A geophysical perspective on the lithosphere-asthenosphere system of the Qinghai-Tibet plateau and its adjacent areas

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The Tibetan Plateau and the North China Craton (NCC), two key areas in mainland China, offer excellent laboratories to understand continental tectonics over a broad span of Earth history. Particularly, the deep structure of the lithosphere as imaged from geophysical data on the Tibetan Plateau and the NCC provide important clues in understanding orogeny and cratonization. The Tibetan Plateau is the largest and highest plateau on Earth in terms of mean altitude, and it is an important region for understanding the mechanisms of continent–continent collision and Cenozoic plateau uplift. The NCC is an Archean craton that underwent lithospheric disruption during the Mesozoic. Here we reconstruct the main features of the structure of the crust and upper mantle from surface wave tomography and gravity modeling in Tibet and its neighboring regions, as a clue to understand the modality of the convergence and collision process between the Indian and Eurasian plates, and the influence of this process on the uplift of the plateau. In the NCC, geological, geochemical, geophysical and tectonic investigations demonstrate that lithospheric destruction mainly occurred in the Eastern Block.

Data and method

The 3D model is obtained through the ensemble of cellular models expressed in terms of shear waves velocity (V_S), thickness and density of the layers, to a depth of 350 km. These physical properties are obtained by means of advanced non-linear inversion techniques, such as the "hedgehog" inversion method of group and phase velocity dispersion curves for the determination of V_S (e.g. Panza et al., 2007 and references therein) and the non-linear inversion of gravity data by means of the method GRAV3D (Li and Oldenburg, 2008). The "hedgehog" method allows for the definition of a set of structural models without resorting to any a priori model, considering the V_S and the thickness of the layers as independent variables. Given the well-known non-uniqueness of the inverse problem, the representative solution of each cell is determined through the application of optimization algorithms (Boyadzhiev et al., 2008) and is also validated with the use of independent geological, geophysical and petrological data.

Results

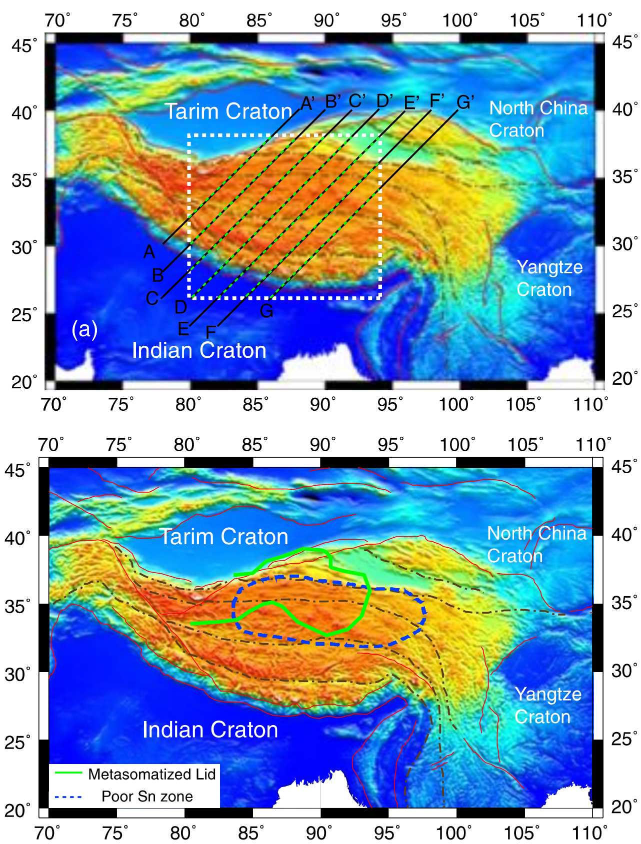
From the 3D density structure beneath the Tibetan Plateau, a 3D gravitational potential energy (GPE) map can be constructed (e.g Zhang et al. 2014, Deng et al., 2014). The GPE difference with respect to the average GPE to the depth of 350 km under the Tibetan Plateau along seven sections, A-A, B-B, C-C, D-D, E-E, F-F, and G-G, is shown in Figure 1a. Along most of these NE-SW sections not only the distribution in space of Vs and ρ but also that of the GPE difference evidence that, in some instances, the subducted lithosphere is less dense than the ambient rocks, and thus, the lithosphere cannot be driven by its negative buoyancy (i.e., slab pull). Therefore, the subduction process requires the presence of another dynamical force that is able to drag the upper plate lithosphere over the Indian plate. These observations highlight that the top asthenosphere (LVZ) acts as the lithosphere base decoupling, and the underlying mantle should flow NE-ward to SE-ward along the tectonic mainstream (e.g. see Panza et al. 2010).

The Vs absolute tomography (Foulger et al., 2013) and the density (ρ) models of the crust and upper mantle (to about 350 km depth) demonstrate the lateral variation of the thickness of the metasomatic lid (see Figure 1b) between the south and north of the Bangong–Nujiang suture (BNS) and the west and east of Tibet, which suggest that the leading edge of the subducting Indian slab reaches the BNS. The subduction angle of Indian Plate indicates a transition from steep to shallow from the west to east Tibet.

Cite as: Romanelli, F. and Panza, G.F., 2014, A geophysical perspective on the lithosphere-asthenosphere system of the Qinghai-Tibet plateau and its adjacent areas, in Montomoli C., et al., eds., proceedings for the 29th Himalaya-Karakoram-Tibet Workshop, Lucca, Italy.

Both Vs and ρ models suggest the following: (1) north–southward lower-crust flow beneath the eastern NCC and interaction between the westward mantle flow and eastward escape flow beneath the central NCC (in addition to the earlier proposed mechanisms of delamination and thermal erosion) played important roles in the lithospheric disruption of the Archean craton; (2) mantle flow plays an important role in the continental tectonic transition between neighboring tectonic blocks and within the cycle between orogeny and cratonization.

The direction of the Himalaya subduction is along the trend of the tectonic equator that deviates from NE to SE moving from India to China as indicated both by plate motions in the last 50 Ma and the GPS data in the no-net rotation and net rotation reference frameworks (e.g. Panza et al., 2010). Therefore, the W-E extension in the Tibetan Plateau is compatible with the global flow of plates, and it may be related to the back-arc extension operating along the western margin of the Pacific realm and not necessarily to tectonic escape.



a)

b)

Figure 1. a) Spatial distribution of seven sections labeled A-A′, B-B′, C-C′, D-D′, E-E′, F-F′, and G-G′ in black lines. All of these sections were constructed from Vs cellular models (e.g. Zhang et al., 2014). The dashed white rectangle denotes the region wherein density inversion has been made. The tectonic units are: ID, Indian Craton; QDM, Qaidam Basin. AST, Asthenosphere.
b) Spatial distribution of the metasomatic lid in the Tibetan Plateau.

Acknowledgments

We thank all co-authors (see references) for their contribution and we acknowledge partial financial support from PRIN 2011- 2010PMKZX7 (MIUR) and from PNRA projects 2004/2.7-2.8, 2009/A2.17.

References

Boyadzhiev, G., Brandmayr, E., Pinat, T. and Panza, G.F., 2008, Optimization for non linear inverse problem. Rendiconti Lincei: Sci. Fis. e Nat., 19, 17-43.

Deng, Y., Panza, G.F. Zhongje, Z., Romanelli, F., Ma, T., Doglioni, C., Wang, P., Zhang, X. and Teng, J., 2014. Transition from continental collision to tectonic escape? A geophysical perspective on lateral expansion of the northern Tibetan Plateau, Earth, Planets and Space, doi:10.1186/1880-5981-66-10.

Foulger, G.R., Panza, G.F., Artemieva, I.M., Bastow, I.D., Cammarano, F., Evans, J.R., Hamilton, W.R., Julina, B.R., Lustrino, M., Thybo, H. and Yanovskaya, T.B., 2013, Caveats on tomographic images. Terra Nova, 25, 259-281.

Li, Y. and Oldenburg, D.W., 1998, 3D inversion of gravity data, Geophysics, 63, 109-119.

Panza, G.F., Doglioni, C. and Levshin, A., 2010, Asymmetric ocean basins. Geology, 38, 59-62. 10.1130/G30570.1

Zhang, Z., Teng, J., Romanelli, F., Braitenberg, C., Ding, Z., Zhang, X., Fang, L., Zhang, S., Wu, J., Deng, Y., Ma, T., Sun, R. and Panza, G.F., 2014, Geophysical constraints on the link between cratonization and orogeny: Evidence from the Tibetan Plateau and the North China Craton, Earth-Science Reviews, 130, 1-48, ISSN 0012-8252.