Crust-mantle density distribution in the eastern Qinghai-Tibet Plateau revealed by satellite-derived gravity gradients

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INTRODUCTION AND GEOLOGICAL SETTING

As the highest, largest and most active plateau on Earth, the Qinghai-Tibet Plateau has a complex crust-mantle structure, especially in its eastern part. In response to the subduction of the lithospheric mantle of the Indian plate, large-scale crustal motion occurs in this area. Knowledge of crust and upper mantle density distribution allows a better definition of the deeper geological structure and thus provides critically needed information for understanding the underlying geodynamic processes.

Our research confirmed that GOCE (Gravity field and steady-state Ocean Circulation Explorer) mission products with high precision and a spatial resolution better than 80 km, can be used to constrain the crust-mantle density distribution.

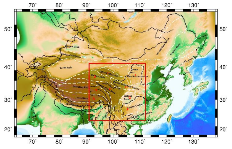


Figure 1. Localization of the Qinghai-Tibet Plateau

In the eastern part of the Tibetan Plateau,
there are five major crustal blocks as:
A Lhasa,
B Qiangtang
C Songpan–Ganzi
D Kunlun–Qaidam
E Qilian Shan terranes

To the east of Tibetan Plateau ,
there are four major crustal blocks as:
F Yangtze Craton
G Sichuan Basin
H Qinling Dabie Fold System

2

DATA PRESENTATION: GRAVITY GRADIENT MEASUREMENTS AND MODELING CONSTRAINTS BY TOMOGRAPHIC DATA

Gravity Gradient Anomaly
(spherical harmonic expansion)

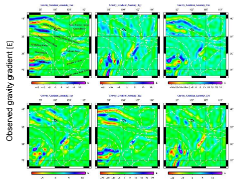


Figure 2. Gravity Gradient Anomaly
Calculated from the spherical harmonic expansion
model GO CONS GCF 2 TIM R5
(http://www.esa.int
http://icgem.gfz-potsdam.de/ICGEM/)

Data characteristics:
- GOCE-only solution
- Grid spacing of 80 km (N = 250)
- Uniform sampling
- Calculation height 10 km

Tomographic Data
(Yang (2012) Tibet Vs Model + LLNL-G3Dv3 Vp Model)

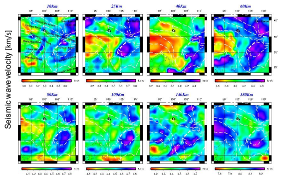


Figure 3:Seismic wave velocity of the Eastern Tibetan Plateau (1°x 1°).
(Yang（2012）Tibet_Vs Model for 10-140 km interface + LLNL-G3Dv3 Vp Model for 180 km interface)

The density of the lithosphere is temperature, pressure dependent, with the relationship with P,S wave as:

$$\rho=\begin{cases}2.78+\Delta\rho & (6.0\ge v_p\ge 5.5)\\ 3.07+\Delta\rho & (7.5\ge v_p\ge 6.0)\\ 3.22+\Delta\rho & (8.5\ge v_p\ge 7.5)\end{cases}\qquad \Delta\rho=\begin{cases}0.59(v_p-6.0) & (6.0\ge v_p\ge 5.5)\\ 0.29(v_p-7.0) & (7.5\ge v_p\ge 6.0)\\ 0.20(v_p-7.5) & (8.5\ge v_p\ge 7.5)\end{cases}\qquad v_p=v_p/v_s\times v_s$$

(Feng et al. 1986)

Average crustal Vp/Vs= 1.73 for eastern Tibetan Plateau

3

TOPOGRAPHIC, ISOSTATIC, SEDIMENT REDUCTION

Gradient anomalies are the integrated response to interface undulations and subsurface density heterogeneities. The contribution of topographic masses above the sea level and the isostatic Moho interface and density changes in sedimentary deposits need to be removed before the inversion.

a)

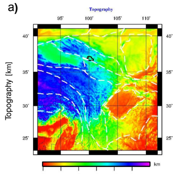


Figure 3a:Terrain from Topo30
(http://www.esa.int
http://icgem.gfz-potsdam.de/ICGEM/)

b)

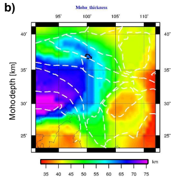


Figure 4a: Moho depth (Li, 2006)

D

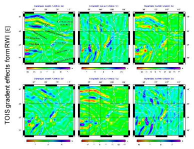


Figure 6:Topographic and Isostatic gradient effects calculated from RWI 2012 (Grombein et al., 2013; 2014)

A

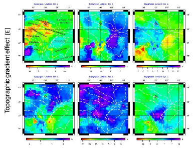


Figure 3A:Topographic gradient effects
calculated from tesseroids-1.1.1 (Uieda)
Observation height: 10km; Spacing: 5'*5';Reference depth: Geoid;
Density constrast: 2670 kg/m³ for the land and 1640 kg/m³ for the sea
after the filter by GMT with the radius = 480km

B

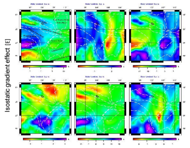


Figure 4A:Isostatic gradient effects
calculated from tesseroids-1.1.1
Observation height: 10km; Spacing: 0.25*0.25 degree
Reference depth: -35km; Density contrast: 420 kg/m³

C

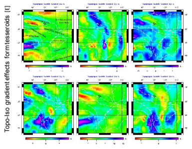


Figure 5:Topographic and Isostatic gradient effects
calculated from tesseroids-1.1.1
after the filter by GMT with the radius = 480km

c)

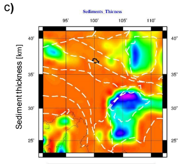


Figure 7: Sediment thickness model from crust1.0

E

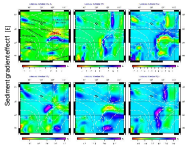


Figure 9a:Sediment gradient effects
calculated from tesseroids-1.1.1
Observation height: 10km; Spacing: 1°*1°
Density contrast: -200 kg/m³

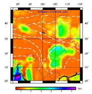
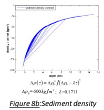


Figure 8b:Sediment model



$\Delta\rho(z)=\Delta\rho_0^3/(\Delta\rho_0-\lambda z)^2$
$\Delta\rho_0$=-500 kg/m^3 ; λ=0.1711

Figure 8b:Sediment density
contrast decrease with
the depth curve
after Silva (2014)

Density changes with depth
in sedimentary deposits
should not be ignored!

F

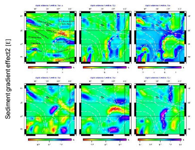


Figure 9b:Sediment gradient effects
calculated from tesseroids-1.1.1
Observation height: 10km; Spacing: 1°*1°
Density contrast decreases with depth (see fig.8b)

4

RESIDUAL GRADIENTS

G

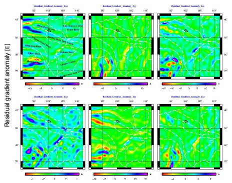


Figure 10:Residual gradient anomaly

$$T_{res}=T_{obs}-T_{topo}-T_{moho}-T_{sed}$$

Residual gradient anomaly
Observed gradient anomaly
Topographic gradient effect
Isostatic gradient effect
Sediment gradient effect

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DENSITY INVERSION OF THE GRAVITY GRADIENTS BASED ON SEISMIC DATA

The numerical model is composed of rectangular blocks, each of which has a uniform density, with widths of about 100 km and variable thickness and depths. The thickness of the rectangular cells changes from 10 to 60 km in accordance with the seismic model. The calculation seeks for a least squares solution, with available prior shape constraints given by seismic wave velocity data.

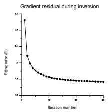

Figure 13: Gradient residual during inversion

Residual gradient anomaly
Density contrast

$T_{\alpha\beta}=\sum G^{i}_{\alpha\beta}\rho^{i},\ \alpha=x,y,z;\ \beta=x,y,z$

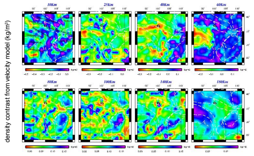

Figure 11: Starting density contrast

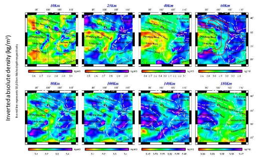

Figure 12: Inverted absolute density. Conversion from density contrast to absolute values see Panel 2.

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DISCUSSION AND CONCLUSION

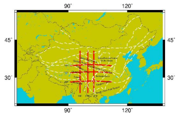

Figure 14: Location of the NS and EW sections of final density model

a)

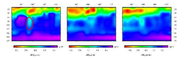

Figure 15a: EW sections

b)

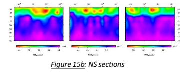

Figure 15b: NS sections

DISCUSSION

1) Accomplished preliminary inversion of GOCE gradients. Method was tested on synthetic crustal model
2) Seismic Vs tomography is constraint down to 140km depth,
below Vp layer up to 180 km depth
3) Seismic constraint gives starting density model
4) Gradient isostatic residuals are inverted. Starting density model is modified through inversion
5) Density contrasts are converted to absolute densities referring to starting tomography values

RESULTS

1) Cratonic lithosphere of China and India plate
has low density below 100km depth.
2) Thick crust of Tibet is layered. Mid crust of Qiang Tang block and
part of Lhasa block have reduced density
3) Further work must be done to cross check results and test influence
of starting model on final result

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