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Characteristics of isostatic gravity anomaly in Sichuan-Yunnan region, China

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ABSTRACT

Sichuan-Yunnan region in China, a tectonic transition belt where earthquakes occurred frequently and intensely, has a distinct variation characteristic of gradient zone of Bouguer gravity anomaly (BGA). Many deep faults and epicenters of severe earthquake scatter along the BGA gradient zones. Here we apply two forward models (Airy model and Vening Meinesz model) of isostatic gravity mechanisms (local versus regional) in this region to calculated the isostatic gravity anomaly (IGA). Afterwards, the relationship between IGA and distribution of faults as well as seismicity is also illustrated. The IGA results show that the two models are similar and most parts of the study area are in an isostatic state. Most featured faults are distributed along the steep anomaly gradient zones; earthquakes tend to occur in the non-isostatic area and steep gradient belt of IGA. The distribution of root thickness based on regional mechanism can be associated with the main trend of BGA variation. The regional mechanism is more plausible and closer to the reality because of its relatively further consideration of the horizontal forces derived from adjacent particles in the crust. Then we analyze the effect of isostasy on the tectonic movements and find that the isostatic adjustment is not the main cause of the continuous uplift process of Longmenshan Mountain fault zone, which is due to the Indian-Eurasian continental collision.

1. Introduction

Sichuan-Yunnan region in China is located at the south of the well-known North-South Seismic Belt (NSSB). Connecting the complicated Tibetan Plateau in the northwest and Yangtze Plate in the east, it is a tectonic boundary with a complex structure. There are three featured fault zones in this region: 1) Longmenshan Fault– the boundary of the Sichuan Basin and the Tibetan Plateau; 2) Xianshuihe Fault, Anninghe Fault, Zemuhe Fault and Xiaojiang Fault –the eastern margin of the rhombic Sichuan-Yunnan Block; 3) Jinshajiang Fault and Red River Fault– the western margin of Sichuan-Yunnan Block. In the dynamic and tectonic environment that features the northward colliding of Indian Plate with Eurasia, the north-southward squeezing and the eastward extrusion of Tibetan Plateau, this region is full of dramatical contrast of landform, intense tectonic activity and frequent severe earthquakes. Furthermore, the crustal movement in Yunnan acts as a clockwise rotation, with a trend of plateau material flow. Since the 1980s many researchers have conducted a multitude of studies on this region and achieved abundant results, especially in lithospheric structure and tectonics, deep tectonic environment as well as dynamic process of strong earthquakes. Kan et al. [1] gained the 3-D velocity structure of the crust and upper mantle in Yunnan region by means of deep seismic sounding. Kong et al. [2] and Li et al. [3] studied the electrical conductivity structure of the Panxi Rift and Longmenshan Mountain. Lou et al. [4] analyzed the subsection feature of the deep structure as well as material properties of Longmenshan Fault zone. Wu et al. [5] conducted the inverse of Moho depth in the North-South Seismic Belt.

These studies focused mainly on the structural characteristics or surveying methods, and relatively few findings discussed the features of gravity anomaly, especially the isostasy in the entire region. Focusing on the vertical movement of the crust, the isostatic gravity anomaly reflects the equilibrium status and mass distribution of

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the crust. Its variation characteristics has a correlation with tectonic movements and seismic activities [6–8]. Therefore, it is necessary to study the characteristics of isostatic gravity anomaly in this region for geophysical and seismic research.

Various methods are proposed to improve the precision of model or the speed of calculation with the evolution of isostatic theory. Isostasy has developed local (Airy model), regional (Vening Meinesz model), experimental and dynamic mechanisms since 1855 as it is applied to geodesy and geophysics. Abd-Elmotaal [9] suggested that the behavior of the Earth's crust due to topographic loads can be derived by either forward or inverse approach. Airy model and simple regional model are based on geophysical intuition to computes the model's gravity effect so they are representatives of forward models. In the inverse method, Fast Fourier Transform is widely applied to geophysical data processing, such as Parker-Oldenburg method [10–12], the experimental mechanism [13], which aim at a rapid calculation. Abd-Elmotaal [9] and Sjöberg [14] also develop the inverse theory by spherical harmonic analysis. All these inverse methods require an advance mathematical knowledge. Tenzer et al. [15,16] and Bagherbandi et al. [17] have made use of these methods for Moho depth inversion and crustal thickness modeling.

We make use of Free-air gravity data and topographic data to calculate the Bouguer gravity anomaly (BGA), root thickness and isostatic gravity anomaly (IGA) based on the Airy and Vening Meinesz forward models in Sichuan-Yunnan region. After that, these two models are compared and their advantages are displayed. Then the relationship between IGA and the faults as well as seismicity in this region is discussed. At last, the isostatic effect on the uplift process of Tibetan Plateau and its boundary, Longmenshan Fault, is analyzed with other tectonic forces.

2. Data processing and results

2.1. Data processing

The topography and gravity (Free-air gravity anomaly) data of recent years is extracted from the global satellite geodesy data (Topography – V18.1; Gravity – V23.1, 2014) maintained collaboratively by David T. Sandwell and H. F. Smith [18]. The Bouguer gravity anomaly is obtained after a couple of corrections [19]. After that, the isostatic correction related to different mechanisms can be assimilated into the gravity field. So isostatic gravity anomaly can be written as

$$\Delta g_I = \Delta g_F + (\Delta g_{BP} + \Delta g_{TC} + \Delta g_{IC}) + \Delta g_N \tag{1}$$

where Δg_I, Δg_F are isostatic and free-air gravity anomaly, $\Delta g_{BP}, \Delta g_{TC}, \Delta g_{IC}$ denote Bouguer plate, terrain (or topographic) and isostatic corrections respectively.Δg_N represents other corrections that are beyond the scope of this paper (such as adjustments for drift, tides, and network ties). Bouguer gravity anomaly Δg_B equals $[\Delta g_F + (\Delta g_{BP} + \Delta g_{TC})]$.

Formula for Bouguer plate correction is

$$\Delta g_{BP} = 2\pi G \rho_B h \tag{2}$$

where G denotes the universal gravitational constant, ρ_B stands for the density of the Bouguer plate, and h is the topographic height.

The corrections of terrain (or topography) Δg_{TC} as well as isostasy Δg_{IC} use prism volume integration formula

$$\Delta g_C = G\rho\left[x' \ln(y' + r') + y' \ln(x' + r') + z' \arctan\frac{z'r'}{x'y'}\right]\Bigg|_{x_1}^{x_2}\Bigg|_{y_1}^{y_2}\Bigg|_{z_1}^{z_2} \tag{3}$$

where ρ is the density of prism, Δg_C represents the terrain or isostatic correction (Δg_{TC} or Δg_{IC}), x', y', z', r' are parameters of prism [19].

For the isostatic correction Δg_{IC} of the two models, we need to get the thickness of root as the first step. In Airy model, the thickness of root r can be calculated directly (locally) in terms of topographic height h

$$r = \begin{cases} \dfrac{\rho_c}{\rho_m - \rho_c} h, & h \geq 0 \\ \dfrac{\rho_c - \rho_w}{\rho_m - \rho_c} h, & h < 0 \end{cases} \tag{4}$$

where ρ_c, ρ_m, ρ_w are the density of crust, mantle and oceanic water, respectively.

It is more complicated for regional Vening Meinesz model as it distributes the load of a surface feature over a horizontal distance wider than the feature (shown in Fig. 1). We choose the polynomial method to simulate the flexural curve (Fig. 2) of elastic plate [20], whose approximate parameters are listed in Table 1.

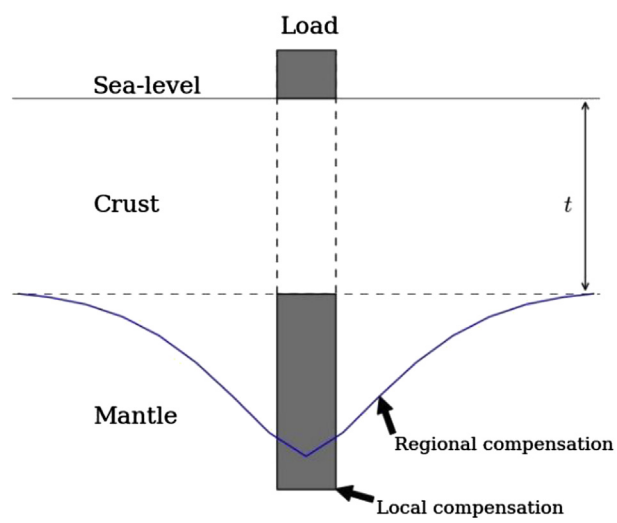

Fig. 1. Airy (local) and Vening Meinesz (regional) models.

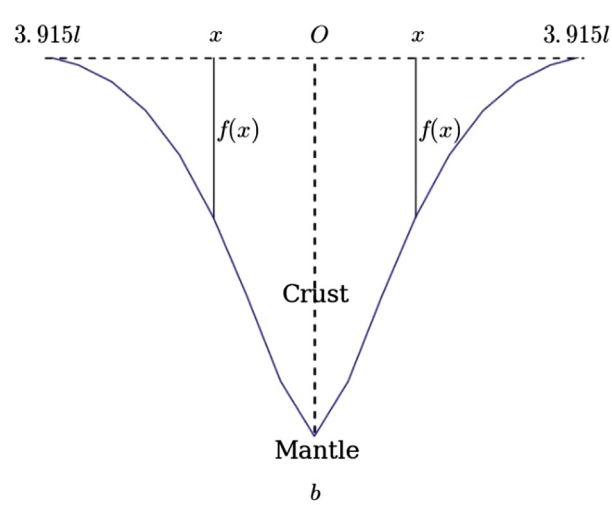

Fig. 2. Flexural curve of elastic plate (Blue line represents the curve, where x denotes horizontal distance from the load and $f(x)$ the flexure at the circle of radius x).