Estimating Moho basement and faults using gravity inversion in Yushu-earthquake area, China

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Abstract: A gravity survey was conducted one month after the 2010 Yushu earthquake in the epicenter area. The cross-fault survey line was 500 km long, from Langqian county to Qinghuai county, in a transition zone between Bayan Har block and Qiangtang block, in an area of high elevation, large undulating terrain, and complex geological features. An interpretation of the data was carried out together with other kinds of data, such as seismic exploration and magnetic exploration. The result shows that gravity is sensitive to fault boundary; the geologic structure of the region is complex at middle and upper depths, and the density profile reveals an eastward-pushing fault movement.

Key words: Moho basement; gravity; faults; Yushu earthquake; inversion

1 Introduction

The Yushu earthquake occurred on April 14, 2010 in the boundary zone between Bayan Har block and the Qiangtang block in the eastern section of the Qinghai-Tibet plateau\(^{[1]}\), where Ganzi-Yushu fault together with Xianshuihe fault constitute a high-speed sliding boundary between the Bayan Har block and the Qiangtang block, and where several devastating earthquakes larger than Ms7.0 occurred in history. GPS measurements showed that during 1999 – 2007, the fault movement was mainly left-lateral strike-slip in character, but when the earthquake was about to occur (2007 – 2009), compressive strain rate increased significantly in the west of Yushu, while the east of Yushu the fault movement was dominantly right-lateral strike-slip, implying a stress-accumulation process in the Yushu area\(^{[2]}\). In May 2010, we carried out a gravity survey across the Yushu area to study the deep crustal structure of there and the tectonic background of eastern Qinghai-Tibet Plateau for the purpose of earthquake monitoring (Fig. 1). We used the gravity data and seismic velocity-structure data and performed joint inversion to get some initial results\(^{[3]}\). As an increasing amount of data of other kinds, such as magnetotelluric and geologic data, was obtained, we conducted a more detailed analysis, and thus obtained a more refined deep structure and a better understanding of the crust movement of this area.

2 Geological sketch

The study area around Yushu is located in eastern Qinghai-Tibet plateau from 30.5° N to 35.5° N and 95°E to 101°E (Fig. 1). Being mostly higher than 4000 m in altitude, this area is geologically complex and has been undergoing intense crustal movement, as the greater region. The earthquake occurred on the
Yushu fault, which is part of the Yushu-Ganzhi-Xianshuihe fault zone. In history, many earthquakes greater than magnitude 7 had occurred along the Xianshuihe fault, which was a major active fault in the North-South Fault Zone. Earthquakes that occurred near the Bayan Har block during the past two decades include Karakoram Ms7.1 earthquake in 1996, Mani Ms7.9 earthquake in 1997, and Yutian Ms7.3 earthquake in 2008 in its western part; West of Kunlun Pass Ms8.1 earthquake in 2001 in its midwestern part; and Wenchuan Ms8.0 earthquake in 2008 in its eastern boundary zone. From the crustal-structure point of view, the Yushu earthquake occurred in the Jinsha River-Xianshuihe fault zone, which lies in the south of the Bayan Har block, under the control of its surrounding boundary faults of Xianshuihe, Ganzi-Yushu, Minjiang, and East Kunlun, as well as the Longmenshan nappe structure (Fig. 1).

3 Data acquisition and interpretation

We used CG-5 Autograv (automated gravity meter), a microprocessor-based automated meter with numerous revolutionary features made by Scintrex, to survey 290 gravity stations that covered the study area (Fig. 1) with an interval of 2 - 3 km, according to fault location, observation condition and topography. Different corrections (drift, tide, latitude, free-air, and simple Bouguer) were performed[^4]. Terrain correction was made, using three-dimensional terrain data from ASTER GDEM[^5] and USGS terrain correction software[^6], to estimate terrain effect of different zones. Based on the corrected gravity values, we used XYZGMS software to construct a complete Bouguer gravity-anomaly section. Figure 2 shows all the measured free-air and Bouguer gravity anomalies projected to the strike line (dash line in Fig. 1).

As shown in Figure 2, the free-air anomalies are obviously terrain related. The Bouguer anomalies are relatively low in the south-west and high in the northeast; both kinds of anomalies are relatively variable in the southwestern part. The abrupt changes in the profiles of Bouguer and free-air anomalies basically correspond to the locations of fault boundaries, which are from left to right (southwest to northeast): Nujiang fault, Baqin-Riwoqe fault, Zanaqu-Zhexiao fault, Ziga

![Figure 1: Location map of the study area](image-url)
Temple-Deqin fault, South Yushu-Southern Foot of Fenghuoshan fault, Ganzi-Yushu-Fenghuoshan fault, Chengduo-Qumalai-Wudaoliang fault, Zayun-Chumaerhe fault, Qingshuihe fault, Bayan Har Mountain Peak fault, Dari fault, Kunlun Pass-Jiangcuo fault, and Maduo-Gander fault. The gravity anomalies are especially obvious for Baqin-Riwoqe fault, South of Yushu-Southern Foot of Fenghuoshuan fault, Ganzi-Yushu-Fenghuoshan fault, Kunlun pass-Jiangcuo fault, and Maduo-Gander fault. The gravity anomalies show a prominent change in the Yushu seismogenic zone (coordinate 0), corresponding to Ganzi-Yushu-Fenghuoshan fault, which is the Bayan Har and Qiangtang block boundary zone. The free-air anomalies mainly reflect topography changes, whereas the Bouguer anomalies reflect the deep structure. Our results suggest that these faults extend from the surface to almost the base of the whole upper crust.

The seismic data used in this study came from a deep-reflection seismic observation along a 540 km-long profile, using 280 geophones and six shots of 3–5 tons of explosives at intervals of 10 km, and from a reflection-refraction seismic observation along a 50 km-long profile, using 220 geophones and shots of 300–500 kg of explosives at intervals of 100–300 m. We also collected some other data acquired by surface-wave imaging in this area to supplement the velocity structure.

In addition, we collected some geologic data to help us understand the rock properties, and to check gravity corrections and density conversion from seismic velocity structure. We also collected results of some other deep seismic-sounding studies as supplement to establish the layered structure in this region.

4 Inversion algorithm

We used Parker-Oldenburg iterative algorithm for Moho inversion, and the iterative error or total number of iterations as a condition to end the calculation. We set 70 km as the initial average depth of Moho, and assumed a constant value of 0.4 g/cm³ for crust-mantle density difference. The flowchart of inversion is shown in figure 3.

We used the gravity data mainly to determine the source depth of the observed anomalies. With a layered structure from seismic velocity and its geologic interpretation as initial constraint, we used iterative inversion to obtain our final result of layer locations and densities. A quantitative interpretation of gravity data was carried out through trial-and-error modeling, assuming a 2D approach. We assumed a density of 2.2 gm/cm³ for the sedimentary cover, 2.65 gm/cm³ for the basement complex, and 3.25 gm/cm³ for the basaltic layer, in accordance with the published values by Nafe-Drake formula. The result includes information
of section structure, stratum interface, lithology structure, and density distribution.

5 Result and discussion

The result of combined modeling of the gravity data is shown in figure 4. The dotted and solid lines on top of the figure represent observed and calculated gravity-anomaly values, respectively. It is evident that the gravity profiles correlate well with each other, both in response to the depth of the Moho basement.

The model in figure 4 shows such information as variations of the thickness of the sedimentary layer, the topography of stratum, and the Moho basement. With these results, we may draw a map of the depth of the basement interface and a map of the depth of the Conrad interface, which separate the granite from the deeper basaltic formations. The basement-interface map together with a sketch of the main layers reveal that the Moho basement is deeper at the southwestern part of the area, reaching a depth of 74.5 km, and shallower at the northeastern part, with a depth of 68.8 km (Fig. 5). This result agrees well with the interpretation of the seismic data in this area.
From the density-section maps shown in figure 6, we see that the shallow structure is more complex than the deep. To find out the characteristics of the crustal structure, we conducted a three-dimensional inversion, using Parker-Oldenburg iterative algorithm. High-pass and low-pass filter techniques were used to decompose the Bouguer anomaly into components related to shallower depths (residual anomalies) and those related to greater depths (regional anomalies)\(^9\).

The regional Bouguer-anomaly maps (Fig. 6, C1 to C3) indicate that the deep-seated sources are deeper in the northeastern part than the southwestern part. The uneven distribution of the density at shallow depths indicates the complexity of the structural conditions. This is in agreement with the frequent occurrence of earthquakes in this area.

![Figure 6 Regional crustal interface depth (km) inverted by Parker-Oldenburg iterative algorithm (C1-upper crust, C2-middle crust, C3-lower crust)](image)

### 6 Conclusion

The present results obtained from an integrated interpretation of gravity and seismic data basically agree with those of previous studies of seismic tomography and geology of the study area. From the tectonic point of view, the collision between Indian plate and Eurasian plate has formed Tibet plateau and is still causing the plateau to rise, to move northward, to thicken, and to shorten in the north-south direction. As a result of pushing and gravitation, materials in the region tend to migrate to the surrounding regions, but this migration has been strongly confined by some relatively rigid blocks (Ordos block, South Block Sichuan Basin, North China Block, etc.), thus forming the foreland basins and large-scaled shear zones in the eastern-edge region of the Qinghai-Tibet Plateau, including Bayan Har block and Longmenshan thrust belt. Yushu earthquake, like Wenchuan earthquake, was caused by crust materials’ eastward creeping while Indian plate was embedding beneath Tibet due to the expansion of the Indian Ocean ridge. The Tibetan Plateau is a collection of multi-block collage since Mesozoic-Cenozoic;
it includes rigid blocks from Precambrian basement as well as fold belts and the suture lines of closed ocean basin. This “alternately hard and soft” composition is very conducive to block movement. The recognition of “block movement and collision-induced earthquake” should provide a good line of thought for the study of Chinese earthquakes, especially those around the Tibetan plateau.

Through the interpretation of the gravity data, we can identify the trends of fault movement (red arrows in Fig. 4). However, this two-dimensional profile reveals only a certain amount of approximate information. Since a better recognition of the overall crustal movement in this seismically active region is important for understanding the process of earthquake preparation/generation, we plan to follow up with more work in this region by including more geophysical data.

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References