the Ailao Shan–Red River fault zone (Chung et al., 1997; Xiao et al., 2003). It is likely that the later tectonic events have resulted in major disruption of the former province (Courtillot et al., 1999). The petrologic link between the seismically high velocity lower crust and the Emeishan basalts led Xu and He (2007) to re-estimate the volume of the Emeishan basalts to be 3.8×10^6 km^3, typical of plume-generated LIPs in the world.

The Emeishan flood basalts can be divided into two major groups, i.e., high-Ti and low-Ti basalts (Xu et al., 2001). The low-Ti basalts are largely confined to the lower sequence of volcanic successions in the western part of the Emeishan LIP, whereas lavas of the high-Ti group occur in the upper successions nearly in the entire region (Fig. 1b; Xu et al., 2001). This temporal variation in basalt chemistry (i.e., from low-Ti to high-Ti) indicates not only a deepening of the melting column, but also the transition from the peak to the waning stage of the mantle plume activity. The spatial variation in rock type, on the other hand, is likely controlled by the

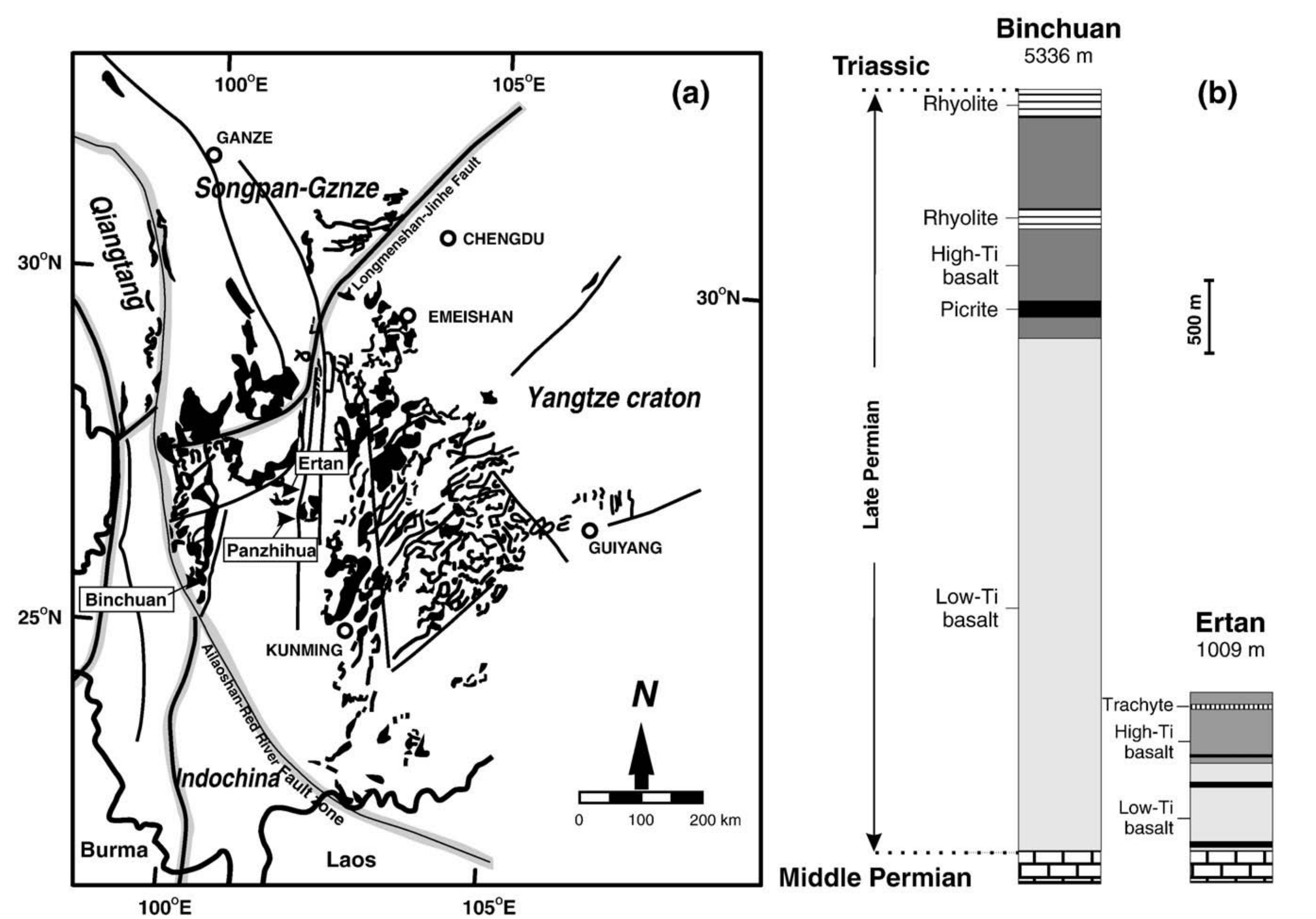

Fig. 1. (a) Schematic map showing the distribution of the Permian volcanic successions (black areas) and sampling location of silicic rocks in the Emeishan large igneous province. (b) Simplified stratigraphic sections at Binchuan and Ertan (modified after Xu et al., 2001) from which rhyolite and trachyte samples were collected respectively for this study. Both sections show that the low-Ti basalts are overlain by the high-Ti basalts with silicic rocks occurring at the uppermost volcanic sequence.