Tectonophysics 627 (2014) 159–170

Contents lists available at ScienceDirect

Tectonophysics

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

3-D density structure under South China constrained by seismic velocity and gravity data

Yangfan Deng [a,b,*], Zhongjie Zhang [b], José Badal [c], Weiming Fan [a]

[a] 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] Physics of the Earth, University of Zaragoza, Pedro Cerbuna 12, 50009 Zaragoza, Spain

ARTICLE INFO

Article history:
Received 25 April 2013
Received in revised form 16 July 2013
Accepted 24 July 2013
Available online 2 August 2013

Keywords:
P-wave velocity
Bouguer gravity
3-D density model
Vp–density laws
South China

ABSTRACT

Until now the crustal structure of South China has been studied through 2-D seismic surveys. While informative, the results generated from these surveys cannot be easily interpreted from a regional outlook due to the sparse sampling of the area. In this paper, we have investigated the 3-D density structure of South China based on an integrated dataset, namely: P-wave velocities previously determined from seismic profiles and Bouguer gravity anomalies. The density structure is solved through a robust inversion of Bouguer anomalies with the help of Grav3D software, so that the results can be extended to zones lacking constraints or sufficient deep seismic coverage. The key issues arising from this density analysis shed new lights on South China, as: (1) The Moho depth extracted from the density model is consistent with the information supplied by deep seismic soundings. (2) The linearly increasing density below the eastern part of the Dabie orogenic belt, in a frame of low density at the bottom of the middle crust, is consistent with the speculated dome of relatively high P-wave velocity suggested by previous deep seismic soundings, and understood as a geophysical fossil of the continental collision/extrusion. (3) The Chenzhou–Linwu fault seems to be the southern transection of the boundary between the Yangtze and Cathaysia blocks constrained by our crustal density model. (4) Different laws formulated as linear relationships between seismic velocity and density allow distinguishing the tectonic units forming South China. These laws are the consequence of the crustal composition and temperature distribution.

1. Introduction

South China, lying in the southeast of Eurasian continent and bordering with the Philippine Sea plate to the east and the Indian plate to the west (Fig. 1), is a major tectonic unit belonging to the continental margin of eastern Asia (Li and Li, 2007; Liu et al., 2012; C. Wang et al., 2003; Q.S. Wang et al., 2003; Y.J. Wang et al., 2003). It contains three Triassic–Jurassic orogens: the Qinling–Dabie orogenic belt along its northern margin, which records the collision with the North China block; the Longmenshan belt along its northwestern margin, likely related to the lower crust flow in the Tibetan Plateau; and the South China fold belt, which has a broad northeastward tread (Deng et al., 2013; Li, 1994; Li and Li, 2007; Wang, 2009; Wang and Shu, 2012; Zhang et al., 2009c, Z.J. Zhang et al., 2011, 2013).

In the course of the last 90 years, substantial research has been made to study the geological features of South China, and also the seismic velocity structure and the geometry of the main crustal interfaces. All these valuable data were acquired after many works of geophysical prospecting involving deep seismic soundings (DSS), deep reflections and broadband seismic surveys undertaken across many parts of South China (Deng et al., 2011; Li et al., 2006; Xiong et al., 2009; Zhang et al., 2005; Z.J. Zhang et al., 2011; Zhao et al., 2013a,b). However, due to uneven datasets, both in quality and quantity, the overall knowledge of the geological basement and the structure of the crust remains rather poor, and the boundary between the Yangtze and Cathaysia blocks is still a subject that even today raises a lively debate. Moreover, seismic data alone do not provide sufficient information about the density structure of the medium because the P- and S-wave velocities are controlled by a high number of factors including composition, temperature and volatile content of the crust–upper mantle structure (Mooney and Kaban, 2010). Gravity data and subsequently density data provide valuable constraints on the physical state of the lithosphere that are complementary to the seismic data. For example, density variations within the crust and sublithospheric mantle often control the surface elevation (Mooney and Kaban, 2010). So much so that a better understanding of South China can be achieved using a 3-D inversion of gravity data that integrates existing geological and geophysical information, to extrapolate the results to poorly sampled regions and thus fill the existing information gap.

In order to obtain the density structure in South China and discuss the feasible boundary between the Yangtze and Cathaysia blocks, in this paper, based on the available data of gravity, we have studied the

* Corresponding author at: Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou, 510640, China. Tel.: +86 010 82998345.
E-mail address: dengyangfan@mail.iggcas.ac.cn (Y. Deng).

0040-1951/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.tecto.2013.07.032

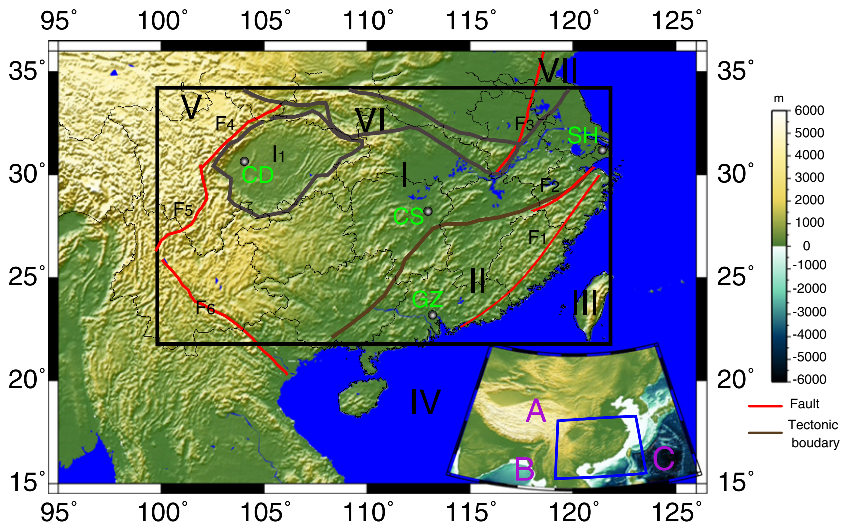

Fig. 1. Tectonic map of South China framed within the spatial window 100–122°E, 22–34°N. The inset in the bottom right corner shows the study area bounded by a rectangle. The elevation of the terrain (in meters) is indicated on the vertical scale on the right of the map. Faults (red lines) and tectonic boundaries (dark brown lines) are also drawn. Key to symbols: A, Asian plate; B, Indian plate; C, Philippine Sea plate; I, Yangtze block; II, Cathaysia block; III, Taiwan orogeny; IV, South China Sea basin; V, East of the Songpan–Ganzi block; VI, Qinling–Dabie orogen; VII, North China block; I1, Sichuan Basin; F1, Zhenghe–Dapu fault belt; F2, Jiangshan–Shaoxing fault belt; F3, Tanlu fault belt; F4, Longmenshan fault belt; F5, An'ninghe fault belt; F6, Honghe fault belt; CD, Chengdu City; CS, Changsha City; SH, Shanghai City; GZ, Guangzhou City.

area framed within the spatial window 100–122°E, 22–34°N (Fig. 1), taking into account a reference structural model constrained by P-wave velocity that was previously obtained by kriging interpolation from 57 DSS profiles (Deng et al., 2011). The so obtained results supply new insights about the geodynamics of South China.

2. Gravity data

The starting data of Bouguer gravity with reference to South China were taken from the Earth Gravitational Model 2008 (EGM2008) proposed by Pavlis et al. (2008, 2012), which provides information on a $2.5' \times 2.5'$ sized grid displayed both inland and on the ocean, including synthetic gravity generated by GRACE and terrestrial gravity anomaly. The standard deviation of the field data is less than 5 mGal in the study region (Pavlis et al., 2008).

The Bouguer gravity sums all density changes due to the non-homogeneous structure of the crust caused by different geological formations, shallow deposits of materials and the undulation or dipping of the layers (Q.S. Wang et al., 2003; Zeng, 2005). In South China, small positive gravity anomalies (<100 mGal) are confined to regions near the coastal areas (Fig. 2). At a larger scale, small negative gravity anomalies (around −200 mGal) can be observed in part of the Qinling–Dabie orogen and Sichuan basin. In the Songpan–Ganzi block the Bouguer gravity increases progressively westward to more negative values reaching up to −550 mGal. Thus, it can be summarized that the higher the elevation of the terrain the lower the gravity anomaly. While, other direct information related to the faults and boundaries separating the tectonic units cannot be observed clearly in the study area.

3. Inversion for density structure

3.1. Implementation

The forward modeling of gravity involves computing the gravitational response from a prescribed density anomaly model. Conversely, the inversion for a density anomaly structure or inverse modeling implies generating a model that fits the observed gravitational field in the subsurface, even though the resulting model is non-unique and simply represents one of many models that can satisfy the observations (Welford and Hall, 2007; Welford et al., 2010).

The inverse problem was formulated as an optimization by which an objective function defining the density model is minimized subject to the constraints of that the data be reproduced within a tolerance interval or error margin (Wang, 2002). With the purpose of constructing a 3-D density model we performed a robust inversion of the data using Grav3D software, by controlling the generation of the model type and to what extent the inverted model can reproduce the observed data within their error bounds (misfit) (Welford and Hall, 2007). The first step is made through the norm of the model that is described in terms of directionally dependent smoothing length scales, which can generate a variety of model types (e.g. small, flat, blocky). The norm can be further adapted to minimize the difference between the inverted density model and a reference density model. The misfit is a least-squares measure of the difference between the observed gravity values and those predicted from the inverted density anomaly model. The difference is weighted by the reciprocal of the observed data errors so that the misfit for inversion is dimensionless and should be equal to the number of data points provided that the data errors are independent and Gaussian with zero mean (Li and Oldenburg, 1996, 1998).

It is well known that the gravity data have no inherent resolution at depth; as most they lead to structures located near the surface when considered a simple model, i.e. a small or flat model, regardless of the true depth of the causative bodies. Since the amplitude of the inversion kernels decreases rapidly with depth, the data measured at surface are not enough as to generate a function (a density model) able to reveal a significant structure at depth. In order to overcome this drawback, the inversion process needs to introduce a weighting at depth to counteract this natural decay of the inversion kernels. Intuitively, such a weighting will approximately cancel the natural decay and will make possible constructing the model at gradually increasing depths, with equal probability of including non-zero density data in the solution (Grav3D 3.0).

With the Grav3D algorithm, a specific density anomaly is initially assigned to each grid cell covering the reference density model, and also a variation range wherein the density anomaly is allowed to vary during the inversion process. This allows that portions of the reference model that are well constrained by other geophysical methods may vary slightly or even remain fixed during the inversion process (Welford et al., 2010).

The Grav3D mesh, onto which the 3-D density anomaly distribution is modeled, consists of rectangular prisms of certain size with a particular