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Magmatic underplating and crustal growth in the Emeishan Large Igneous Province, SW China, revealed by a passive seismic experiment

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ABSTRACT

In an attempt to characterize the subsurface structure that is related to fossil mantle plume activity, a comprehensive geophysical investigation was conducted in the Emeishan Large Igneous Province (ELIP). The nature and geometry of the crust were examined within the scheme of the domal structure of ELIP, which comprises the Inner, Intermediate and Outer zones, which are defined on the basis of the biostratigraphy of pre-volcanic sediments. The bulk crustal properties within the Inner Zone are characterized by high density, high P-wave velocity, high Vp/Vs ratios and large crustal thickness. A visible continuous seismic converter is present in the upper part of the crust in the whole Intermediate Zone and the eastern part of the Inner Zone, but it is absent in the Inner Zone, where another seismic converter is observed in the lower part of the crust. The geometric configuration of these converters is attributable to the addition of mantle-derived melts to the pre-existing crust and subsequent interaction between them. The crustal geometry, which is delineated by the migrated image of receiver functions from the passive seismic experiment, and the crustal properties collectively suggest that a mafic layer of 15–20 km thickness and 150–180 km width exists at the base of the crust in the Inner Zone. Such a mafic layer reflects a vertical crustal growth through magmatic underplating at the base of the crust and intraplating within the upper crust. The salient spatial correlation between the deep crustal structure and the dome strongly supports a genetic link between crustal thickening and plume activity, if the pre-volcanic domal uplift is generated by the Permian Emeishan mantle plume. This arrangement is further supported by the consistency of the extent of crustal uplift estimated by isostatic equilibrium modeling and sedimentary data. This study therefore characterizes and provides evidence for a plume-modified crust in a large igneous province.

1. Introduction

The Permian, which is characterized by emplacements of a number of large igneous provinces (LIPs), is an important period in the earth's history (Wignall et al., 2009). Recently, recognition of the potential role of LIPs in affecting biotic evolutionary pathways and metallogenic systems has led to growing interest in these provinces (Xu et al., 2014). The Emeishan flood basalt in SW China (Fig. 1) has been recognized as one of the major mafic LIPs (Xu et al., 2004, 2007). It was emplaced over a short time with a termination age of 259.1 ± 0.5 Ma, which is very close to the Guadalupian–Lopingian Boundary (Zhong et al., 2014). Thus, it is possibly synchronous with a number of major global events during the late Paleozoic, such as the double mass extinctions, ocean superanoxia, sharp C and Sr isotopic excursions, sea-level drop and the Illawara geomagnetic reversal (Wignall et al., 2009; Xu et al., 2014). There are many mafic–ultramafic intrusions within the Emeishan LIP (hereafter ELIP) that host Fe–Ti–V and Ni–Cu–

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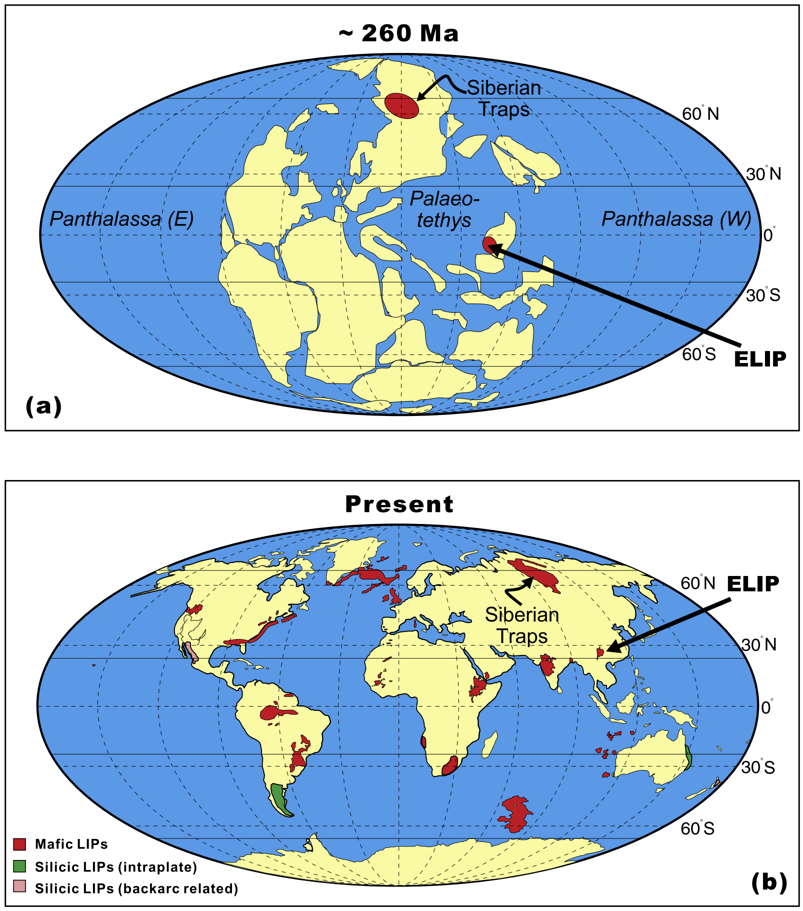

Fig. 1. The emplacement site of Emeishan Large Igneous Province (ELIP) shown in a paleogeographic map of late Permian (a) (modified from Ali et al., 2005) and its present location (b) with other LIPs exposed on the Earth (modified from Bryan et al., 2002). Note the very large dimensions that the ELIP has traveled in space and time since its formation and, hence, the mismatch between the locations of the Permian plume source and the present-day ELIP and the exhaustion of thermal effect in ELIP.

PGE deposits (Zhou et al., 2008), which have already become important targets for mineral exploration.

Over the past decade, multidisciplinary investigations have been conducted in ELIP on the origin of this LIP, the mineralization system associated with a mantle plume, and paleoclimatic reconstructions and their implications for the Permian mass extinctions. A mantle plume model has been used to explain the physical and chemical features of ELIP, including the eruption of high magnesian lavas and evidence for pre-volcanic crustal domal uplift. Xu et al. (2007) summarized the identifications of mantle plume in ELIP and argued that there would be at least seven pieces of evidence that support a Permian mantle plume origin for this province. Most of the evidence for the mantle plume is from geochemical, paleontological, paleomagnetic, and geochronological studies, but the geophysical constraints are very limited. Most of the seismic evidence for mantle plumes is confined to the modern, active hotspots such as Hawaii, Kerguelen, Iceland and Yellowstone (Montelli et al., 2004). The thermal effects of high temperature and low viscosity magma-derived and subsequent geophysical responses (especially low seismic velocity) within the deep interiors are the most important clues to tracing a modern mantle plume for seismic investigation. The ELIP is related to an ancient plume, whereas the thermal effects that are plume-derived would have decayed with a time constant of approximately 60 Myr (McKenzie, 1984). Since the termination of the volcanism, ELIP has traveled more than three thousand kilometers away from its putative source (Fig. 1), and the mantle has continuously cooled down for over 250 Myr. Both the thermal decay and the drifting away from the original site would result in great difficulty in tracing an ancient plume for geophysical investigation. Fortunately, as an archive of the earth's history, the solidified continental crust has the most possible ability to preserve the imprints of the earth's evolution, by its composition and structure (Hawkesworth et al., 2013). Thus, in this sense, the constraints on the crustal composition and geometric structure from the geophysical investigations could provide an opportunity to identify an ancient mantle plume. However, to understand the origin of an ancient LIP, great care must be taken when a real-time geophysical observation on the deep-seated and hence volatile structures (e.g., the mantle transition zone) is used as a discriminator (He et al., 2014).

In an attempt to trace the geological records that were left by the proposed ancient mantle plume, a series of geophysical investigations were conducted in ELIP discontinuously from November 2010 to April 2013. Four east–west trending profiles that are approximately along the latitude 27°N are involved in a COMprehensive investigation on ELIP: 1) a linear PASSive seismic array (COMPASS-ELIP experiment, ca. 850 km long); 2) a WIDE-angle reflection/refraction seismic profile (COMWIDE-ELIP experiment, ca. 650 km long); synchronous measurements of 3) GRAVity (COMGRA-ELIP experiment, ca. 800 km long) and 4) geoMAGnetism (COMMAG-ELIP experiment). In this paper, we will present observations of the crustal nature and geometry mainly from the COMPASS-ELIP experiment and discuss their implications in the origin of voluminous mafic basalts and the crustal growth mechanism in this igneous province.