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Lithos 79 (2005) 475–489

LITHOS

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Emeishan large igneous province, SW China

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Received 23 September 2003; accepted 9 September 2004
Available online 5 November 2004

Abstract

In recent years, there have been major advances in our understanding of the Emeishan large igneous province (LIP) of SW China following publication of a number of LIP-focused investigations of the terrain and associated rocks. This paper reviews the current state of knowledge. The volcanic and upper-intrusive portion of the province is relatively small (~0.3×10^6 km^3), even when offset fragments, eroded sections and buried portions are included in the volume calculation. The most reliable radiometric age dates (zircon U–Pb SHRIMP from an associated layered intrusive body several kilometers in area) indicate generation at ~259 Ma, consistent with the end-Guadalupian (end Middle Permian) stratigraphic age. In addition, several Ar–Ar dating studies have been carried out, mainly on the volcanic rocks, with a number of reported dates ~253–251 Ma (Late Permian), but a consensus is emerging that these ages are problematic because they are in conflict with the stratigraphic data (possibly due to a monitor standard miscalibration). The Ar–Ar investigations have also yielded a large number of secondary ages, which are clustered at ~175, ~142, ~98 and ~42 Ma, and these are inferred to record sub-regional tectonic events that affected the western Yangtze Block as East Asia was assembled and later deformed by India's collision–indentation into Asia. Magnetostratigraphic data and field observations suggest that the bulk of the volcanic sequence formed within 1–2 my. The geochemistry of the volcanic rocks and bio-lithostratigraphic studies of the underlying Maokou Formation suggests a mantle plume generated the province. The basalts can be classified into low and high Ti groups with different parental magmas. The low Ti basalts are confined to the western part of the province and are overlain by the high Ti basalts. The low Ti magmas formed at shallow mantle depths in the spinel–garnet field transition zone (60–80 km), whereas the high Ti magmas formed by low degrees of partial melting within the deeper garnet stability field. This observation suggests a deepening of the melting column as the lithosphere thickened due to underplating and a transition from peak basalt generation to the waning stage. Outstanding issues, which might focus future studies, are also outlined.

Keywords: Emeishan; LIP; Guadalupian; Mantle plume; Flood basalts; Permian

1. Introduction

For more than 60 years, the Permian Emeishan (or Omeishan) basalts in Sichuan, Yunnan and

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0024-4937/$ - see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.lithos.2004.09.013

Guizhou Provinces have featured in lithostratigraphic descriptions of China's geology (Lee, 1939; Yang, 1986; Liu and Xu, 1994a,b; Enos, 1995). In northern Vietnam, tectonic lenses of the same basalt sequence (Camthuy Formation) and associated rocks are present (Tien, 1993, 2000; Shi and Shen, 1998), displaced several hundred kilometers to the southeast by Oligo-Miocene sinistral motion along the Ailao Shan-Red River Fault. Modern work on the Emeishan Basalts started in the late 1970s, and in the 1980s and early 1990s, a number of prominent Sino-Western palaeomagnetism teams were particularly active, studying the rocks for plate tectonic modeling purposes, trying to exploit the generally excellent magnetic signature of basalt flows (e.g., McElhinny et al., 1981; Chan et al., 1984; Huang et al., 1986; Ma et al., 1993; Van der Voo et al., 1993). However, none of the investigations had a LIP focus, and were instead aimed at understanding South China's motion history within the wider context of East Asia's Late Palaeozoic through Mesozoic assembly (e.g., McElhinny et al., 1981; Lin et al., 1985; Enkin et al., 1992). Luo et al. (1990) were the first to describe in the English language press, and within a modern geotectonic framework, how the basalts may have been generated (by rifting). A rift model was also proposed by Dmitriev and Bogatikov (1996). Coffin and Eldholm (1994) mentioned the flood basalt terrain in their synthesis of LIPs. Chung and Jahn (1995) and Chung et al. (1998) suggested, after also carrying out geochemical studies, that the Emeishan Basalts formed above a mantle plume, and these works were instrumental in raising awareness of the province among the wider geological community.

Since 2000, a substantial number of LIP-focused Emeishan basalt papers have been published, particularly in the fields of geochemistry and geochronology. As regards LIP studies, answers to the following questions are of most interest: How big is the igneous province? What is its basic stratigraphy and that of the associated deposits? What is its age? How long did volcanism last? Does its age coincide with one of the past mass extinctions, and if so are they linked? How was the province generated and was a mantle plume involved? Does the new data from the Emeishan province add to, or refute, recent suggestions for Earth having experienced particularly enhanced mantle plume and related continental rifting activity in the latter part of Permian–early Triassic? Does the province possess any other notable features? This review of the Emeishan LIP will attempt to answer these questions, drawing together information presented in the recent and in-press publications, as well as older work.

2. Aerial extent and volume of the Emeishan province

Estimating the original extent and size of the Emeishan igneous province is not as simple as for younger, better preserved large igneous provinces, and the values obtained usually involve corrections to account for erosion, buried portions and structural dismemberment. The summary geological map of Boven et al. (2002; redrawn here in Fig. 1) is a useful guide for assessing the various proposed area/size estimates. The main outcrop occupies a rhombic shape with an area of $\sim 2.5\times10^5$ km^2. Additional parts of the terrain are known from drill wells in the Sichuan Basin to the NE, and there are Red River Fault displaced fragments in southern China (Xiao et al., 2003) and northern Vietnam (Tien, 1993, 2000; Shi and Shen, 1998). Likely correlative basalts (Pearce and Mei, 1988) also occur on the eastern Qiangtang Terrane in Tibet. Therefore, assuming an average thickness of 700 m, the volume of the province is likely to be $\sim 0.3\times10^6$ km^3 (e.g., Xu et al., 2001); the recent suggestions of Wignall (2001) and Courtillot and Renne (2003) arguing for a volume $\sim 10^6$ km^3 are almost certainly too large. Thus, in comparison to other large igneous provinces, the Emeishan flood basalt terrain is small (see Fig. 2, where the mean size of Earth's Permian and younger LIPs is $\sim 2\times10^6$ km^3).

Using seismic information and geochemical data (processed using Ghiorso and Sack (1995) "MELTS" modeling package), Zhu et al. (2003b) estimated the total volume of material added to the crust during the generation of the Emeishan LIP to be $\sim 9\times10^6$ km^3. The results, they argued, also explain why huge layered gabbro intrusions, rich in Fe, V and Ti, are present in some parts of the terrain (southern-central), are absent in others