Geoscience Frontiers (2010) 1, 45–56

available at www.sciencedirect.com
China University of Geosciences (Beijing)
**Geoscience Frontiers**
journal homepage: www.elsevier.com/locate/gsf

ORIGINAL ARTICLE

# The principal characteristics of the lithosphere of China

**Tingdong Li** [a,b,*]

[a] *Chinese Academy of Geological Sciences, Beijing 100037, China*
[b] *College of Earth Sciences, Jilin University, Changchun, Jilin 130026, China*

Received 3 April 2010; accepted 25 June 2010
Available online 6 October 2010

**KEYWORDS**
Crust;
Lithosphere;
Asthenosphere;
China

**Abstract** The lithospheric structure of China and its adjacent area is very complex and is marked by several prominent characteristics. Firstly, China's continental crust is thick in the west but thins to the east, and thick in the south but thins to the north. Secondly, the continental crust of the Qinghai–Tibet Plateau has an average thickness of 60–65 km with a maximum thickness of 80 km, whereas in eastern China the average thickness is 30–35 km, with a minimum thickness of only 5 km in the center of the South China Sea. The average thickness of continental crust in China is 47.6 km, which greatly exceeds the global average thickness of 39.2 km. Thirdly, as with the crust, the lithosphere of China and its adjacent areas shows a general pattern of thicker in the west and south, and thinner in the east and north. The lithosphere of the Qinghai–Tibet Plateau and northwestern China has an average thickness of 165 km, with a maximum thickness of 180–200 km in the central and eastern parts of the Tarim Basin, Pamir, and Changdu areas. In contrast, the vast areas to the east of the Da Hinggan Ling–Taihang–Wuling Mountains, including the marginal seas, are characterized by lithospheric thicknesses of only 50–85 km. Fourthly, in western China the lithosphere and asthenosphere behave as a "layered structure", reflecting their dynamic background of plate collision and convergence. The lithosphere and asthenosphere in eastern China display a "block mosaic structure", where the lithosphere is thin and the asthenosphere is very thick, a pattern reflecting the consequences of crustal extension and an upsurge of asthenospheric materials. The latter is responsible for a huge low velocity anomaly at a depth of

---

* Chinese Academy of Geological Sciences, Beijing 100037, China. Tel.: +86 13910931872., +86 10 68999610, +13910931872 (mobile).
*E-mail address:* litdong@163.com.

Peer-review under responsibility of China University of Geosciences (Beijing).
doi:10.1016/j.gsf.2010.08.005

85–250 km beneath East Asia and the western Pacific Ocean. Finally, in China there is an age structure of "older in the upper layers and younger in the lower layers" between both the upper and lower crusts and between the crust and the lithospheric mantle.

## 1. Introduction

Between 2001 and 2006, a special research project, "The 3-D Structure of the Lithosphere of China", was undertaken by the Ministry of Land and Resources of China. More than 100 scientists from 14 relevant academies, institutes, universities, geological prospecting institutions, and private enterprises were gathered together to facilitate a synthetic investigation drawing upon all of the available geological, geophysical, geochemical, and geotraverse research information. The results obtained in this research were abundant. From the basis of these results the present paper provides a preliminary analysis of some of the major characteristics of the lithosphere of China.

China is located at the junction of four tectonic plates, namely, the Eurasian, the Indian–Australian, the Pacific, and the Philippines plates. The structure of its lithosphere is very complicated and is marked by several prominent characteristic features.

The lithosphere of the continent of China and its adjacent sea area has undergone a prolonged and complicated geological evolution process. The subduction and collision of the Indian–Australian and Pacific plates towards the Eurasian plate and the subsequently induced crust–mantle interaction have played an important role in the formation and evolution of the lithospheric structures of the continent of China and its adjacent areas. The result of these interactions is an enormous change in lithospheric composition and structure of the central and the eastern parts of the entire Asian continent. Continental crust was greatly thickened in the Qinghai–Tibet Plateau and central Asia, forming the magnificent Qinghai–Tibet plateau and the basin–range system in northwestern China. Simultaneously, in the eastern zone bordering the Pacific the continental crust greatly thinned, thus, forming a series of rift basins at various scales and an accompanying tectono-magmatic belt.

The China and its adjacent areas comprise an amalgamated continent made up of several continental blocks of different sizes and history with orogenic belts interspersed between them. The major blocks are Tulan, Tarim, Sino-Korean, and Yangtze. The major orogenic belts are the Ural–Mongolian orogen, the Tethyan–Himalayan orogen, and the Circum-Pacific orogen (Fig. 1).

The Qinghai–Tibet Plateau and the East Asian area is one of the most fascinating places on Earth for the study of plate collision, mantle convection, crust–mantle interaction, intraplate magmatism, and metallogenesis. It is the best natural laboratory for research into intraplate melting-related geodynamic processes (Flower et al., 1998). These conditions make the Chinese continent and its adjacent areas a key region for the study of fundamental problems regarding lithospheric formation and evolution.

## 2. The major characteristics of the continental crust of China

The relief of the Moho beneath the Chinese continent is rather large and it is principally a mirror image of the surface topography. The crustal thickness is high, with an average value of 47.6 km, which is 8.4 km greater than the global average crustal thickness. The seismic P-wave (i.e. longitudinal wave) mean velocity of the crust is 6.28 km/s, which is much lower than the global mean velocity 6.45 km/s (Zhu et al., 2006). It is reported that the global crust mean thickness is 33 km (Tao et al., 1999), meaning that China's mean continental crust thickness is 14.6 km greater than the global mean. This high mean crustal thickness is due to the large crustal thickness of West China, especially the very thick crust found beneath the Qinghai–Tibet Plateau. The complicated geological evolution process that has unfolded in China, especially since the Mesozoic era has caused the following characteristics of the present east Asian continent.

### 2.1. Crustal thickness variability

The crustal thickness of the China and its adjacent sea areas is highly variable. The principal tendencies are thicker in the west and thinner in the east, thicker in the south and thinner in the north, and thicker in the orogenic belts, but thinner in the regions between them (Fig. 2). The great variability in crustal thickness in China and its adjacent areas reflects the complexity of surface topography and the lithospheric structure of China. The Qinghai–Tibet plateau is the area of greatest crustal thickness in China and in Asia. The mean thickness of the crust in this area is 60–65 km, 30 km thicker than the crust in southeast coastal area of China, which is only 30–35 km thick. In the plateau's surrounding areas, the crustal thickness ranges from 48 to 60 km, whereas that in the hinterland of the plateau is generally around 70 km, with maximum of 80 km in central Tanggula. Conversely, in the South China Sea's central basin, the mean thickness of the continental crust is a mere 4.9 km (Wan et al., 2006). Differences in crustal thickness, therefore, range higher than 70 km. In the northwestern basin–range regions, crustal thickness ranges between 45 and 60 km. The Junggar and Tarim basins have crustal thicknesses of 45 km (Xiao and Jiang, 2008), whereas the adjoining Tianshan and Qilian Mountains orogenic belts have crustal thicknesses between 50 and 60 km. The difference in crustal thickness between orogenic belts and basins is, therefore, as much as 10 km.

In the central areas between the Helan Mountains–Longmen Mountains and the Da Hinggan Ling–Wuling Mountains, crustal thicknesses start at 34 km in the Da Hinggan Ling–Taihang Mountains eastern piedmont and gradually thicken as one moves westwards, reaching 42–44 km along the Helan Mountains–Longmen Mountains. In the Sichuan basin, the crustal thickness is 38–46 km. The difference between eastern and western crustal thickness in these areas is up to 10 km. In basin–range areas to the east of Da Hinggan Ling–Taihang Mountains–Wuling Mountains, such as the Songliao and Jianghan basins, the crustal thickness is generally 32–34 km. The crustal thicknesses of the orogenic belts bordering the eastern and western sides of these basins are 34–38 km. Surprisingly, the crustal thickness difference between the orogenic belts and the basins is less than 2–4 km.

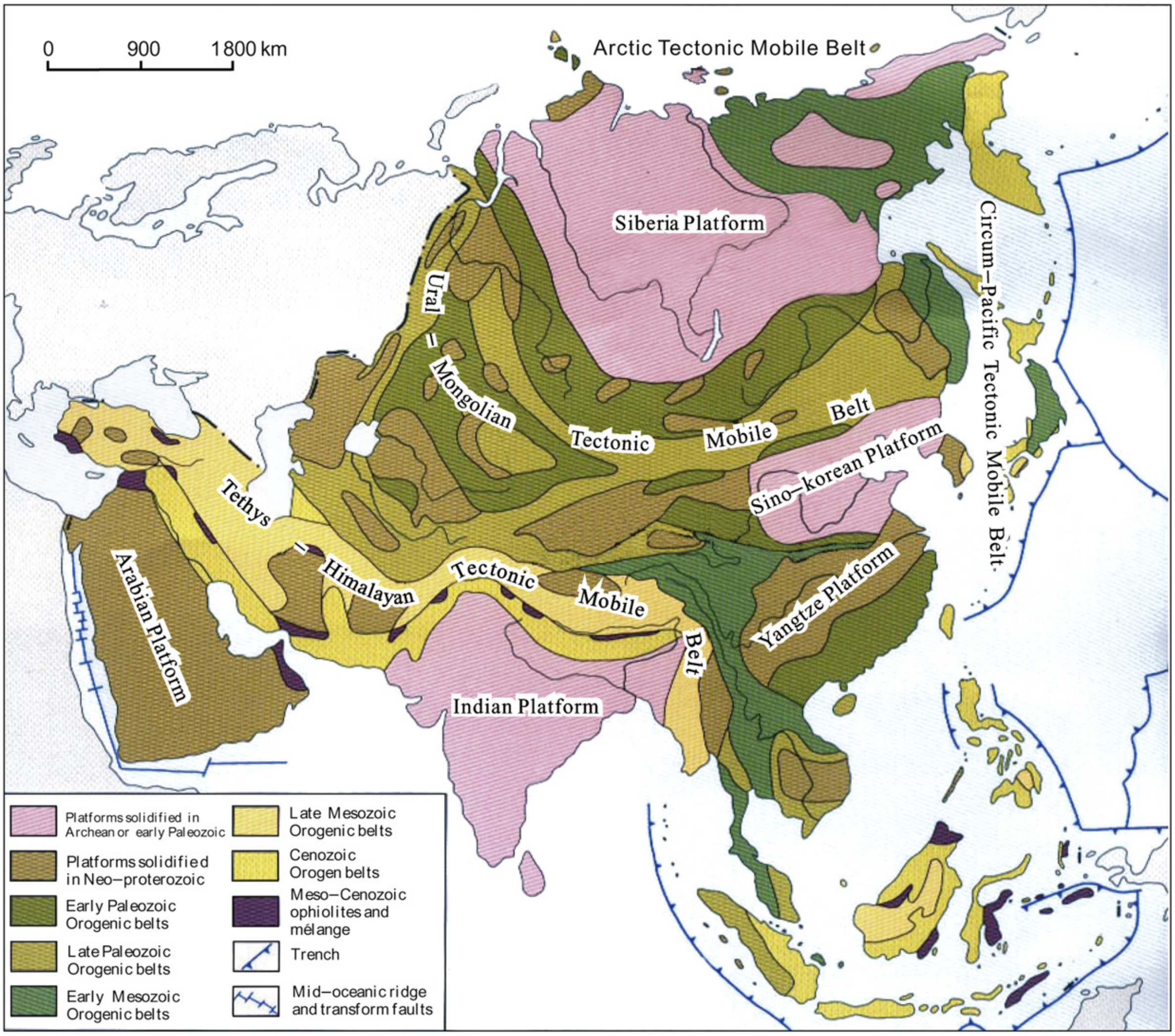

**Figure 1** Simplified tectonic map for the Asian Continent (modified from Li et al., 2001).

In areas bordering the Pacific marginal sea, such as the western Yellow Sea, the East China Sea, and the northern South China Sea, the crustal thickness of the western shelf areas is 28–32 km. Crustal thickness in the eastern East China Sea and the majority of the South China Sea is 16–22 km. In the oceanic central basin of the South China Sea, the crustal thickness is only 4.4–7.91 km, with an average value of 4.9 km (Wan et al., 2006). Therefore, the difference in crustal thickness of offshore sea areas is as much as 20 km or so. Differences of crustal thickness across the South China Sea alone reach 10–15 km.

## 2.2. The existence of 4 steep gradient zones of crustal thickness variation

The second characteristic feature of the crust of China and its adjacent sea areas is the existence of 4 steep gradient gravity anomaly zones.

### 2.2.1. The circum–Qinghai–Tibet plateau gravity gradient anomaly zone

This gravity gradient anomaly zone lies along the periphery of the Qinghai–Tibet Plateau (Fig. 3). It is a large-scale circular gravity gradient anomaly zone, 5000 km long and some 200–300 km wide, in parts reaching a width of up to 400 km. Its southern segment spreads over the southern border of the Himalayan and Gangdise Mountains, trending nearly EW. The difference in Bouguer gravity anomaly abruptly varies from −500 to −240 mGal, with an anomaly gradient of up to 1.5 mGal km$^{-1}$. In the west this zone merges into the Pamir gravity anomaly zone, and in the east reaches northwest Yunnan. There it turns north and passes through the Hengduan Mountains, where it connects with the gravity anomaly zone along the northern border of the Qinghai–Tibet Plateau. This gravity anomaly zone spreads along the Kunlun–Altyn–Qilian Mountains and is more than 2000 km long. The Bouguer gravity anomaly here also varies abruptly from −500 to −240 mGal, with an anomaly gradient of up to 1.4–1.5 mGal km$^{-1}$ (Pan and Kong, 1998).

### 2.2.2. The Hinggan–Taihang–Wuling gravity anomaly gradient zone

The Hinggan–Taihang–Wuling is a large-scale gravity anomaly gradient zone, trending NNE–SSW along the Da Hinggan Ling–Taihang Mountains–Wuling Mountains, with a length of 4000 km and a width of 200–300 km. The Bouguer gravity anomaly value here decreases abruptly from −20 to −100 mGal, within a width of only about 200–300 km. The range of change

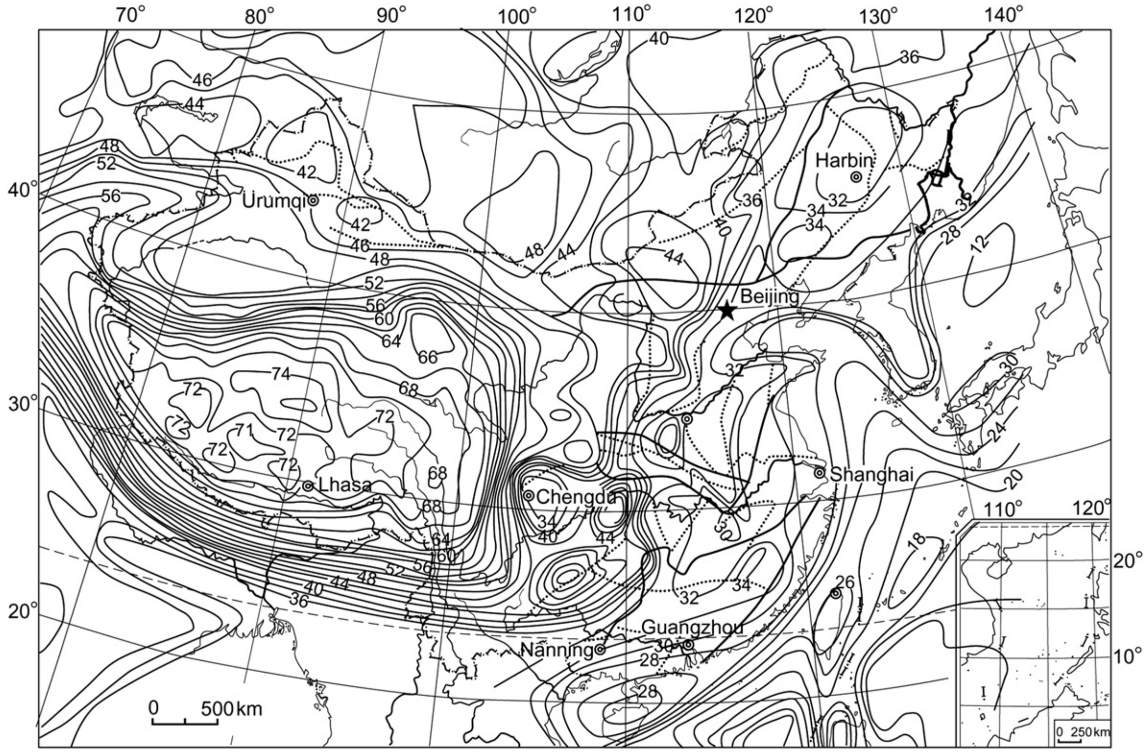

**Figure 2** The thickness of continental crust of China (Peng and Gao, 2000).

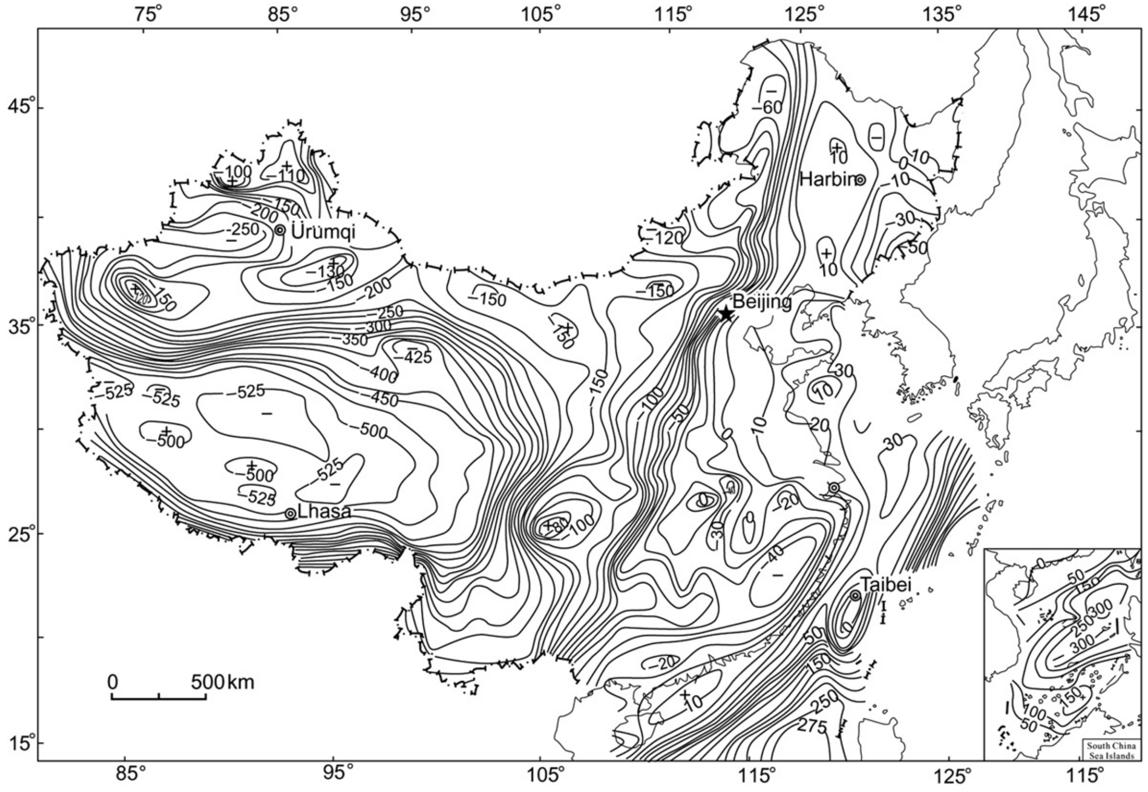

**Figure 3** The 1° × 1° average Bouguer gravity anomaly in Chinese continent and its adjacent sea areas (Yin et al., 1989).

for the anomaly value is 80 mGal, and the anomaly gradient is 1 mGal $km^{-1}$.

### 2.2.3. *The Zhejiang—Fujian gravity anomaly gradient zone*

This gradient zone extends from Shanghai southwards along the Zhejiang—Fujian sea border and reaches the eastern part of Guangdong, its total length being approximately 1000 km. The Bouguer gravity anomaly ranges from 20 to −30 mGal, with a range of 50 mGal. It is a small scale gravity anomaly gradient zone.

### 2.2.4. *The Ryukyu—Taiwan—Nansha gravity anomaly gradient zone*

This gradient zone begins in the north from the west side of Ryukyu archipelago, trending SW-wards passing through Taiwan, Dongsha archipelago, Zhongsha archipelago to Nansha archipelago, stretching in the direction of NNE—SSW. It is more than 4000 km long, 300—400 km wide. The value of Bouguer gravity anomaly varies from 250 mGal in the east to 20—30 mGal in the west, the variation range is up to 200 mGal and the maximum anomaly gradient is 1.75 mGal $km^{-1}$.

## 2.3. *The heterogeneity of crustal structure*

The crustal structure of the Chinese continent and adjacent sea areas shows obvious heterogeneity both vertically and laterally. This kind of heterogeneity can be observed by differences in geophysical fields and crustal stress fields in various regions, in crustal layering and its vertical heterogeneity, and the variations in the trending of tectonic lines. Viewed in terms of crustal layering, there are 2-fold crustal layerings in the Ordos, upper Yangtze, and Tianshan areas. Most of the other areas are 3-fold structures (according to Yang Baojun's personal communication). For example, in the Qinghai—Tibet Plateau, Tianshan Mountains, Qilian Mountains, Qinling—Dabie Mountains, and Zhejiang—Fujian coastal areas, there are low velocity, low resistivity layers (Cui et al., 1995; Li, 1996; Lu et al., 2000; Zhao et al., 2008) in the basal part of the upper crust or the middle crust (mostly at depths of 15—20 km). Even in stable blocks such as the Ordos there are low resistivity layers in the upper part of lower crust (Zhao et al., 2005). In northeast China, at a depth of 12—30 km, there are widespread low resistivity layers; in the Tianchi area of the Changbai Mountains there is a low resistivity body at a depth of 12 km, which is inferred to be a magma trap (Liu et al., 2006). In the Qinghai—Tibet Plateau and in many areas of eastern China there are widespread crust—mantle transition zones (crust—mantle mixing zones).

Considering the contour and the trend of the isopleths of crustal thickness, there are great differences in structural framework between eastern and western China (Fig. 4). In western China, along the Altay—Sayan Mountains and western Mongolia, isopleths of crustal thickness trend NS. However, for most of the regions they spread EW. In the Qinghai—Tibet plateau the isopleths of crustal thickness form a gigantic EW-trending "mantle basin" in which the depth of the Moho is only 44 km at the periphery, but 72—74 km in the hinterlands. For the basin—range region of northwest China there occurs an EW-trending plan of "mantle rise" alternating with "mantle depression".

In eastern China, the isopleths of crustal thickness trend NS—NNE. From the gravity anomaly gradient in Da Hinggan Ling—Taihang Mountains—Wuling Mountains, the Moho gradually deepens westwards, forming a "mantle slope". The depth to the Moho is 38 km in the east and deepens to 44 km in the Helan Mountains—Longmen Mountains. Beneath the Songliao plain, the North China plain, the sea of Japan, the East China sea, and the South China sea, "mantle rises" are observed.

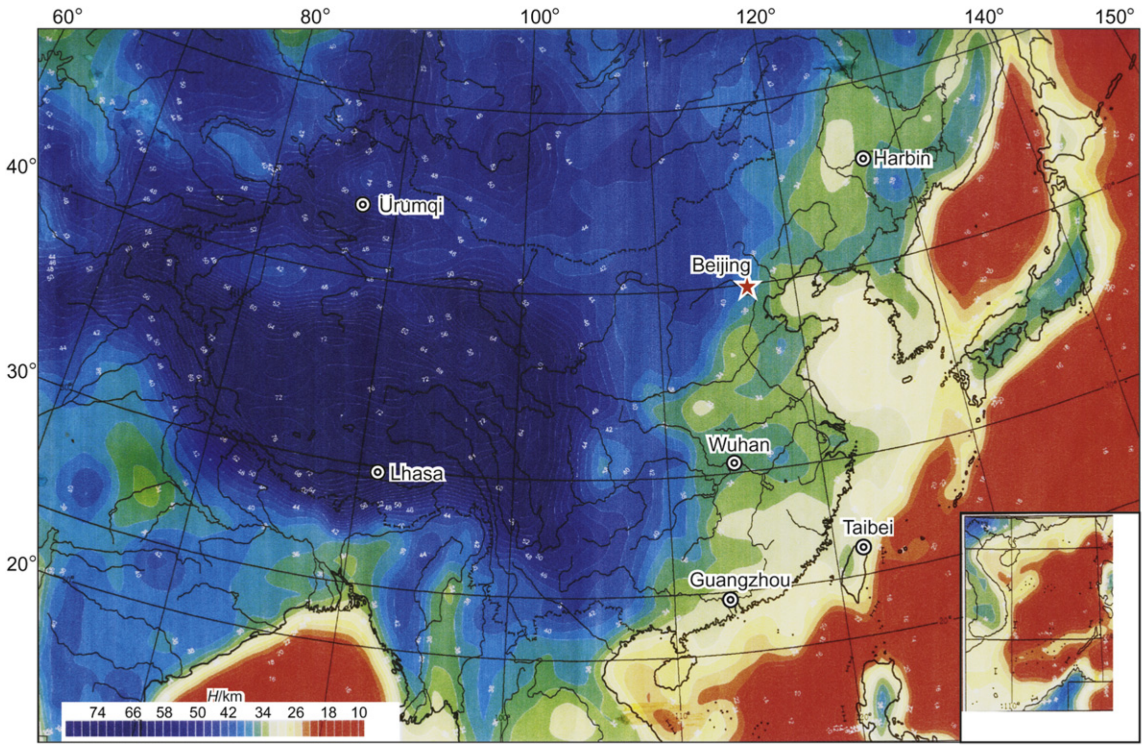

**Figure 4** Thickness distribution of the crust in the continent of China and its adjacent areas (Zhu et al., 2006).

### 2.4. The heterogeneity of crustal composition in China

Physical and chemical properties of crustal composition include rock association, mineral assemblages, degrees of acidity ($SiO_2$ content), and the relative abundance of chemical elements. Because of the regional differences in the tectonic evolution in China, crustal compositions are prominently heterogeneous both in vertical and in lateral extents (Table 1).

Rock association shows that the chemical composition of the crust in eastern China ranges between granodioritic and adamello—dioritic. The upper crust in the Da Hinggan Ling—Mongolia—Jilin—Heilongjiang block is granodioritic. Its mid-lower crust is quartz-dioritic, and its bulk chemical composition ranges from quartz-dioritic to tonalitic. The upper and lower crust of the North China Block is quartz-dioritic, and its bulk chemical composition ranges between adamello—diorite and granodiorite. The upper crust of the South China Block is granodioritic, its mid-lower crust ranges between granodioritic, quartz-dioritic, and tonalitic. Collectively, the bulk chemical composition of this block is granodioritic (Yan and Chi, 1997).

Rock acidity (the % of $SiO_2$) is an important indicator of crustal composition and chemical properties. The petrochemical composition of the Chinese continental crust is equivalent to granodioritic ($SiO_2 = 65\%$), the acidity of which is higher than the global mean acidity of the crust (63%; Qiu et al., 2006). The major variation tendency in the acidity of the Chinese continental crust is as follows: higher in the east ($SiO_2 = 65.12\%$) and lower in the west ($SiO_2 = 64.32\%$); higher in the south and lower in the north. In the western part of China, it is higher in the southwest ($SiO_2 = 65.43\%$) but lower in the northwest ($SiO_2 = 64.88\%$). In the eastern part of China, South China has the highest acidity ($SiO_2 = 65.98\%$); North China is in middle ranges ($SiO_2 = 64.88\%$) and northeast China is the lowest ($SiO_2 = 63.18\%$; Qiu et al., 2006).

Crustal acidity differences reflect differences in rock association and the petrochemistry of the granitoids that developed in these regions. Crustal acidity differences, therefore, indirectly reflect the different tectonic settings of these areas. For example, in eastern China the petrogenetic types of Mesozoic granites are prominently different from north to south. In the northeast, granitoids are mainly M-type, I-type granites; A-types are subordinate and there is a lack of S-type granites. In North China (including Qinling and the mid-lower reaches of the Yangtze River) there are mainly I-type or M-type granites, while in South China there are mainly S-type and S + I-type subordinate granites. In southeastern coastal areas, the Cretaceous granites are mostly I-type. This variation trend in the petrogenetic types of granite from north to south is matched with the crustal acidity in the corresponding areas.

## 3. The principal characteristics of China's lithosphere

Owing to the effects of its prolonged evolutionary history and multi-staged intensive tectonic movements, the composition and structures of the Chinese lithosphere are very complex. The subduction and collision of the Indian plate and the interaction of the Pacific and the Eurasian plates with China since the Late Mesozoic, as well as the interactions and magmatism between crust and mantle and between lithosphere and asthenosphere induced by their mutual collision, has caused enormous changes in the lithospheric structure of China and its adjacent areas. Specifically, the crustal thickness in the Qinghai—Tibet plateau was doubled; the North China block was intensively deformed and its lithosphere thinned significantly; finally, the South China lithosphere was heavily affected by intensive magmatism.

### 3.1. Lithospheric thickness subdivisions in China and its adjacent areas

From Fig. 5 it can be seen that if one considers the lithospheric thickness isopleths of 170 and 85 km as boundaries, the lithosphere of China and its adjacent areas can be subdivided into 3 lithospheric regions of different thickness.

**Table 1** Crustal composition and geochemical characteristics of various lithospheric blocks in eastern China.

| Lithospheric unit | Crustal thickness (km) | Velocity of longitudinal wave $v_p$ (km/s) | Acidity of crust ($SiO_2$ %) | Rock association | Geochemistry |
|---|---|---|---|---|---|
| The Da Hinggan Ling—Mongolia—Jilin—Heilongjiang Block | 36<br>Upper: 14<br>Mid-Lower 22 | 6.45 | 63.18 | Qtz-diorite—tonalite | Al-rich, high $Na_2O/K_2O$, Low oxidation, Rich in As, Be, Li, Mn, Ti, V, HREE. Poor in Cu, Ni, F, Se, Ba, PGE, LREE, Low $La_N/Lu_N$ |
| North China Block | 38<br>Upper: 15<br>Middle: 10<br>Lower: 13 | 6.39 | 64.88 | TTG<br>Adamellite–diorite—granodiorite | Rich in Fe, Mg, Ca, Na, poor in K ($Na_2O > K_2O$). Low oxidation. Rich in Fe-phile, poor in lithophile and incompatible elements |
| South China Block | 34<br>Upper: 12<br>Mid-lower: 22 | 6.35 | 65.98 | Granodiorite | Rich in Si, K, poor in Fe, Mg, Ca, low $Na_2O/K_2O$, rich in Rb, Cs, Nb, Ta, U, Th, REE. Upper crust rich in W, Sn, Sb, Bi, etc. |

Note: Information in this table is derived from Yan and Chi (1997) and Qiu et al. (2006). The crustal thickness: Upper = upper crust, Middle = middle crust, Lower = lower crust.

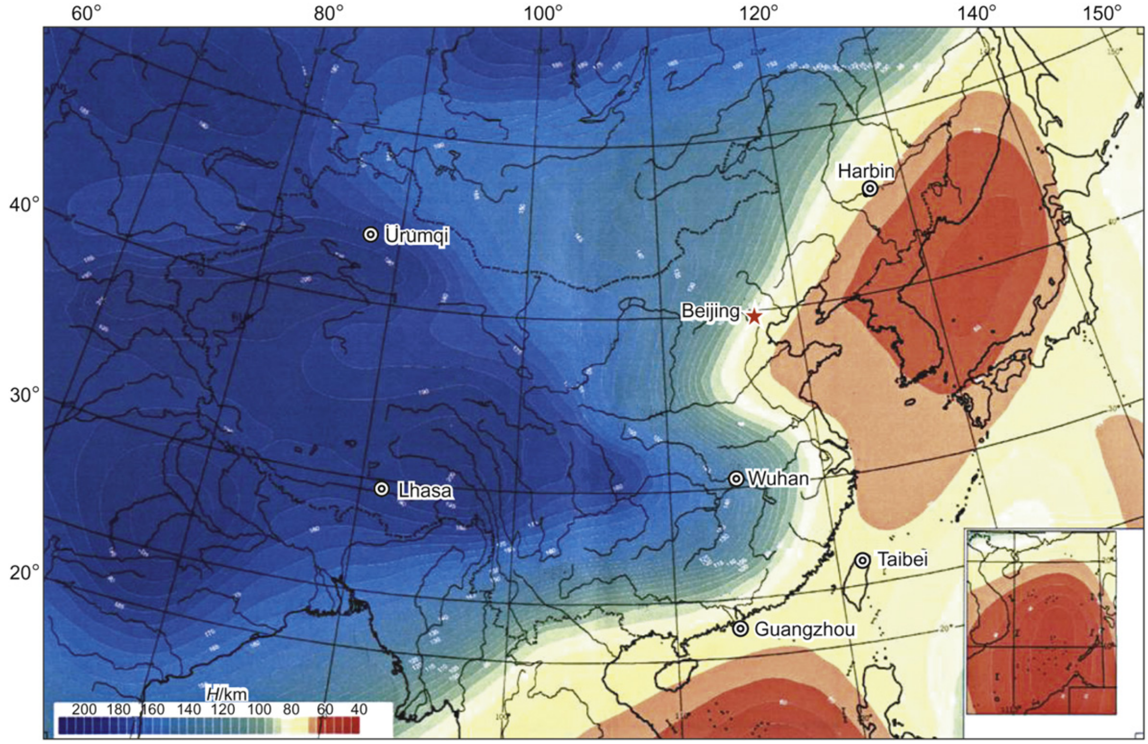

**Figure 5** Thickness distribution of the lithosphere in the continent of China and its adjacent areas (Zhu et al., 2006).

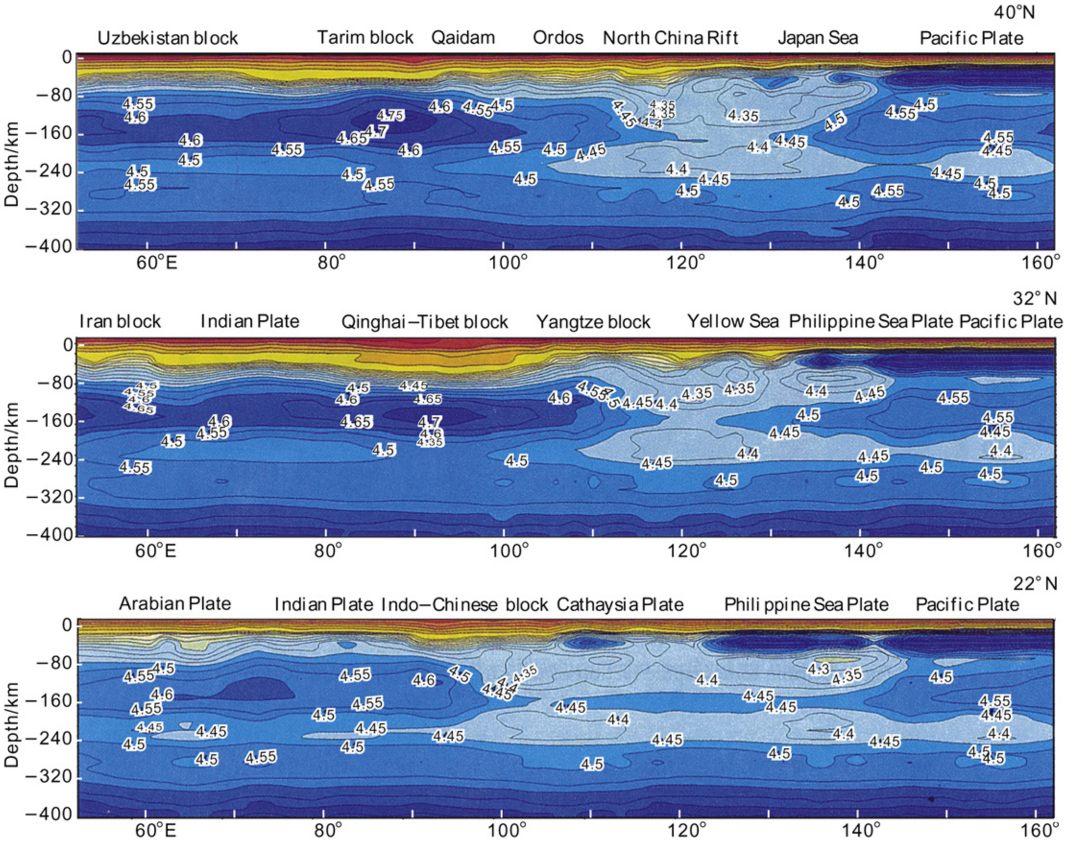

**Figure 6** Three latitudinal S-wave velocity sections traversing China (Zhu et al., 2002).

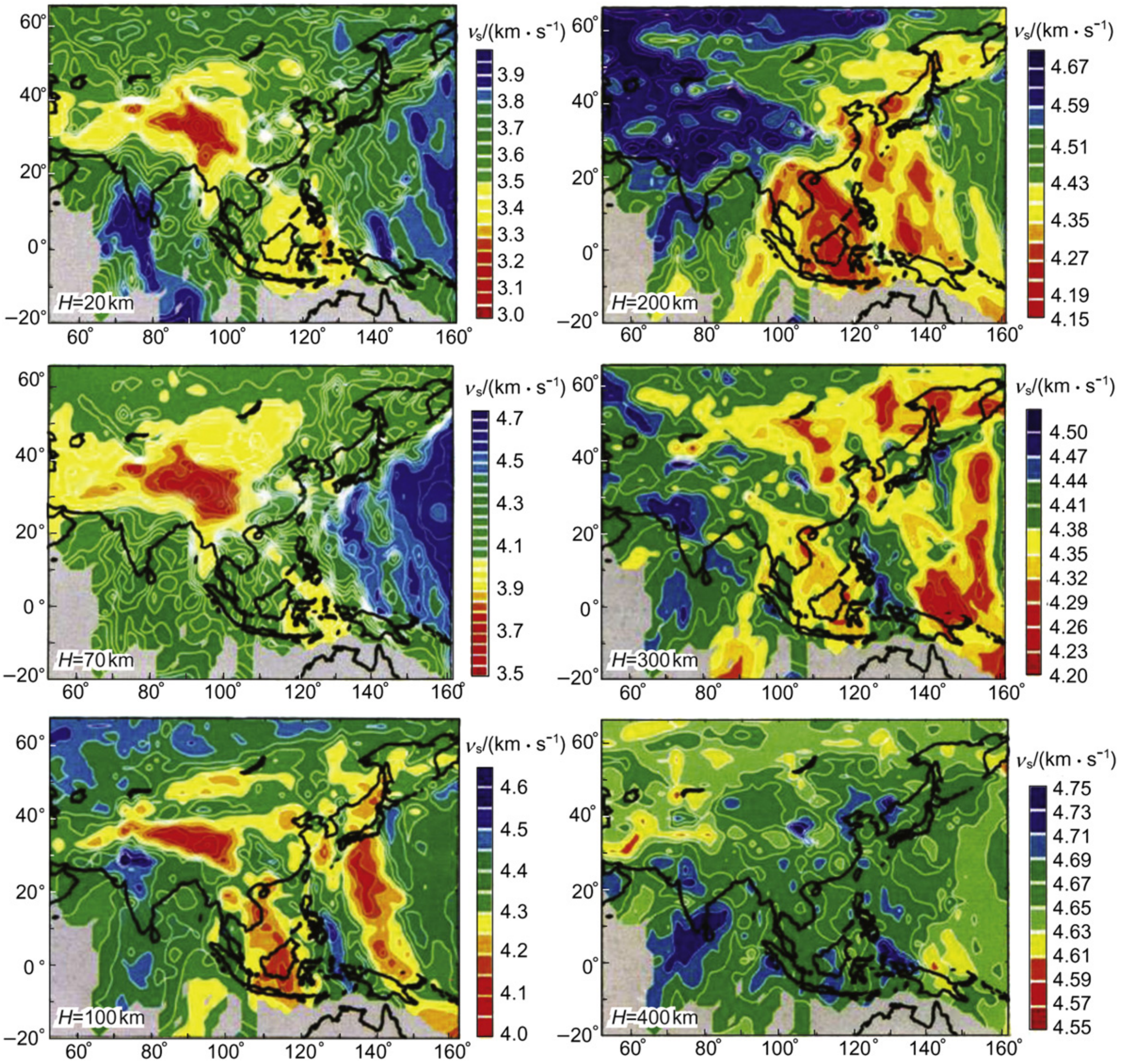

**Figure 7** High resolution surface wave tomography in the East Asia and West Pacific area (Zhu et al., 2002).

### 3.1.1. *The central Asia—Qinghai—Tibet lithosphere thickened region*

This area is shown on the figure as an eastwards-pointed triangle. In the northeast, the Altay—Qilian Mountains—Daba Mountains can be taken as a border, and in the southeast the Yichang—Kunming—Dhaka—EastGhats Mountains can be taken as another border, thus defining a huge region of lithospheric thickening. Lithospheric thickness generally ranges from 170 to 200 km, but in some areas it is as thick as 240 km, making it the thickest lithosphere worldwide.

### 3.1.2. *The China—Mongolia lithosphere thinned region*

This area includes the northern part of China and the southern parts of Mongolia and Siberia, forming a westward-pointing triangle that points towards the Da Hinggan Ling—Taihang Mountains. Its north border runs along the edges of the Zaysan Lake—Baikal—Sea of Okhotsk. The lithosphere in this area is from 85 to 170 km thick.

### 3.1.3. *The Circum Pacific lithosphere greatly thinned region*

This area includes the vast stretch of land and the adjacent wide stretch of sea to the east of the line running along the Da Hinggan Ling—Taihang Mountains and from Zhengzhou—Nanjing—Guangzhou. The thickness of the lithosphere ranges from 58 to 85 km and constitutes an area of very thin lithosphere surrounding two upper mantle domes in the Japan—East China seas and the South China sea.

## 3.2. *The thickness heterogeneity of the lithosphere*

The thickness of the lithosphere changes greatly in China and its adjacent areas, with a range of about 200 km, from 50 to 240 km. The general patterns of the thickness variations are: thicker in the west and thinner in the east, thicker in the south and thinner in the north, and thicker beneath cratonic blocks, but thinner in orogenic belts and rift basins.

In China and adjacent areas there are 4 areas of thickest lithosphere. The thickness isopleths form a circular trap. These areas are:

(1) The Pamir: its center is located at N 36°, E 72°. The thickness of lithosphere decreases from more than 200 km at the center to 185 km outwards;

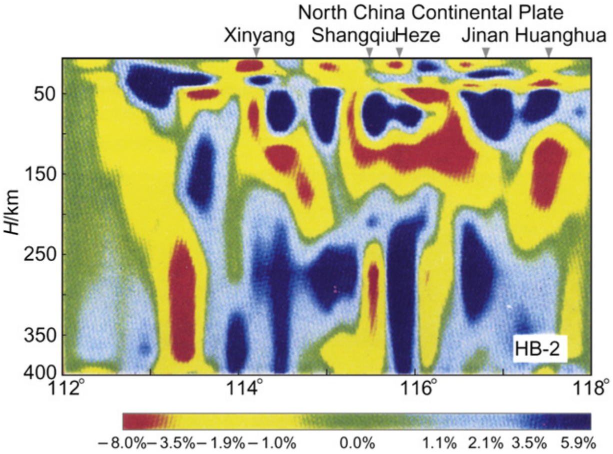

**Figure 8** Seismic tomographic section of the Qinling−North China regions (Lu et al., 2005).

(2) The east-central of Tarim: its center is located at N 41°, E 84°; the thickness of lithosphere is 200−190 km;

(3) The Ganges: its center is located in the upper reaches of the Ganges river at N 25°and E 79°. The thickness isopleths of lithosphere define a gigantic circular pattern. The maximum thickness is over 200 km.

(4) The Changdu region: if Changdu is taken as the center of this region, the lithospheric thickness isopleths form a large circular pattern. Its center is located at N 31°and E 97°. The maximum lithospheric thickness is over 200 km.

### *3.3. The lateral heterogeneity of lithospheric and asthenospheric structures*

Fig. 6 displays the $v_s$ velocity profiles at N 40°, N 32°, and N 22°, respectively. From these profiles it can clearly be seen that if one roughly takes E 105°−110° longitudes as a boundary, then the eastern and western parts of China are greatly different in terms of lithospheric and asthenospheric structures.

In the western part of China, the lithosphere and asthenosphere show an obvious layered structure. The lithosphere is about 130−200 km thick; the asthenosphere is relatively thin, at 40−100 km. This structural regime of lithosphere and asthenosphere reflects the characteristic features of the collision and convergence of the Indian Plate with the Eurasian Plate in western China. In the eastern part of China, the lithosphere and asthenosphere show a "block mosaic structure". The lithosphere is thin, at only about 50−100 km; the asthenosphere is thick, and its thickness is greatly variable within a general range 200−300 km. This structure reflects the upsurge of asthenospheric materials and the extension and thinning of the lithosphere in eastern China since the Mesozoic period.

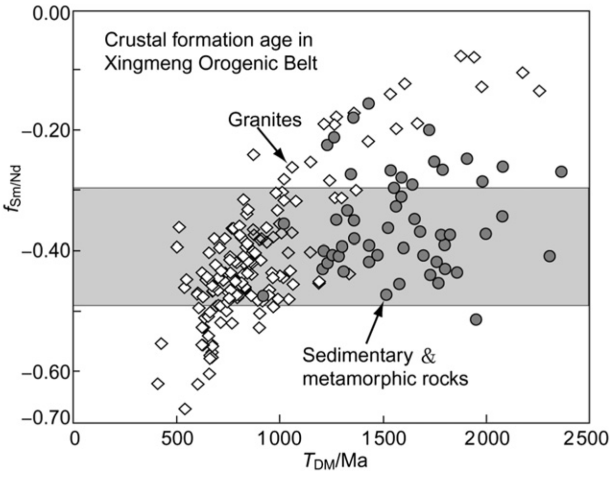

**Figure 9** Crustal formation age of Xingmeng (Hinggan−Mongolia) orogenic belt.

### *3.4. The vertical heterogeneity of lithospheric and asthenospheric structures in China and adjacent areas*

On the basis of $v_s$ tomographic lithosphere and asthenosphere imagery results from east Asia and the west Pacific (Zhu et al., 2002; Lebedev and Nolet, 2003), it is revealed that from the surface to a depth of 400 km, velocity anomalies are widely variable. This variability reflects differences in material composition, physical and chemical properties, and structure (Fig. 7). From Fig. 7 the variations between layers can be delineated.

From the surface to a depth of 70 km: Essentially taking the Da Hinggan Ling−Taihang Mountains−Wuling Mountains as a boundary separates the low velocity area in the west from the high velocity area in the east. The velocity isopleths trend nearly EW in the west, and trend mostly NS in the east. In more detail, the isopleths trend NE in South China and NW in the South China Sea. All trends are in concordance with the tectonic framework on the surface.

100−200 km: still using the Da Hinggan Ling−Taihang Mountains−Wuling Mountains as a boundary, to its west is the high velocity area; to its east is the low velocity area. The velocity isopleths on the continental part of this area trend mainly EW, while those on the oceanic part of the area trend NNW−NS. It is worth pointing out that at a depth of 100 km there is a prominent EW-trending low velocity zone in the Kunlun−Qinling orogen (probably including Qiangtang). The image of the low velocity and high velocity zones is very similar to the thickness distribution map of the area; the Pamir, Tarim, and Changdu are the 3 areas of greatest lithospheric thickness. They are all circular low velocity or relatively low velocity areas, the origin of which is still open to study.

300−400 km: with the exception of regions, south of the Siberian block, and the Hindu Kush−Kunlun−Qinling orogen which display EW low velocity zone, most other areas are high velocity zones, with an indefinite orientation of the velocity isopleths.

### *3.5. The existence of a transition zone between the lithosphere and the asthenosphere in eastern China*

Tomographic image demonstrates that in the lithospheric mantle of eastern China the high velocity (high resistivity) bodies are juxtaposed with the low velocity (low resistivity) zones (Fig. 8). Lu et al. (2005) named this "the transition zone between lithosphere and asthenosphere", or the interaction zone of lithosphere and asthenosphere. She pointed out that these regions were an important source of magma in the Cenozoic period. The high velocity bodies are probably relics of the older lithosphere and are composed of ancient fertile mantle; the low velocity bodies are probably the relics of asthenospheric bodies left by asthenospheric upsurge and are composed of depleted mantle. The widespread

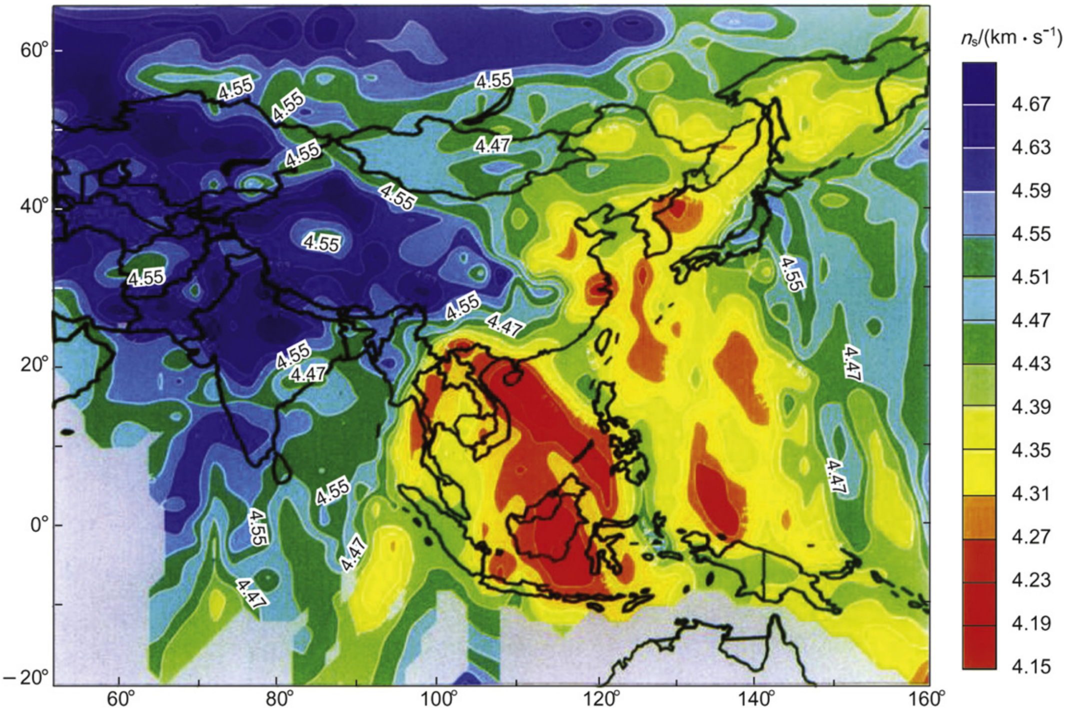

**Figure 10** The huge low velocity zone in East Asia and West Pacific marginal sea (depth 130 km).

existence of this complex transition zone confirms that intensive asthenospheric upsurge has occurred in eastern China since the Mesozoic period. The depths of the transition zone are different in various areas. For example, in northeast China the depth is 30–225 km, in north China it is 100–330 km, and in south China it is 60–300 km. In the Qinling region the transition zone appeared in two segments with depths of 60–100 km and 150–300 km, respectively.

### *3.6. The age structure of "older the upper, younger the lower" displayed in the lithosphere of eastern China*

By using Nd-isotope model ages and the results of Os-isotope dating, it is possible to study the vertical chemical structure of the lithosphere and its age sequence through the crust and lithospheric mantle. In using northeastern China as an example (Wu et al., 2003; Zhang et al., 2006), Fig. 9 shows that the supracrustal ages as reflected by Paleozoic sedimentary and metamorphic rocks are mostly Mesoproterozoic; conversely, the Nd-model age of Mesozoic granite indicates that the source area's crustal age can be traced back to Neoproterozoic period. In simpler terms, study of the granite demonstrates that the lower crust is younger than the upper crust, therefore illuminating an evident age structure of "older in the upper and younger in the lower". This kind of age structure is widespread in many areas. Zhai and Fan (2002) called this phenomenon "the Mesozoic replacement of bottom crust" in the North China craton, whereby the Precambrian lower crust was replaced by Mesozoic lower crust.

### *3.7. The gigantic low velocity anomaly in the East Asia and West Pacific areas*

Seismic surface wave tomography image inversion results indicate that there is a gigantic low velocity anomaly (Flower et al., 1998; Cai et al., 2002) stretching from the eastern margin of the Asian continent to the west Pacific. This gigantic low velocity anomaly is located beneath the Earth's surface at a depth of 85–250 km, with a thickness of about 160 km. It is 2500–4000 km wide from east to west and 12,000 km long from north to south (Fig. 10). It includes vast areas of the Asian continent, the marginal sea of the West Pacific, the Indochina peninsula, and Borneo. The following traits characterize this low velocity anomaly.

(1) The shape of the low velocity anomaly is smaller in its upper regions and larger in the lower regions; it is narrower in the north and wider in the south and, therefore, it is shaped like a clothes iron. At the depths of 85–100 km and 200–250 km there are two nearly N–S trending high velocity zones. The former begins in the coastal areas of southeastern China, and trends southwards through the Philippines to the Moluccas archipelago; the latter begins from Honshu of Japan and trends south through the Bonin Islands, the northern Mariana Islands, and finally reaches New Guinea (see Fig. 7).
(2) At about 4.20–4.35 km/s, the lithospheric $v_s$ is small.
(3) The thickness of lithosphere is a thin 50–80 km.
(4) The asthenosphere is thick, generally 300 km so, with a maximum thickness of 300–400 km.
(5) Asthenospheric $v_s$ is in the low velocity range, from 4.15 to 4.28 km/s.
(6) Within the asthenosphere there are high velocity blocks of varying scale, with velocity ranges from 4.40 to 4.50 km/s.

## 4. Conclusion and discussion

The Chinese continent is one of the most complex continents in forms of global lithosphere structure, especially because its interaction with the Siberian, Indian–Australian, and Pacific plates since the Mesozoic have yielded the following crustal and lithospheric characteristics:

(1) The mean thickness (47.6 km) of the Chinese continental crust is far greater than the planetary mean thickness (39.2 km); the crust of China is thicker in the west and thinner in the east; thicker in the south and thinner in the north. Thickness changes are pronounced. Mean crustal thickness on the Qinghai−Tibet plateau is 30 km greater than it is in coastal areas of eastern China. The crustal thickness in the middle of Tanggula on the Qinghai−Tibet Plateau is the greatest, with a difference of 70 km when compared with the thickness of the crust of the central basin in the South China Sea. On the periphery of the Qinghai−Tibet Plateau in the Da Hinggan Ling−Taihang Mountains−Wuling Mountains, in the Zhejiang−Fujian coastal area, and in the Ryukyu−Taiwan−Nansha islands there are four gravity anomaly gradient zones, constituting of four steep gradient zones of crustal thickness. The great changes in crustal thickness in China reflect the complexity of the surface topography and lithospheric structure.

(2) The crustal composition of the Chinese continent shows vertical and lateral heterogeneity, the acidity of which ($SiO_2 = 65\%$) is higher than that of the global average. The petrochemical composition is equivalent to granodioritic. The variation in acidity of the crust is higher in the east ($SiO_2 = 65.12\%$) but lower in the west ($SiO_2 = 63\%$), and higher in the south but lower in the north. In eastern China, the south China block is the highest in acidity (65.98%), while north China block ranks in the middle (64.88%), and northeast China is the least acidic ($SiO_2 = 63.18\%$). The difference in crustal acidity in various regions in the Chinese continent reflects the difference in rock association and granitic genetic types developed in these areas.

(3) The thickness of lithosphere is markedly heterogeneous. It is thicker in the west and thinner in the east, and thicker in the south and thinner in the north. The thickness varies greatly (50−240 km). In the western part of the Qinghai−Tibet Plateau and in central Asia, the lithosphere's thickness is 170−200 km, with a maximum thickness of 240 km; in the east, in the Circum-Pacific region, lithospheric thickness is 50−85 km. There are four zones of great lithospheric thickness, all of which are thicker than 200 km, in Pamir, Changdu, the central−eastern parts of the Tarim Basin and in the upper reaches of the Ganges River.

(4) The lithosphere−asthenosphere structure of China and its adjacent areas shows prominent lateral and vertical heterogeneity. In the west, the lithosphere−asthenosphere presents a layered structure, wherein the lithosphere is thick and the asthenosphere is thin. In the east the lithosphere−asthenosphere presents a "block mosaic structure", with a thin lithosphere and a thick asthenosphere. The ubiquitous existence of transitional zones between the lithosphere and asthenosphere yields a juxtaposition of steep, high velocity, high resistivity bodies set against low velocity, low resistivity bodies. From the surface down to a depth of 400 km the seismic wave velocity anomaly shows drastic changes in its nature, shape, and trend in accordance with depth; the age structure of the lithosphere is clearly characteristic of an "older in the upper, and younger in the lower" pattern.

(5) The results of seismic surface wave image inversion reveal that there is a gigantic low velocity anomaly in East Asia and the West Pacific at a depth of 85−250 km. This low velocity anomaly is 12,000 km long from north to south, and 2,500−4,000 km wide from east to west. The vast area includes East Asia, the Circum-Pacific region, the marginal sea of the West Pacific, the Indochina Peninsula, and Borneo; its origins are still open for further study.

## Acknowledgment

Much of the information in this paper is derived from the reports and papers published by colleagues working in concert on the project, "The 3-D Structure of the Lithosphere of China". This collaborative effort yielded many insights to the author of this paper. The author is furthermore indebted to the two anonymous referees who reviewed the paper and shared numerous good ideas and suggestions.

## References

Cai, X.L., Zhu, J.S., Cao, J.M., Yan, Z.Q., Yang, Z.X., Hong, X.H., 2002. Structure and dynamics of lithosphere and asthenosphere in the gigantic East Asian-West Pacific rift system. Geology in China 29 (3), 234−245.

Cui, Z.Z., Li, Q.S., Wu, C.D., Yin, Z.X., Liu, H.B., 1995. The crustal and deep structures in Golmud-Ejin Qi GGT. Chinese Journal of Geophysics 38 (Suppl.), 15−28.

Flower, M., Tamaki, K., Hoang, N., 1998. Mantle extrusion: a model for dispersed volcanism and Dupal-like asthenosphere in East Asia and the western Pacific. In: Flower, M.F.J., Chung, S.L., Lo, C.H. (Eds.), Mantle Dynamics and Plate Interactions in East Asia. Geodynamic Series, vol. 27. AGU, Washington, DC, pp. 67−88.

Lebedev, S., Nolet, G., 2003. Upper mantle beneath Southeast Asia from S velocity tomography. Journal of Geophysics Research 108 (B1), 2048. doi:10.1029/2000JB000073.

Li, T.D., 1996. The process and mechanism of the rise of the Qinghai-Tibet Plateau. Tectonophysics 260, 45−53.

Li, T.D., Dai, W.S., Wei, G.M., 2001. Geology of Asia. In: Ma, L.F. (Ed.), Altas of the Geology of China. Geological Publishing House, Beijing, pp. 5−7.

Liu, G.X., Zhang, Z.H., Han, J.T., Tang, J.H., 2006. Features of the electric structure of the lithosphere beneath the Hinggan-Inner Mongolia and Jilin-Heilongjiang region. Geology in China 33 (4), 824−831.

Lu, D.Y., Li, Q.S., Gao, R., Li, Y.K., Li, D.X., Liu, W., Zhang, Z.Y., 2000. A deep seismic sounding profile across the Tianshan Mountains. Chinese Science Bulletin 45 (22), 2100−2106.

Lu, F.X., Wu, Q.F., Li, W.P., 2005. Composition, Structure, and Interaction between Interior Layers of Lower Lithosphere in Typical Area, Eastern China. China University of Geosciences Press, Wuhan, pp. 5−16.

Pan, Y.S., Kong, X.R., 1998. Lithosphere structure, evolution and dynamics of Qinghai-Xizang (Tibet) Plateau. In: Sun, H.L., Zheng, D. (Eds.), Formation, Evolution and Development of Qinghai-Xizang (Tibet) Plateau. Guangdong Science & Technology Press, Guangzhou, pp. 3−13.

Peng, C., Gao, R., 2000. Lateral Change in the Lithospheric Asthenospheric Structures in Continental China and Its Adjacent Sea Area. Seismological Press, Beijing, pp. 1−21.

Qiu, R.Z., Li, T.D., Deng, J.F., Zhou, S., Xiao, Q.H., Ye, T.Z., Geng, S.F., 2006. Petrological structure, types and inhomogeneity of the lithosphere beneath continental China. Geology in China 33 (4), 842−851.

Tao, S.L., Wan, T.F., Cheng, J., 1999. Introduction to Earth Sciences. Geological Publishing House, Beijing, pp. 80−135.

Wan, L., Yao, B.C., Zeng, W.J., Wu, N.Y., Xia, B., Zhu, B.D., 2006. Lithospheric structure and petroleum distribution in the South China Sea. Geology in China 33 (4), 874−884.

Wu, F.Y., Ge, W.C., Sun, D.Y., Guo, C.L., 2003. Discussions on the lithospheric thinning in Eastern China. Earth Science Frontiers 10 (3), 51−60.

Xiao, X.C., Jiang, M., 2008. The Three-dimensional Structure of Lithosphere and Its Evolution in Western Part of China. Geological Publishing House, Beijing, pp. 1−237.

Yan, M.C., Chi, Q.H., 1997. The Chemical Composition of Crust and Rocks in the Eastern Part of China. Science Press, Beijing, pp. 156—170.

Yin, X.H., Shi, Z.H., Liu, Z.P., 1989. Bouguer gravity anomalies averaged in grid 1°×1°. In: Ma, X.Y. (Ed.), Lithospheric Dynamics Atlas of China. China Cartographic Publishing House, Beijing, p. 8.

Zhai, M.G., Fan, Q.C., 2002. Mesozoic replacement of bottom crust in North China Craton: anorogenic mantle-crust interaction. Acta Petrologica Sinica 18 (1), 1—8.

Zhang, X.Z., Yang, B.J., Wu, F.Y., Liu, G.X., 2006. The lithospheric structure in the Hingmeng-Jihei (Hinggan-Mongolia-Jilin-Heilongjiang) region, northeastern China. Geology in China 33 (4), 816—823.

Zhao, G.Z., Chen, X.B., Wang, L.F., Wang, J.J., Tang, J., Wan, Z.S., Zhang, J.H., Zhan, Y., Xiao, Q.B., 2008. Evidence of crustal channel flow in the eastern margin of Tibet Plateau from MT measurements. Chinese Science Bulletin 53 (12), 1887—1983.

Zhao, G.Z., Tang, J., Zhan, Y., Chen, X.B., Zhuo, X.J., Wang, J.J., Xuan, F., Deng, Q.H., Zhao, J.M., 2005. Relation between electricity structure of the crust and deformation of crustal blocks on the northeastern margin of Qinghai-Tibet Plateau. Science in China, Series D 48 (10), 1613—1626.

Zhu, J.S., Cai, X.L., Cao, J.M., Yan, Z.Q., 2006. Lithospheric structure and geodynamics in China and its adjacent areas. Geology in China 33 (4), 793—803.

Zhu, J.S., Cao, J.M., Cai, X.L., Yan, Z.Q., Gao, X.L., 2002. High resolution surface wave tomography in east Asia and west Pacific Marginal Seas. Chinese Journal of Geophysics 45 (5), 646—664.