Mapping the deep lithospheric structure beneath the eastern margin of the Tibetan Plateau from gravity anomalies

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Received 18 August 2004; revised 17 March 2005; accepted 8 April 2005; published 30 July 2005.

Various authors have investigated the mechanism of lateral support of the lithosphere in maintaining the uplift of the Tibetan Plateau, based on gravity data and elastic flexural modeling, in the south of the plateau across the Himalayas and in the north and the northwest across the Altyn Tagh and West Kunlun Shan. However, the degree of the regional compensation and lateral support to the east of the Tibetan Plateau has remained unknown. In this paper we present a lithospheric flexure model by interpreting gravity and topography to understand the first-order problem of lateral support of the lithosphere at the eastern margins of the Tibetan Plateau. The flexural modeling constrains the geometry and strength variation of the lithosphere from the eastern margin of Tibet past the Longmen Shan ranges on to the Sichuan Basin. A lithosphere of intermediate strength \( Te = 45 \text{ km} \) beneath the Sichuan Basin is weakened \( Te = 36 \text{ km} \) by the thrusting underneath the eastern margin of the Tibetan Plateau. The strength variations indicate that about 10 km of the crustal material of the lithosphere has been ripped off and integrated into the thickened, upper crust of the Tibetan Plateau, which, however, has no appreciable strength. The stiffness of the lithosphere keeps the Tibetan Plateau relatively stable at its eastern margin and enables the weight of the plateau to be supported in the east by the Sichuan. Lithospheric deformation in the southern Longmen Shan area is more pronounced than in the northern region.


1. Introduction

The geodynamic processes forming and maintaining the Earth’s largest plateau, the Tibetan Plateau, have been a focus of study for decades. It has been well established that the present-day Tibetan Plateau arose from the collision of the Indian plate with the Eurasian plate beginning about 45 million years ago. However, the mechanism of maintaining a high plateau of over 4000 m in average with a horizontal dimension of about 3000 km in the E-W direction and about 1500 km in the NS direction is still debated. One hypothesis is that the high plateau retains its great gravity potential and maximum instability by convectively upholding its thickened lithosphere by crustal thickening and a thermal mantle dynamic process [Molnar et al., 1993]. If this scenario holds, then the mantle lithosphere beneath the Tibetan Plateau will be reduced to a minimum. It might also be hypothesized that the entire Tibetan lithosphere is consistently deformed from top to bottom, as a viscous body, by compression from India [England and McKenzie, 1982]. Both these models require a (relatively) weak lithosphere beneath the Tibetan Plateau. However, does Tibet have its own lithosphere, strong enough to support its highly uplifted elevation and keep the plateau relatively stable? Studies based on gravity data and elastic mechanical modeling suggest, first, that the southern part of the Tibetan Plateau, including the Himalayas, the Gangdise mountains, and the Lhasa block, is supported partially by the subducting Indian lithosphere, even though the strong Indian plate has been weakened to intermediate strength during the subduction [Lyon-Caen and Molnar, 1983; Royden, 1993; Jin et al., 1996] and, second, that the northwestern margin of Tibet, the Kunlun Shan area, is laterally supported by the subducting Tarim lithosphere [Lyon-Caen and Molnar, 1984; Jiang et al., 2004]. An exception is the northern margin of Tibet along the Altyn Tagh left-lateral strike-slip fault zone where the gravity study of Jiang et al. [2004] shows that the lithosphere is in Airy isostasy and there is no lateral support from the Tarim block.

In the interior of the Tibetan Plateau, studies based on the response function of the lithosphere to surface and subsurface loading show that the lithosphere beneath Tibet has a mechanical strength variation from \( Te = 10 \) to 40 km but is not weak [Jin et al., 1994; Braイトenberg et al., 2003]. However, a mass loading with a spatial wavelength over
1000 km tends to keep the lithosphere in a state of Airy isostasy whether the loaded lithosphere has mechanical strength or not [e.g., Forsyth, 1985].

[4] As we mentioned above, the extent of lateral support to maintain a high plateau has been investigated by various workers in the south, north, and northwest margins of the Tibetan Plateau. However, the eastern margin, the Longmen Shan area, has not been similarly studied. In this paper we will present three gravity transects across the Longmen Shan (Figure 1). Our mechanical modeling allows for the lateral variation of the strength of the lithosphere so that we can quantify the variable rigidity of the lithosphere from the Tibetan Plateau to the Sichuan Basin. Flexural modeling takes into account the sensitivity of Bouguer gravity anomalies to Moho bending, and the extent of the bending tells us how weak the lithosphere is. Ultimately, we aim to better understand the mechanics of lateral support of the lithosphere in maintaining the uplift of the Tibetan Plateau.

2. Geological Setting

[5] The Longmen Shan is a north-northeast trending orogenic belt which might have been initiated during the Indo-Sinian Orogeny in the Mesozoic, and reactivated in Cenozoic [Dirks et al., 1994; Burchfiel et al., 1995; Wallis et al., 2003]. There are two major faults observed in the

\[\text{Figure 1. Location of the three 2-D flexural modeling transects plotted on the top of topography. Black lines represent faults [after Ren et al., 1999; Tapponnier et al., 2002]. The red dot is the well location from the density log in Figure 4. Numbered lines are the locations of three profiles modeled in this paper. The color bar shows elevation.}\]
Longmen Shan fold belt. From west to east, they are the Longmen Shan (LM) fault and Guanxian-Anxian (GA) fault (Figure 1). West of the LM fault is the Songpan-Ganzi fold belt with deep marine flysch rocks of early-middle Triassic age [Dirks et al., 1994]. Songpan-Ganzi is a remnant Paleotethyan ocean basin developed along the northwestern margin of the Yangtze plate due to the collision between the Yangtze and Sino-Korean plates [Yin and Nie, 1993]. Its topography was uplifted during the Oligocene and Miocene due to the collision between India and Eurasia [Tapponnier et al., 2001]. The northwest trending folds and faults within the Songpan-Ganzi fold belt (Figure 1) indicate that the NE-SW crustal shortening is dominant here, which is consistent with the convergent direction of the Indian plate subducting beneath the Eurasian plate. Different from the Songpan-Ganzi fold belt, northeast trending folds and faults (parallel to the Longmen Shan) are observed in the east of LM fault (Figure 1). The crustal deformation here is dominated by nappe tectonics in which several nappes and klippes appear in the Longmen Shan fold belt and the western Sichuan Basin. [Liu et al., 2001; E. Q. Wang et al., 2001; Jia et al., 2003]. Precambrian and Paleozoic rocks are emplaced over the Mesozoic rocks of the Sichuan Basin. Substantial metamorphism accompanied Mesozoic deformation in the Longmen Shan region. The metamorphic grade of the passive margin sequences generally increases toward the hinterland [Dirks et al., 1994; Burchfiel et al., 1995]. East of the GA fault is the western Sichuan Basin. The Sichuan Basin is almost entirely a Mesozoic feature, which contains many km of Triassic-Cretaceous terrestrial sediments with fluvial mudstones, sandstones and conglomerates. The maximum thickness of these deposits exceeds 10 km [Burchfiel et al., 1995; Song and Lou, 1995]. However, the basin also has a sliver of Eocene and some Miocene-Quaternary sediments confined to its southwest corner [Burchfiel et al., 1995; Song and Lou, 1995]. The maximum thickness of Cenozoic deposits is <700 m [Kirby et al., 2002]. Cenozoic deformation is only found in the southwestern Sichuan Basin. A series of NE trending detachment folds consisting of Cretaceous-Oligocene rocks are reminiscent of wrinkles in a rug sliding on flat-lying Neogene sediments. It indicates that some shortening occurred in the southern Longmen Shan ranges after the Oligocene. Except in its southern part, both surface geology and space geodetic studies indicate that active shortening across the Longmen Shan is only about 5 mm/yr or less [Burchfiel et al., 1995; King et al., 1997; Royden et al., 1997; Chen et al., 2000].

3. Data
3.1. Bouguer Gravity
[6] The Bouguer gravity used for our gravity transects in this study is shown in Figure 2. The gravity data were originally digitized from the map by Sun [1989]. This gravity map was compiled by the Institute of Geophysical and Geochemical Exploration and the Technical Centre of

Figure 2. Bouguer gravity map showing the gravity contour used in the flexural modeling on the 2-D transects.
Regional Gravity Survey, Ministry of Geology and Mineral Resources (MGMR) in the period of 1987–1988. Gravity data measured since 1979 by geophysical prospecting under the supervision of MGMR have been integrated into this map. The gravity surveys were implemented according to the Technical Stipulation for Regional Gravity Survey issued by the MGMR of China on the scales of 1:100,000, 1:200,000 and 1:500,000. The original survey scale in most of our study area is 1:500,000.

The original gravity measurements were reduced to the Potsdam standard within the geographical reference of the Beijing 54 Coordinate System and the Yellow Sea Elevation System [Sun, 1989]. Data were reduced using Helmert normal gravity, usual practice for survey teams in China. The Bouguer gravity field was calculated using a terrain density of 2670 kg/m³. Terrain corrections were applied out to a distance of 166.7 km using digitized topography data from the map of Sun [1989]. The cumulative error in the Bouguer gravity field, including errors from elevation, is estimated to be 0.6–1.5 mGal. Our digital Bouguer gravity data are digitized from Sun’s [1989] map on a 3’ × 3’ grid. The topography used in Figure 1 is from the Topo 30 data set.

3.2. Basement Depths of the Longmen Shan Foredeep for Gravity Correction

Seismic exploration data [Song and Lou, 1995] show that the Longmen Shan foredeep has a sediment thickness of over 10 km (Figure 3). Sediments contribute significantly to the observed Bouguer gravity anomalies, as evidenced, e.g., in the western Kunlun foredeep [Jiang et al., 2004]. We thus digitized the basement depths of the Sichuan Basin for sediment correction (Figure 3).

The sediment density was obtained from a density log located at 114°30’E and 30°22’N. The density log shows that there is a density break at about 1100 m depth (Figure 4). Above the break, the average density is about 2400 kg/m³, and below the break the average is about 2550 kg/m³. Because most of our sediment package is thicker than 7 km, an average density of 2450 kg/m³ is applied in our modeling. We also referred to a map of the average density distribution of Sichuan Basin compiled by Sichuan Oil Complex from the integration of geological and geophysical seismic and log investigations and borehole measurements [Wu et al., 1995]. This map shows that the value of average density in the foreland basin ranges from 2410 kg/m³ to 2580 kg/m³. The density log is commercially available.

The Bouguer anomalies derived from the sediments are calculated along the two-dimensional (2-D) profiles (Figure 1) and deducted from the total observed Bouguer field before flexural modeling. Thus sedimentary loading on the flexed plate will be taken into account.

4. Modeling

One fundamental problem of flexural modeling across the margins of the Tibetan Plateau from the lowlands.
to the highland is that in the lowlands, the two major components of the lithosphere, the crust and upper mantle lithosphere, are coupled with each other. Therefore the Moho deformation detected from flexural modeling reflects the bending of the whole lithosphere. Bouguer gravity anomalies reflect lateral variations in density at depth. The largest subsurface density discontinuity near the surface of the Earth occurs at the Moho. The large variation in Moho depth from the lowland Sichuan Basin to the high Tibetan Plateau contributes most of the gradient signal in the measured Bouguer gravity. The flexural modeling can possibly track down the geometry and elastic deformation of the subducted lithosphere of the lowland underneath the highland and underneath the transition zone between the highland and the lowland.

To some extent, the lithosphere of the Sichuan Basin behaves similarly to the lithosphere of the Tarim basin. The Tarim block limits the growth of the Tibetan Plateau to the north and the Sichuan Basin limits it to the east. Therefore we apply the same modeling principle as Jin et al. [1996] and Jiang et al. [2004] to model the eastern margin of Tibet. Because of a lack of constraints on the structure of the upper mantle lithosphere in the study area, we had to allow for a considerable latitude in possible plate models. We searched for the best fitting models by assuming either one continuous plate beneath this study area or two separate plates. The elastic plate thickness \( T_e \) of the plate or plates was allowed to vary laterally, and we also considered the possibility of lateral compression on the system.

The finite difference code used for the flexural modeling [Sheffels and McNutt, 1986; Jin et al., 1996; Jin and Jiang, 2002] allows lateral variations of flexural rigidity. It also considers all possible boundary conditions such as known flexure at boundaries (possibly from Airy isostasy), known gradient of flexure (from bending), second derivative (known bending moment), and third derivative (known end shear). The gravity modeling is integrated into the flexural modeling package, based on the theory of Okabe [1979].

The reason for using Okabe’s instead of Talwani et al.’s [1959] or Parker’s [1972] theory is twofold: first, our 2-D gravity modeling (particularly for the sediments and the broken plate boundaries) needs considerable lateral variation of density, so a spectral domain approach as Parker’s is ruled out; second, Talwani’s method requires the evaluation of a volume integral which is computationally challenging. Okabe uses Gauss’s theorem to convert the volume integral into a surface integral, which significantly accelerates the calculation. The misfit between the observed Bouguer gravity and the theoretical gravity is used to adjust the flexural rigidity parameters of the model lithosphere. By computing iteratively, we obtained the best fit lithospheric rigidity and flexure, for which the residual gravity anomaly, root-mean-square misfit (RMS), is minimized.

All of our modeling is in two dimensions along three profiles. The topography is used to calculate vertical surface loading with a density of 2670 kg/m³ in the study area except for the Sichuan Basin where a density of 2450 kg/m³ is used for the Longmen Shan foredeep.

### 5. Results

The locations of the three transects used in our two-dimensional modeling are shown in Figures 1, 2, and 3, and are numbered as 1, 2, and 3 from south to north. The boundary condition of the flexural equation at the ends of the profiles is one of Airy isostasy in all models. Various modeling assumptions were examined to fit to the data along the three profiles. Their features will be illustrated only in profile 1, although the conclusions are generally valid for the other two transects.

Our modeling suggests that there are large discrepancies between the predictions of the Airy model and the observed data along the profile 1. This model, for which topographic relief is point-wise compensated by crustal thickening at the Moho, produces a theoretical Bouguer gravity anomaly that resembles an inverted, low-pass- filtered version of the topography. The fact that the fit of the Airy model to the measured data along all three profiles is the worst at the eastern margin of the Tibetan
Plateau suggests that the deformation does not involve the entire lithosphere.

[17] Figure 5 examines the fit to the gravity data along profile 1 for a continuous plate model with uniform rigidity, assumed $Te$ values 30, 40, and 60 km, respectively. None of these models comes close to fitting the gravity. The $P$ and $S$ wave analysis of Chan et al [2001] shows that the Sichuan Basin has a crustal thickness of 36–40 km, whereas the crustal thickness of the Tibetan Plateau next to Sichuan reaches over 50–55 km. Thus it is not surprising that the strength of the lithosphere will be changed at the steep transition both in Moho and elevation from the Sichuan Basin through the Longmen Shan to the Tibetan Plateau.

[18] Different parameters for continuous plate models with variable rigidity were tested; their features are shown in Figures 6, 7, and 8. We model a moderately weak Tibetan Plateau plate, with elastic thickness $Te = 35$, 40, 45 km in the west, and moderately high rigidity Sichuan plate, with elastic thickness $Te = 40$, 50, 60 km; 45, 50, 60 km and 50, 60 km in the east, respectively. The values of elastic thickness about ±40 km are consistent with those determined in previous studies [Lyon-Caen and Molnar, 1983; Jin et al., 1994, 1996; Braitenberg et al., 2003; Jiang et al., 2004]. The Sichuan Basin lies in the Yangtze craton. Our 3-D modeling results have suggested that the elastic thickness of its lithosphere is 40–50 km [Jiang et al., 2001]. Thus it is assumed that a moderately high rigidity is reasonable. The plate was allowed to weaken beneath the high Longmen Shan ranges. From Figures 6, 7, and 8, fits to the Bouguer gravity data along profile 1 are substantially improved when the elastic thickness of the plate equals 35–40 km on the Tibetan and 45–50 km on the Sichuan side. These parameters were input as initial parameters to iterate to obtain our best modeling.

[19] Figure 9 shows models with two separate pieces of a broken plate with breaking point at the Longmen Shan (LA) fault. Similar to the continuous plate model, we tested the $Te = 35$ km on the Tibet and $Te = 40$, 50, and 60 km on the Sichuan and the $Te$ decreasing beneath the Longmen Shan fold belt. It is clear that these models, both two broken plates with uniform rigidity and with variable rigidity, cannot explain the observed gravity data. It implies that the weight of the Tibetan Plateau is partially supported eastward by the Sichuan Basin.

[20] The successful model requires a continuous plate with an elastic thickness of 45 km in the Sichuan Basin,
decreasing westward to 36 km in Tibet, where the lithosphere begins to be weakened from the front of the ranges (Figure 10). Its RMS is 4.82 mGal. The lithosphere is weakened by about 10 km in elastic thickness, which is consistent with the missing crust of the subducting lithosphere of the Sichuan Basin. Because there is no broken point detected along the profile, the mantle lithosphere and the lowermost crust of the Sichuan Basin could be the same as the lithosphere beneath eastern Tibet. The 3-D flexural modeling by Jiang et al. [2001] has derived a similar result.

The compensation style and the lithosphere structure of profiles 2 and 3 also look similar to the results derived from the first profile. The gravity data are well explained by flexure of one continuous plate with variable rigidity (Figures 11 and 12). They are characterized with an elastic thickness $T_e = 43$ or 47 km in the Sichuan Basin, decreasing to $T_e = 36$ or 38 km in the Tibetan Plateau. A series of brittle faults beneath the Longmen Shan fold belt were generated by the Sichuan plate thrusting underneath the eastern margin of the Tibetan Plateau (Figure 1). Among them are two major thrust faults, the Longmen Shan (LM) and Guanxian-Anxian (GA) faults. The GA fault is the main frontal thrust dividing the strong lithosphere to the east and the weakened lithosphere to the west. The LM fault, the major boundary fault of eastern Tibet, denotes an earlier brittle surface detaching the crust from the lithosphere. The thrust faults allow us to pin down the exact location of the change in rigidity for profiles. The descent of the plate was traced continuously, and more modest weakening was also observed, in which $T_e$ change begins from the GA fault (for profiles 1 and 2) and drops to about 40 km beneath the Longmen Shan fold belt and continuously weakens westward.

Figure 6. Topography and Bouguer gravity along profile 1, showing model fits for a continuous model with variable rigidity. The south end in the eastern Tibetan Plateau was assumed to have an elastic thickness of 35 km. The responsible value for the Sichuan Basin to the north of Guanxian-Anxian (GA) fault was assumed 40, 50, and 60 km, respectively. The plate was allowed to weaken beneath the Longmen Shan fold belt (LM fold belt). The Bouguer gravity predicted by the Airy model was shown for reference. LM fault denotes Longmen Shan fault.

6. Discussion

On the basis of our modeling, the elastic thickness of the Sichuan block is about 45 km, which reflects a moderately rigid continental plate. This rigid plate continuously extends underneath the eastern part of the Tibetan Plateau, even though its top part is ripped off during underthrusting at the eastern margin of the plateau. This result is consistent...
with other geophysical studies (L. H. Royden, personal communication, 2004) and our 3-D flexural modeling over Tibet and its vicinity [Jiang et al., 2001]. Given that the basement of the Sichuan Basin is thought to be older than Cambrian [Ministry of Geology and Mineral Resources, 1991], a $T_e$ of about 40 km is somewhat low. Many studies have shown that the Sichuan crust has acted as a stable block with relatively little internal deformation, even though the orogeny in its western margin began in the Mesozoic [Burchfiel et al., 1995; Zhou and Graham, 1996; Arne et al., 1997; Kirby et al., 2002]. While the Indian plate began to collide with the Eurasian plate 50 million years ago, the southwestern edges of the Sichuan block were further deformed correspondingly [Burchfiel et al., 1995; E. Q. Wang et al., 2001; Kirby et al., 2002; Jia et al., 2003]. We can only evaluate the rigidity of the flexed part of the Sichuan through our modeling. Therefore it is possible that the nondeformed core of the block remains more rigid than what we derived from the modeling. In addition, anisotropic flexure and small-scale (less than 1000 km) effects may be the reasons that the old and stable Sichuan plate has not obtained high effective elastic thickness [Simons et al., 2000; Simons and van der Hilst, 2002].

[23] The result that elastic thickness of the Tibetan Plateau is about 36 km is consistent with our previous work [Jin et al., 1994, 1996; Jiang et al., 2004]. Between the strong upper crust and the upper mantle of Tibet, a weak ductile channel with widespread lower crustal partial melting is inferred [e.g., Nelson et al., 1996; Owens and Zandt, 1997]. A previous study [Clark and Royden, 2000] supports the result that partial melting occurs in the lower crust of the eastern margin of Tibet. When subjected to stresses from surface and subsurface loads acting vertically, the overall mechanical behavior of the two rheological strong regions separated by a ductile channel is governed by an effective elastic thickness given by $(T_c^3 + T_m^3)^{1/3}$ [McNutt et al., 1988], where $T_c$, $T_m$ denote upper crust and upper mantle rigidity, respectively, which in our case is slightly more than the effective elastic thickness of the stronger of the two layers. Thus an elastic thickness of $\sim$36 km for the eastern Tibet is plausible, even though its crust is 50 km thick.

[24] The thickened crust of eastern Tibet was created through thick-skinned progressive sheet thrusting. The successively episodes of underthrusting have weakened the strength of lithosphere from basin to plateau. The continuous plate thickness of $T_e = 36-45$ across the eastern
Tibetan Plateau to Sichuan Basin suggests that the eastern margin of Tibet is laterally supported by the underthrusting Sichuan lithosphere, which keeps the plateau relatively stable. Because the Altyn Tagh Fault defines the northern boundary of Tibet, the mantle lithosphere should be extruding eastward [e.g., Tapponnier et al., 2001; Jiang et al., 2004]. The continuous plate, with just a change in relative stiffness across the eastern margin of Tibet, makes this eastward extrusion possible.

[25] Our results show that the Moho transition in the Sichuan Basin and the Tibetan Plateau is sharp in profile 1 and 2 (Figures 10 and 11) but flat in profile 3 (Figure 12); the weakening of the elastic thickness of the lithosphere is more pronounced in the southern Longmen Shan area than in the northern one. It indicates that lithospheric deformation in the southern Longmen Shan area is more widespread than in the northern one at present. This suggestion is supported by geology, petroleum seismic reflection and dating studies [Liu et al., 2001; Jia et al., 2003]. Some eastward verging, rootless thrust sheets and imbricates of Cambrian to Triassic rocks are observed in the northern Longmen Shan area [Jia et al., 2003]. The tectonic action of the Indo-Sinian Orogeny is dominant here [E. Q. Wang et al., 2001; Jia et al., 2003]. Cenozoic deformation is observed in the northern Longmen Shan area [e.g., Q. Wang et al., 2001]. However, basement-involved thrust structures are observed in the southern Longmen Shan [Tao, 1999; Jia et al., 2003]. Except for the deformation in the Indo-Sinian period, deformation in the southern Longmen Shan also occurred in the late Cretaceous-Paleogene and Himalayas periods [Tao, 1999; E. Q. Wang et al., 2001; Jia et al., 2003]. Thus the Cretaceous-Cenozoic rejuvenated foreland basin is restricted to the southwestern Sichuan Basin. This indicates that, although rapid uplift of the eastern Tibet started in the Miocene in reaction to the collision between the Indian and Asian plates, the Late Cenozoic tectonic deformation propagated only to the southern Longmen Shan fold belt, but not into the northern Longmen Shan.

7. Conclusions

[26] Our flexural modeling across the eastern margin of the Tibetan Plateau does not answer the question why the deformation in the eastern Tibet and Longmen Shan (Sichuan Basin) is not of the same age: topography uplift occurred in the Himalayan period and the basin formed in the Indo-Sinian period, except for its southwestern part. However, our study suggests that the two components of the
**Figure 9.** Topography and Bouguer gravity along profile 1, showing model fits for a two separate plates model with broken point at Longmen Shan fault. The parameters of model were assumed as in Figure 6. The Bouguer gravity predicted by the Airy model is shown for reference.
Figure 10. (a) Topography. (b) Best fit to the Bouguer gravity data along profile 1 for a continuous model with variable rigidity. The lithosphere begins with an elastic thickness 45 km to the north of GA fault in the Sichuan Basin, which reduces to 40 km after it passes beneath the Longmen Shan fold belt and then drops to 36 km beneath the eastern Tibet on the southern end of this profile. (c) Crustal model corresponding to the gravity interpretation in Figure 10b. Because the fit to the Bouguer gravity data in Figure 10b only depends on the product $\Delta \rho$ and $w$, where $\Delta \rho$ is the density error of crust and mantle and $w$ is the Moho deflection (lithosphere flexure), the absolute depth of the Moho is not uniquely determined by gravity modeling alone without some assumption of $\Delta \rho$. So, we choose $\Delta \rho = 500 \text{ kg/m}^3$ so that our Moho depths would be consistent with those derived from $P$ and $S$ wave seismic data in this area [Chan et al., 2001].
Figure 11. Same as Figure 10, but for profile 2.
lithosphere along the eastern margin of Tibet, crust and upper mantle, are still coupled with each other. The elastic thickness of the Sichuan block and eastern Tibet suggests that their lithospheres are virtually indistinguishable with a $T_e$ of 45 km in the Sichuan Basin and 36 km in Tibet. The thickened part of the Tibetan crust has almost no strength and is pervaded by brittle failure shown by large clusters of earthquakes. The reduced $T_e$ of about 36 km beneath the eastern Tibet is caused by successive underthrusting. The stiffness of the lithosphere keeps the Tibetan Plateau relatively stable at its eastern boundary and enables plateau convergence eastward. Lithospheric deformation in the southern Longmen Shan area is more pronounced than in the northern one now.

Acknowledgments. We thank Leigh Royden, who previewed the manuscript and gave constructive and detailed comments for improving our results. We also thank Frederik Simons and two anonymous reviewers, whose detailed reviews and annotations have improved our manuscript.

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