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Determination of mantle upwelling rate beneath Taiyuan basin by using absolute gravity, GPS, groundwater and GLDAS data

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ABSTRACT

The Taiyuan basin is in the Shanxi rift system of China. Results of tectonic studies indicate that the Moho is uplifted by 2–3 km under the Taiyuan basin. However, there is no quantitative evidence showing whether the rift is still in the status of mantle upwelling. Herein, we estimated mantle upwelling rate of Taiyuan basin by using absolute gravity, GPS, groundwater and GLDAS data in this paper. In order to utilize the absolute gravity measurements in terms of tectonic study it is necessary to reduce all disturbing environmental effects. Many of those can be modeled, such as tide, polar motion, ocean tidal loading and atmospheric mass components. The Taiyuan station located in the Taiyuan basin, and absolute gravity measurements with a FG5 instrument were performed from 2009 to 2014, a secular trend was obtained. In-situ GPS data was used to estimate the vertical motion rate since 2011, and the result indicated a land subsidence. In-situ groundwater level was collected with daily surveys from 2009 to 2015, and local hydrology impact on effect was made. The global terrestrial water storage loading effect on gravity at Taiyuan station was computed by using GLDAS global hydrology model. Furthermore there is a good agreement between GRACE results and GLDAS hydrological model results. Subtracting the gravity change rate attributable to the land subsidence, groundwater level and global hydrology from the absolute gravity change rate, the residual gravity change rate was obtained. It reflects mantle upwelling about 2.1 ± 2.6 cm/yr beneath Taiyuan basin.

1. Introduction

Temporal gravimetry is an efficient tool to monitor mass transfer, such as those implied by crustal uplifting and crustal thickening (Sun et al., 2009), volcanic reservoir charge (Battaglia and Segall, 2004), ground water movements (Longuevergne et al., 2010; Jacob et al., 2010). The physical principle is that changes in the gravity value are due to changes in mass distribution and vertical displacement. As every geodetic quantity, gravity variations integrate different processes. The challenge therefore relies in separating the contribution of each process in the measured signal. The method of removing unwanted signals is to model each source individually: Earth tide, air pressure changes, polar motion, global and local hydrology, and others. What remain are residuals, typically the focus of a particular study. Absolute gravimeters reached a precision about of 2.0 μGal (Niebauer et al., 1995). The feature makes AG the very important tool in geophysical and geodynamics studies. The impact of environmental effects on gravity measurements is needed to be taken into account.

Taiyuan basin is in the central part of the Shanxi Rift system which located in the east margin of the Ordos block. It is well known for its intense neotectonics and strong earthquakes, standing between longitudes 111.5°–113°E and latitude 37°–38°N, is a typical Cenozoic fault basin and bounded by two major faults named Jiaocheng and Taigu located on the northwest and southeast, as showed in Fig. 1. The two faults are formed by a series of NE-striking high-angle normal faults which control the formation and development of the basin (Guo et al., 2007). GPS, leveling and SAR measurements indicate the land extent and subsidence in the Taiyuan basin (Wang et al., 2001; Ma et al., 2006; Zhu et al., 2013). Evolution of the Shanxi Rift system of northern China is thought to have been governed by regional stress fields which developed in conjunction with the collisional interaction of the Indian and Eurasian plates. The most likely mechanism for explaining rifting is flexural bending of the lithosphere due to an isostatic load resulting from necking of the lithosphere. The lower part of the crust is plastically attenuated, and faults are formed only in the upper layer of the crust. The Cenozoic mantle upwelling might control the formation and evolution of the Shanxi rift (Xu and Ma, 1992).

Slant-stacking and migration images of receiver functions reveal uplift about 4–6 km of the Moho in the Shanxi rift. The Moho is uplifted by 2–3 km under the Taiyuan basin (Tang et al., 2010). The Taiyuan basin region might have experienced mantle upwelling since the Cenozoic time. The hot mantle heated the upper mantle and the crust, which caused the large-scale mid and lower crust slow velocity and negative gravity anomaly (Guo et al., 2015).

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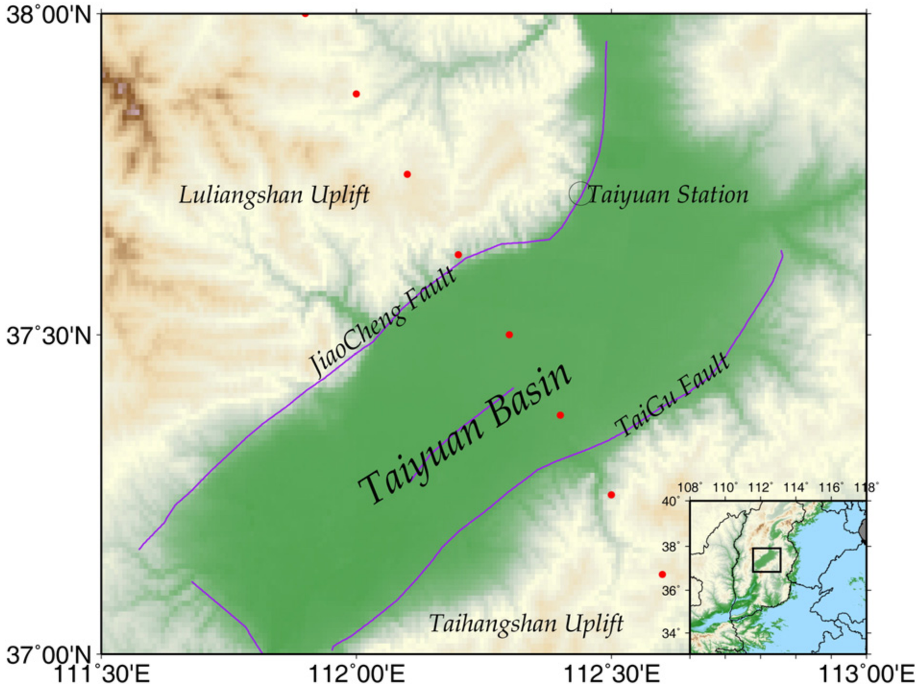

Fig. 1. Topography and tectonic sketch maps of study region. The Taiyuan station is marked as black circle. The purple lines are active faults. The red circle denotes the gravity profile.

The Bouguer gravity anomaly of the profile used here, derived from the EGM2008 spherical harmonic coefficients (Pavlis et al., 2012), was downloaded from the webpage of BGI (http://big.omp.obs-mip.fr). The gravity profile, given in Fig. 2, crosses the Taiyuan basin in the Shanxi rift. The southeast-ward positive gravity trend is about 0.2 mGal/km. Broad residual positive anomalies are associated with the Luliangshan uplift and Taihangshan uplift. A sharp negative anomaly in the Taiyuan basin reveals the thinning of the lithospheric plate and upward expansion of the asthenosphere.

For the interpretation of the gravity profile, we can use modern geodesy method to determine the upward expansion of Moho surface/mantle upwelling in quantity, and this is the primary goal of this paper. A research project was undertaken from 2009 by China Earthquake Administration. The project, including one absolute gravity station performed every year from 2009 to 2015, with in-situ continuous GPS and groundwater level measurements.

This study presents geodetic evidence of the decreasing crustal thickness by gravity observation at the Taiyuan station: a gravity change can reflect material transport accompanying vertical movements at the surface and on the crustal bottom. The vertical displacement, local and global hydrology changes add additional gravity changes at the surface to isolate the signal from mass change. As the bottom of crust is uplifting, the mass beneath the station is increasing because crust is displaced by mantle, causing a reduction in gravity. In-situ continuous GPS and groundwater measurements reveal land subsidence and rise of groundwater level, and a positive absolute gravity change rate is shown. Removing the contribution of surface vertical displacement and hydrology, including groundwater and terrestrial water storage, residual gravity change rate reflects the interior mass distribution.

2. Absolute gravity measurements

Each absolute gravity measurement was performed by using the FG5-232 gravimeter. Each survey consisted of 25 h of repeated measurements. Each measurement included 25 sets, and each set included 100 free-fall drops. A single drop was made at interval of 10 s. In total, 2500 drops were collected.

To minimize computational biases, a common processing scheme for the data analysis has been adopted, ensuring consistency with respect to model and setup parameters. All raw gravity observations were

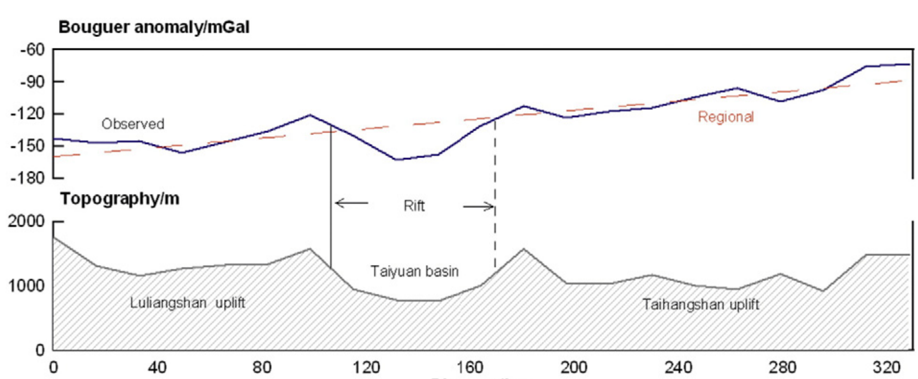

Fig. 2. Bouguer and topographic profiles crossing the Taiyuan basin and extending across the Shanxi rift.