

The Thermal and Rheological Structures of the Lithosphere of Tibetan Plateau

Yang Wang¹

¹ School of Earth Science and Resources, China University of Geosciences, Beijing, China
allen_thalassa@sina.com

The local isostasy analysis is used to constrain the lithosphere temperature distributions of the Tibetan plateau to avoid the difficult from the biased geographic distribution and intrinsic errors of some heat flow observations. Relative topographic variations, assuming local isostasy and taking into account density variations due to thermal expansion in the lithospheric mantle, can be used to constrain the vertical distribution of temperature within the lithosphere (geotherm). Assuming local isostatic conditions, the absolute elevation of a given lithospheric column is determined by comparing its buoyancy force with that of the reference column at the mid-oceanic ridges. The geotherm calculation procedure adopts a five-layer model, consisting of a sedimentary layer (where present), an upper crust, an upper lower crust, and the lowermost crust, as well as, the lithospheric mantle layer. The heat production is assumed as stepwise distributions with depth. The thickness of crust and its sub-layers are obtained from a one by one latitude-longitude grid crustal Vp model of the Tibetan plateau and its adjacent region. The mean elevation of each grid derived from the ETOP5 model is used as the fitting target in this study. The trial-and-error method is applied to search the surface heat flow value and obtain a minimum misfit of the elevation in each grid. The sensitivity analysis shows that the Moho temperature is relative insensitive to the 3-km variation of the crustal thickness, either are the temperatures at 40-km and 70-km depths. The maximum variation of temperature at 40-km depth is less than 25°C. Meanwhile the maximum variation of temperature at 70-km depth is less than 50°C, and is consistent with the accuracy of the downward continuation calculation for geothermal modelling. However, the lithosphere thickness is relatively sensitive to the crustal variation, because of the significant density contrast between crust and mantle. In most cases, a 3-km variation of crustal thickness causes a 9% to 16% depth change of the LAB.

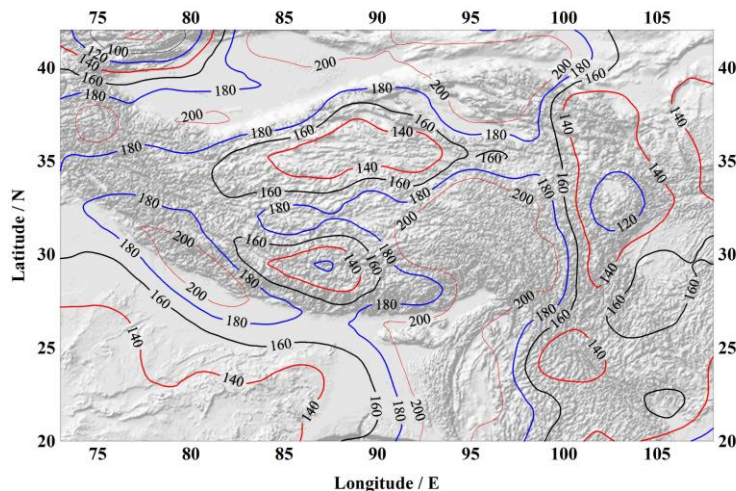


Fig.1 Lithospheric thermal thickness beneath the Tibetan plateau and adjacent areas.

The thickness of the thermal lithosphere defined as the conductive layer above the adiabat with a potential temperature of 1300°C, is more than 120 km in the Tibetan plateau (Fig.1). The lithospheric bulge in the eastern Tibet has thickness of 200 - 240 km. The lithosphere beneath the Qilianshan fold belt is 200 km thick or more. The thicker lithosphere (160 - 180 km) also occurs beneath the Tarim and the Sichuan basins. However, the thinner lithosphere (<140 km) occurs beneath northern Tibet and the eastern margin of the Tibetan plateau (east of 100°E median). The lithospheric thermal thickness of the Tibetan plateau attained by this study is consistent with seismic studies. The agreement between thermal modelling and seismic studies means that the geotherms constructed by the local isostatic equilibrium constraint are reliable.

The lithosphere for the Tibetan plateau is much hotter than that of its surrounding regions. At the same depth, the temperature difference between the tectonically active Tibetan plateau and its surrounding stable regions is greater than 200°C. For example, the temperatures at 40 km depth are higher than 800°C under the major portion of the Tibetan plateau, but lower than 600°C under the Tarim basin. The highest value of Moho temperature within the Tibetan plateau reaches 1200°C. This result confirms that the entire lithosphere of the Tibetan plateau is hot as suggested by a significant number of geophysical and geological observations. The thick but warm lithospheres under the Tibetan plateau, and the Qilianshan fold belt correspond to the shortening caused by the convergence of the Indian and the Eurasian plate. The thickened lithospheric mantle can cause a disturbance to the rheologically stratified system, which induces Rayleigh-Taylor instability with the denser layer descending as a viscous drop and finally results in the convective thinning of the lithospheric mantle in convergent environments. According to seismic evidence, it is suggested that the lithospheric mantle beneath the Tibetan plateau has undergone some form of instability that has led to asthenospheric replacement of some part of the lithospheric mantle, and the basaltic volcanism erupted since *ca.*10 Ma, especially in the northern Tibet, also implies a thinner lithosphere in the northern Tibet. Therefore, the results of our geothermal modelling confirm the argument that the current structure of the lithosphere beneath the Tibetan plateau is a snapshot of the early stages of lithosphere instability.

Adopting estimates for tectonic strain-rates and thermal gradients at different depths provides a first-order description of the strength distribution within the lithosphere. For each depth interval strengths for both brittle and ductile deformation are calculated, with the lesser of these representing the limiting strength of the lithosphere at that particular depth level. A scalar measure for the total strength of a multi-layer lithosphere with a depth-dependent rheology can be obtained by vertically integrating the yield envelope. In this study, a four-layer model, consisting of an upper crust (wet quartzite), the upper lower crust (felsic granulite), a lowermost crust (mafic granulite), and the upper mantle (wet peridotite) is adopted; meanwhile, a steady-state strain rate of 10^{-15} s^{-1} is used. The relative crust strength is calculated for the Tibetan plateau, as the percentage of the crust strength to the integrated strength of whole lithosphere, because the “*crème brûlée*” in here is regarded as including all models with a weak mantle and “*jelly sandwich*” as all models with a strong mantle, not just those with a weak lower crust.

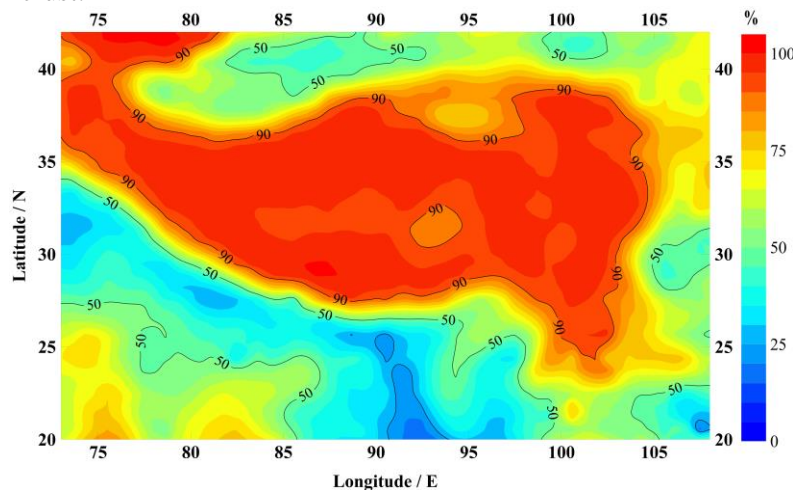


Fig.2 Percentage of crust strength relative to lithospheric strength in the Tibetan plateau.

The lithospheric strength is lower than $2 \times 10^{12} \text{ Pa m}$ within the Tibetan plateau, due to its over-thickened crust and elevated geotherm. The percentage of the crust strength to the integrated strength of the entire lithosphere across the majority of Tibetan plateau is larger than 90%, corresponding to a stronger crust, but a weak upper mantle (Fig.2). This means that the present-day rheology of the Tibetan plateau belongs to the typical “*crème-brûlée*” layering. Previous studies point to the weak ($< 1 \times 10^{13} \text{ Pa m}$) strength of the “*crème-brûlée*” layering as being earthquake-prone. Accordingly, the high intensity of seismic activity in the Tibetan plateau is determined by rheological characteristics of the lithosphere. Meanwhile, the existence of weak lower crust and upper mantle beneath the Tibetan plateau favours the “*channel flow*” model of the large-scale deformation.

 Key words: lithosphere-asthenosphere boundary (LAB); rheology; geotherm; isostasy; Tibetan plateau