Tectonophysics 672–673 (2016) 16–23

Contents lists available at ScienceDirect

Tectonophysics

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

Magmatic underplating beneath the Emeishan large igneous province (South China) revealed by the COMGRA-ELIP experiment

Yangfan Deng [a,*], Yun Chen [b], Peng Wang [c], Khalid S. Essa [d], Tao Xu [b], Xiaofeng Liang [b], José Badal [e]

[a] State Key Laboratory of Isotope Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China
[b] State Key Laboratory of Lithospheric Evolution, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China
[c] Institute of Earthquake Science, China Earthquake Administration, Beijing 100036, China
[d] Department of Geophysics, Faculty of Science, Cairo University, Giza, Egypt
[e] Physics of the Earth, University of Zaragoza, Pedro Cerbuna 12, 50009 Zaragoza, Spain

ARTICLE INFO

Article history:
Received 17 July 2015
Received in revised form 18 January 2016
Accepted 28 January 2016
Available online 4 February 2016

Keywords:
Stripping
Residual gravity
Density anomaly
Underplating
Emeishan large igneous province
South China

ABSTRACT

Because of the abundant geological, geochemical and geophysical studies conducted on the Emeishan large igneous province (ELIP) in South China, the Permian mantle plume model associated with this region is widely accepted. Furthermore, the dome-shaped structure related with this plume has been determined with success by sedimentological data and gravity stripping. Although the sediment thickness, upper crust, Moho depth and the lithosphere–asthenosphere boundary (LAB) are well constrained by active- and passive-source seismological results, the density anomaly in ELIP is still a poorly constrained issue that needs further attention. With the aim especially to understand the impact on surface of the magmatic processes that originated in the deep mantle, we performed the COMGRA-ELIP gravity experiment across this region. Using a stripping method, we determined the residual gravity in ELIP and surrounding areas. The residual gravity reaches a maximum value of +150 mGal in the inner zone of ELIP and its strength decreases gradually when measuring from the inner zone to the middle and outer zones. Combining active and passive seismic results and the least-squares variance analysis method, we propose a strong density contrast of 0.2 g/cm^3 (density of 3.14 g/cm^3) for the 15- to 20-km-thick igneous layer accreted at the base of the crust, as evidence of crustal underplating in ELIP, to explain the present-day residual gravity anomaly.

1. Introduction

The Emeishan large igneous province (hereafter ELIP) lies within a rhombus-shaped area of 250,000 km^2 bounded by the Lijiang–Xiaojinhe fault to the northwest and the Red River fault to the southwest (Xu et al., 2001) (Fig. 1). In recent years, ELIP has drawn the attention of the scientific community because of its great importance in understanding the origin of intraplate igneous structures and its possible synchrony with the end-Permian mass extinctions (Wignall et al., 2009; Wu and Zhang, 2012; Cheng et al., 2014; Shellnutt et al., 2012; Shellnutt, 2014; Xu et al., 2014a; Yuan et al., 2014; Zhong et al., 2014). According to the extent of erosion of the Maokou Formation composed of Mid–Late Permian carbonates (He et al., 2003, 2006; Xu et al., 2004), the dome-shaped structure associated with ELIP can be divided into three zones, namely, the inner, middle and outer zones, and the Xiaojiang fault is the boundary between the inner and middle zones (Fig. 1). The extent of the erosion is more apparent in the inner zone, which is proposed as the site of a rising plume head (He et al., 2003).

It has been suggested that igneous intrusion at the base of the crust may underlie the flood basalts (White and McKenzie, 1989; Coffin and Eldholm, 1994). Magmatic underplating occurs when basaltic magmas are trapped at the Mohorovičić discontinuity or within the crust during its rise to the surface (Cox, 1993). Underplating of magma is an important process for crustal formation and subsequent evolution because the inflow of magma provides a non-tectonic way for growing and thickening of the crust (Thybo and Artemieva, 2013). Geophysical studies (as well as igneous petrology and geochemistry) utilize the differences in density and seismic velocity to identify underplating that occurs at depth (Behera et al., 2004; Singh et al., 2004; Thybo and Artemieva, 2013), but the density studying in ELIP is still poor.

In an attempt to characterize the subsurface structure that is related to fossil mantle plume activity, a comprehensive geophysical investigation was conducted in ELIP, and the properties and geometry of the crust collectively suggest the existence of a 15- to 20-km-thick and a 150- to 180-km-wide mafic layer overlying the base of the crust in the inner zone (Chen et al., 2015). In this paper, since the depth of interfaces and magmatic underplating process seem to be well constrained by comprehensive geophysical investigation (Xu et al., 2015; Chen et al., 2015; Chen et al., in preparation), we assess the density of the mafic

* Corresponding author at: 511 Kehua Street, Tianhe District, Guangzhou, China.
E-mail address: yangfandeng@gig.ac.cn (Y. Deng).

http://dx.doi.org/10.1016/j.tecto.2016.01.039

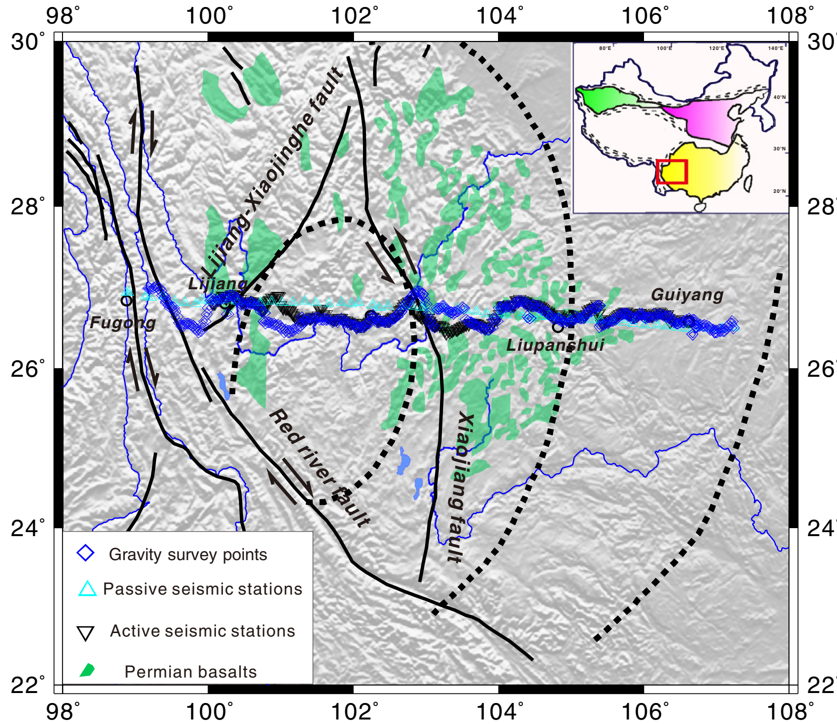

Fig. 1. Tectonic features (main faults) depicted on a topographic map of the Emeishan large igneous province (ELIP). The inset in the top right corner shows a small rectangle on a map of China that reveals the location of the explored area. The dash lines indicate the inner, middle and outer zones of ELIP. Three instrument sets were deployed from west to east in this region: a gravity profile (blue diamonds indicate gravity survey points), a passive-source seismic array (pale blue triangles indicate passive seismic stations) and an active-source seismic array (black inverted triangles indicate active seismic stations). The distribution of Permian basalts is similar to that of Xu et al. (2004, 2007).

layer based on the observed gravity data from the COMGRA-ELIP experiment. Starting from the results obtained by seismology, by least-squares variance analysis and with the help of the trial-and-error method, we estimate both the density and the shape of underplating in the lower crust that fits the residual gravity.

2. Data processing and Bouguer gravity

In order to understand the gravity response to the magmatic process in ELIP, during the months of July and August 2012, we carried out the COMGRA-ELIP experiment for gravity measurement along a west–east 800-km-long profile that crosses the inner, middle and outer zones of ELIP (Fig. 1). This experiment included 338 measurement points measured by a Burris gravity meter (No. B65) whose accuracy reaches 15 μGal (Zhang et al., 2011). The observation points were spaced an average distance of about 2.2 km. Gravity readings were recorded relative to two base points belonging to the national gravity network of China, one located at the east part of the profile near Guiyang (Guizhou Province) and another at the west part near Lijiang (Yunnan Province). In order to carry out the terrain correction, in addition to measuring the relative gravity, we also recorded the elevation of each survey point using a Trimble GeoXM GPS with precision of up to 1 m.

After a series of gravity reductions that include drift correction, tide correction, latitude correction, topography correction and Bouguer correction (Zeng, 2005), the obtained Bouguer gravity is shown in Fig. 2. The elevations along the reference profile fluctuate greatly in the inner and middle zones; the sharpest variation occurs in the middle of the profile and correlates with the Xiaojiang fault, which can be seen clearly as the boundary between these two zones (Fig. 2, upper plot). The Bouguer gravity anomaly increases gradually from west to east, from −330 to −130 mGal, with a dome-shaped variation in the inner zone (Fig. 2, lower plot). To some extent, the respective shapes of the topography and the Bouguer gravity keep mirror symmetry.

The measured Bouguer gravity is a summation of all density anomalies within the lithosphere including the density difference of the layers with respect to those of the reference model and the undulation of intra-crustal and sub-crustal layers. Low-density sediments result in a negative gravity anomaly relative to the crystalline crust, and removing this effect due to the sediments will increase the residual anomaly. Contrarily, an uplift of the Moho produces a positive gravity anomaly and its elimination will lead to a reduction in the residual anomaly. In contrast, a depression of the Moho produces a negative anomaly (Mooney and Kaban, 2010). Although the topography and free-air effects have been removed from the Bouguer gravity, in order to isolate the gravity response of ELIP we have to remove particular gravitational effects caused by the sedimentary cover, the undulation of the upper crust, the Moho and the mantle lithosphere from shallower to deeper depths. This sequential procedure, named *stripping*, was first described by Hammer (1963) and later developed by other authors (Bielik, 1988; Mooney and Kaban, 2010; Bielik et al., 2013a, 2013b; Deng et al., 2014a).

3. Gravitational effects

It is generally assumed that any change affecting the horizontality of the homogeneous reference density model would lead to a change in the residual gravity anomaly (Mooney and Kaban, 2010), whereas the gravity from a uniform horizontal layer with invariable density is a constant. Our reference model corresponds to a continental crust with flat topography (Fig. 3), which consists of a 15-km-thick upper crust with density 2.7 g/cm^3 (Mooney and Kaban, 2010) above a 25-km-thick lower crust with density 2.94 g/cm^3 (Mooney and Kaban, 2010; Deng et al., 2011). The average density of the lithospheric mantle is set to