Forward Simulation of Gravity for Crustal Structure of Xiachayu-Gonghe Profile in Eastern Tibetan Plateau

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Abstract The crustal structure of Xiachayu-Gonghe geophysical profile in eastern Tibetan plateau is simulated with Bouguer anomaly corrected for sediments and lithosphere. The forward simulation shows that the thickness of upper crust in eastern Tibetan plateau is about 20 km, and the density is 2.78×10³ kg/m³. The bottom interface of middle crust changes from 30 km to 40 km, the density of middle crust is 2.89×10³ kg/m³. The materials with low density of 2.78×10³ kg/m³ exist in middle crust, and those with high density of 3.33×10³ kg/m³ exist at the bottom of middle crust between Wenquan and Tanggemu. The density is 3.10×10³ kg/m³ in lower crust. The shallowest depth of Moho interface is about 56 km, and the deepest one is about 74 km, the undulation of interface is large, the deep Moho is located in Xiachayu, Chayu, Nujiang, and Wenquan. The crustal density of eastern Tibetan plateau is larger than that of central section; the low velocity layers are located in middle crust and bottom in eastern Tibetan plateau and at the bottom of the upper crust in the central plateau.

Keywords crustal structure; Tibetan plateau; gravity; forward simulation

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Introduction

The Tibetan plateau is the most outstanding natural laboratory and an active research area for demonstrating the lithospheric structure, orogenic mechanism, and continental geodynamics. The continent-continent collision between the Indian and Eurasian plates starting in the early Cenozoic has resulted in an average topographic elevation up to 5000 m, the crustal thickness changes from 35 km to 80 km,[1] and a lot of earthquake events occurred. The geodetic measurements confirm that the Himalaya terrane is presently continuing its uplift at an average speed of 7.6±5.2 mm/yr, and the Tibetan crust reveals permanent extension at a speed of 9.7±3.0 mm/yr.[2-4] A lot of results about the crustal and lithospheric structures of Tibetan Plateau have been made,[5-9] especially about the velocity structures from the seismic investigations.[10-12]

The gravity investigations of Tibetan plateau focused on the crustal thickness, the structures of Moho interface, the crustal density structures, and the flexure and the effective elastic thickness. Meng et al.[13] computed the Moho depth and isostatic anomalies according to Pratt’s Hypothesis based on the gravity
measurements of 202 stations along the Yadong-Golmud profile, and the isostatic information of the crust and upper mantle were analyzed. Lu et al.\[14\] simulated the Moho shapes with gravity data constrained by the seismic reflection data, analyzed the PKP residual variations along the central Tibetan profile, and found that the Moho steps are the common features beneath the Tibetan Plateau. Wang et al.\[15\] used the gravity data to discuss the crustal structure of Jilong-Lugu region in western Qinghai-Xizang (Tibetan) plateau. Meng et al.\[16\] calculated and analyzed the Airy isostatic anomalies and Moho depth based on the gravity field characteristics along Algan-Laomangya and Golmud-Ejin Banner geoscience transections and divided the study area into 5 second-order tectonic units with 11 relative large faults. Kong et al.\[17\] and Braitenberg et al.\[1\] inverted the three-dimensional Moho depth with gravity data in Tibetan plateau. Shin et al.\[18\] obtained the Moho undulation with GRACE-integrated gravity data. Fang and Xu\[19\] inverted the three-dimensional lithospheric density structures through combining the gravity data and three-dimensional tomographic inversion results of shear velocity in Qinghai-Tibet region. Hélène and Peter investigated the structures of western Tibet and the southern Tarim basin with gravity anomalies\[20\] and discussed the structure of the Himalaya by way of an analysis of gravity anomalies and a flexural model of the lithosphere.\[21\] Braitenberg et al.\[22\] investigated the Tibet-Quinghai plateau and the Tarim basin in terms of spatial variations of the elastic thickness in the frame of the thin plate flexure model. Jordan and Watts\[23\] used Bouguer gravity anomaly and topography data to determine the equivalent elastic thickness of the lithosphere in the region of the India-Eurasia collisional system.

There are three comprehensive geophysical profiles about the crustal structures of Tibetan plateau with gravity data (Fig.1), namely, Jilong-Lugu-Sangehu profile\[15,24,25\] in the western Tibetan plateau, Yadong-Golmud Geoscience Transection and Golmud-Ejin Qi Transection\[13,14,16,26\] in the central Tibetan plateau, and Xiachayu-Gonghe profile\[27,28\] in the eastern Tibetan plateau. There are many research papers focused on the Yadong-Golmud Geoscience Transection, but few persons know about the crustal structure of eastern Tibetan plateau, which is a key area for a series of scientific research on eastward mass flow of Tibetan plateau.\[29-30\] A geophysical profile was surveyed along the Xiachayu-Maduo-Gonghe of eastern Tibetan plateau by the Institute of Geology and Geophysics, Chinese Academy of Sciences, in 2000 (Fig.1). This profile cuts the Bangonghu-Nujiang-East Kunlun Suture and crosses the Lhasa, Qiangtang, Songpan-Ganzi, and East Kunlun terranes. Therefore, the profile is as important as the Yadong-Golmud Geoscience Transection for investigating the uplift mechanism and mass eastward flow of Tibetan
plateau. The detailed crustal layer models have been obtained in central and western profiles, but no detailed model about the eastern profile is given, although the Moho depth has been obtained with gravity data by Wang et al.\cite{27} and Liu et al.\cite{28}

In order to investigate the characteristics of crustal structure in eastern Tibetan plateau, the model of Xiachayu-Gonghe profile is simulated with Bouguer gravity anomaly data to demonstrate the crustal layered structure and density distribution in the eastern Tibetan plateau.

1 Forward simulation of gravity data

1.1 Correction of gravity data

The gravity data are Bouguer anomalies, wherein a complete terrain correction was made using a topographic density of $2.67 \times 10^3$ kg/m$^3$.\cite{1} The effects of sediment and lithosphere are removed from the Bouguer anomalies.

The gravity anomalies from the sediment and lithosphere are calculated by the Parker’s method.\cite{31} The dataset of 30 arcmin $\times$ 30 arcmin sedimentary thickness is based on a collection of different data, mainly seismic investigations.\cite{1,18} In the gravity calculation of sediment correction, the density contrast and the reference depth are $-0.2 \times 10^3$ kg/m$^3$ and 4 km, respectively.\cite{32} The lithospheric thickness data of $2' \times 2'$ from seismic tomography\cite{33} are employed for the lithosphere correction. The density contrast of lithosphere to asthenosphere and the reference depth are $0.04 \times 10^3$ kg/m$^3$ and 100 km, respectively.\cite{1,22} The calculated gravity anomalies from the sedimentary and the lithospheric undulations are removed from the Bouguer gravity anomalies. The residual gravity anomalies with the corrections of the sediment and the lithosphere are used for forward simulation of gravity in the eastern Tibetan plateau (Fig.2).

1.2 Reference model

The software IGMAS (Interactive Gravity and Magnetic Application System), which was developed by Hans-Jürgen Götte and Sabine Schmidt, is used for forward simulation of gravity. IGMAS is an interactive, graphical computer system for interpretation of potential fields (gravity and magnetics) by means of numerical simulation.\cite{34} The modeling procedure is based on ‘trial and error’ methods. The algorithm used for potential field calculation bases on triangulated polyhedrons.\cite{34} IGMAS has already been used in some studies.\cite{35}

A reference model is constructed and overlaid in the crustal structure model. The gravity anomaly from the interface undulation and density variation is related
1.3 Model of crustal structure

The P-wave velocity structures and crustal layered model from the results of wide-angle reflection seismic interpretation are used for reference. Through modifying the interface depth and density values, the modeled gravity anomalies are calculated to fit the residual Bouguer anomalies, the detailed crustal layered model, and density model are simulated, as shown in Fig.4, of which the dotted line is the measured gravity, and the dashed one is the calculated gravity from the model.

2 Discussion

The difference of the result from the gravity simulation compared with the preliminary layered model of seismic interpretation is the shape of the Moho interface. The wide-angle reflection seismic interpretation shows that the downbowing Moho interface is located at positions of distances of 420 km and 800 km; the undulations are not large at other regions. The model from the gravity simulation demonstrates that the undulation of Moho is large, and the Moho interfaces are deep in Xiachayu, Chayu, Nujiang, and Wenquan.

The model is recalculated without considering the low velocity layers and high velocity bodies at Xiachayu-Gonghe profile (Fig. 5). The result shows that the gravity anomalies from the low velocity layers and high velocity bodies are about $(10-40)\times10^{-5}$ m/s², and the maximal value is 10 percent of total gravity anomalies.

The crustal structure of this profile from the gravity simulation demonstrates that the thickness of the upper crust in the eastern Tibetan plateau is about 20 km, and the density is $2.78\times10^3$ kg/m³. The bottom interface of middle crust changes from 30 km to 40 km, and the density of middle crust is $2.89\times10^3$ kg/m³. The materials with low density of $2.78\times10^3$ kg/m³ exist in middle crust, and those with high density of $3.33\times10^3$ kg/m³ exist at the bottom of middle crust between Wenquan and Tanggemu. The density is $3.10\times10^3$ kg/m³ in lower crust. The shallowest depth of Moho interface is about 56 km, and the deepest one is about 74 km; the undulation of interface is large, and the deep Moho is located in Xiachayu, Chayu, Nujiang, and Wenquan.

The comparison of models between the Xiachayu-Gonghe profile in eastern Tibetan plateau and the
Yadong-Golmud profile in central Tibetan plateau shows that the crustal density of eastern Tibetan plateau is larger than that of central section, and the low velocity layers are located in the middle and bottom crusts of the eastern Tibetan plateau and at the bottom of upper crust in the central Tibetan plateau.

3 Conclusion

As one of the three important comprehensive geophysical profiles in Tibetan plateau, the Xiachayu-Gonghe profile is investigated in detail with gravity data. The model of this profile from the gravity forward simulation demonstrates the detailed crustal structure, Moho undulation, and density distribution. The result shows that the low velocity layers and high velocity bodies exist in the eastern Tibetan plateau.

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