Surveying of the deformed terraces and crust shortening rate in the northwestern Tarim Basin

SHEN Jun[1,2], WANG Yipeng, ZHAO Ruibing[2,3], LI Jun[3], D. Burbank[4] & K. Share[4]

1. Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China;
2. Institute of Geology of China Seismological Bureau, Beijing 100029, China;
3. Xinjiang Seismological Bureau, Urumqi 830011, China;
4. Department of Geosciences of Pennsylvania State University, PA 16802-2714, USA;

Correspondence should be addressed to Shen Jun (e-mail: shenjuneq @263.net)

Abstract **Relief surveying and chronology study were carried out on the deformed river terraces across the Artushi anticline belt in the northwestern Tarim Basin. The crust shortening rate of this anticline belt since late Pleistocene was calculated to be up to 5—6 mm/a. The total crust shortening rate from the northwestern Tarim Basin to southwestern Tianshan since late Pleistocene was estimated to be over 10 mm/a.**

Keywords: Tarim Basin, deformed river terrace, crust shortening.

In Cenozoic, the intensive tectonic deformation has occurred in the inland of Asia due to the collision between India and Asia. The area from Pamir to the Tarim Basin and southern Tianshan is one of the most deformed provinces[1—6]. The principle deforming style in this area is characterized as the crust shortening due to the northward indenting of the western syntaxis of the Himalayan Mountains. A series of strong earthquakes have occurred in the west of the Tarim Basin, such as the 1902 Artushi M=8.3 earthquake, the 1985 Wuqia M=7.4 earthquake[8] and the 1997 — 1998 strong earthquake swarm of 9 M>6 earthquakes. These strong earthquakes indicate very intensive present tectonic movement. The GPS results show that the crust shortening rate of northwestern Tianshan in Kykistan and Kazkhstan is around 13 mm/a. According to geological deformation and earthquake moments, the crust shortening rate of southwestern Tianshan is around 6 mm/a. The total shortening rate of Tianshan is almost 20 mm/a[9]. However, for lack of quantitative studies on the 10 ka time scale crust shortening rate of Chinese southwestern Tianshan, the shortening rate of Tianshan is only a rough estimation.

In the compressive areas, the late Quaternary crust shortening rate can be reliably estimated by accurate relief surveying and dating on deformed river terraces. Avouc et al. and Yang et al. estimated the crust shortening rate of thrust fault-anticline belt in front of Chinese northern Tianshan by surveying and dating the deformed terraces [10,11].

In 1998, we surveyed the deformed terraces of the Boguzi River across the Artushi anticline belt with the level. In 1999, we surveyed again with the differential GPS in the same area. The two results are similar. We also collected TL dating samples on every terrace, processed them in the Institute of Geology of China Seismologic Bureau and got the ages of each terrace. Therefore, we calculated the crust shortening rate since late Pleistocene in the northwestern Tarim Basin.

1 Tectonic site of the deformed terraces

The northwestern Tarim Basin is a younger compressive tectonic area between Pamir-west Kunlun arcuate tectonic belt and the southwestern Tianshan. Its thousands meter thick Cenozoic layers have been intensively folded. On the northeastern piedmont of western Kunlun Mountains, the cover layers of the Tarim Basin constructed the external Pamir arcuate structure[4], and on the southern piedmont of southwestern Tianshan they constructed the Keping thrust belt [5,6,12]. Since Middle Quaternary, two nascent thrust fault-anticline belts, the Artushi thrust fault-anticline belt and Lashi thrust fault-anti- cline belt, have been formed between the external Pamir arcuate structure and the Keping thrust belt in the cover layers of the basin (fig. 1).

The Artushi thrust fault-anticline belt is composed of several lateral thrust fault-anticlines in the northwestern Tarim Basin (fig. 1). The folded layers of Artushi thrust fault-anticline are of Upper Tertiary and Lower Pleistocene. Dipping angles are gentler (20°—30°) in the south flank and steeper in the north flank (erect or even reversed). A south dipping low angle thrust fault developed in the core of the anticline. Most part of the northern flank has been under thrust and concealed (profiles A and B in fig. 1). Attitude in the outcrop of the thrust fault is 150°∠40°. Very fresh fault scarp of Paleoearthquakes developed along the fault[10]. This anticline belt was been very active since Middle Quaternary. There have been 5 strong earthquakes with M=6—6.5 occurring along this anticline belt, according to the historical earthquake record.

The river terraces across the Artushi anticline belt have been warped up[13]. Those of the Boguzi River perpendicularly across the Artushi anticline are well reserved. They have typical deformed features. It is an ideal site to carry out quantitative study of the deformed terraces to acquire the crust shortening rate in present thousands of years.

2 Surveying of deformed terraces and calculation of deformation magnitude

(i) Surveying of deformed terraces. In 1998, we surveyed the T2, T3 and T4 terraces with level and range

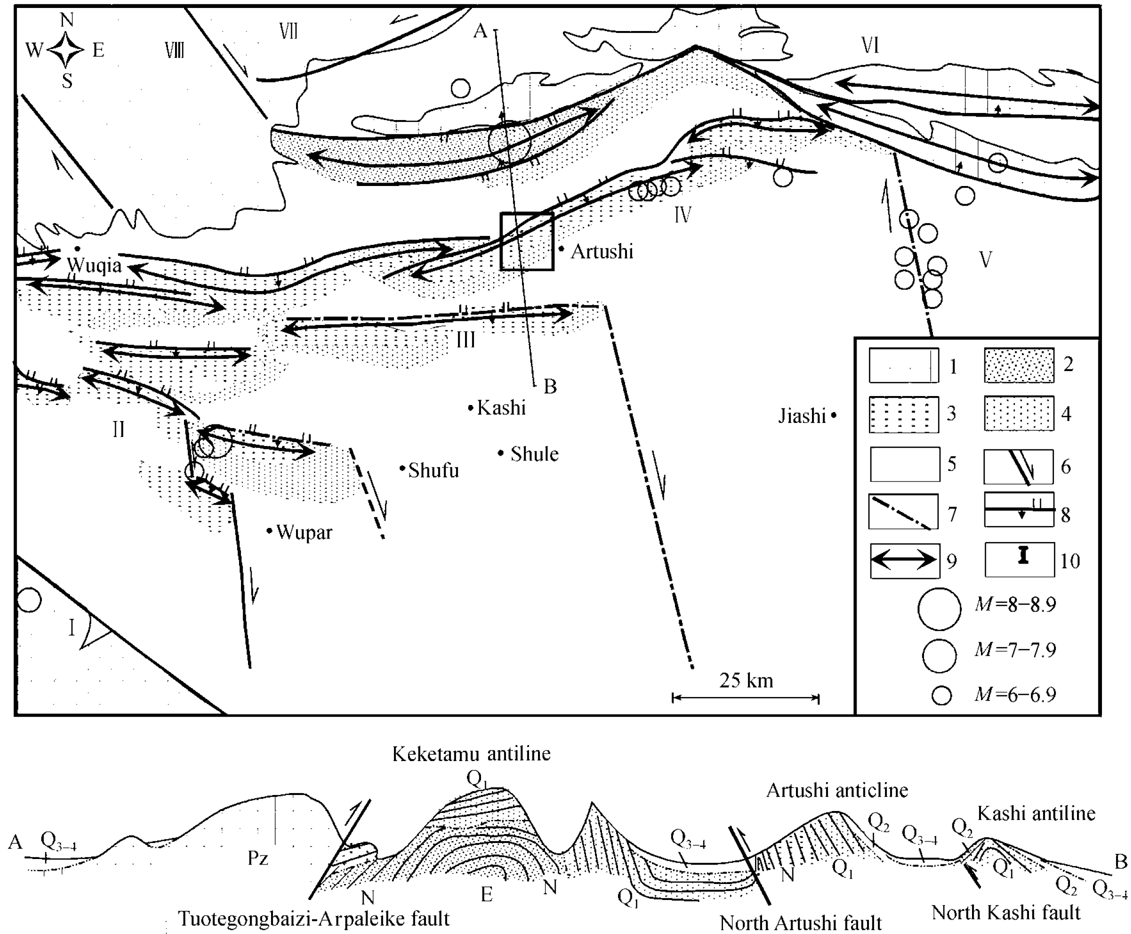

Fig. 1. The principal tectonic belt in the northwestern Tarim Basin. 1, Late Paleozoic; 2, Tertiary; 3, Upper Tertiary; 4, early Pleistocene; 5, middle Pleistocene; 6—8, Holocene active fault; 6, strike slip fault; 7, concealed fault; 8, thrust fault; 9, anticline; 10, seriel number of tectonic belt; Ⅰ, western Kunlun tectonic belt; Ⅱ, external Pamir (Wupar) arcuate structure belt; Ⅲ, Kashi thrust fault-anticline belt; Ⅳ, Artushi thrust fault-anticline belt; Ⅴ, Keping thrust belt; Ⅵ, east of southwestern Tianshan; Ⅶ, west of southwestern Tianshan. In the geological profile, all faults are Holocene active. The Tuotegongbaizi-Arpaleike fault is active in N and Q. The north Artushi fault and north Kashi fault are active since Q_2.

finder, combining with the 1∶10000 relief map (fig. 2). In 1999, we resurveyed the most intensively deformed northern parts of T3 and T4 terraces with differential GPS. Our equipment is GPS system 500 made by Leica-Geo-system Company. The GPS receiver is Leica SR530. Based on the reference, which is an unmoving GPS receiver and the rover, which is a moving GPS receiver, the system can reduce the error and improve the resolution. The vertical resolution is about 5 mm+1 ppm. Our surveying profiles are less than 5 km. Theoretically, the vertical error is no more than 1 cm. It is accurate enough for the quantitative study on the thousands time scale tectonic deformation. The results of 1999 differential GPS surveying and 1998 level surveying are very close to each other (fig. 3(a), (b)).

To improve the efficiency, we got the data for the slightly deformed south part of higher terraces, the lower terraces and the flood bed from the 1∶10000 relief map to finish the relief profiles across the whole anticline (fig. 3).

(ii) Estimation of crust shortening. Normally, the magnitude of crust shortening is calculated by the balanced tectonic layers. In our work, the deformed terraces are formed in about 20000 years. Relative to the kilometers deformation formed in nearly one million years, it is a small deformation issue. It cannot be calculated with the balanced layers. The surveyed profiles of the terraces show that the terraces are warped up around an axis and only curved down near the northern ends. The corridor geological mapping of the anticline shows that it is a typical kink band and the deformation is relative to the thrust fault. The character of the deformed terraces coordinates with the kinetics of the kink band. Therefore, we use the following simple equation to calculate the crust shortening of the small deformation issue:

$\Delta L \approx \tan\theta \cdot H'$(here θ is the dipping angle of the thrust fault).

The dipping angle of the thrust fault is around 40±2°, which is got from the trenches we excavated along the thrust fault. The calculated crust shortening is 90 m for T4, 70 m for T3 and 21 m for T2 (table 1).

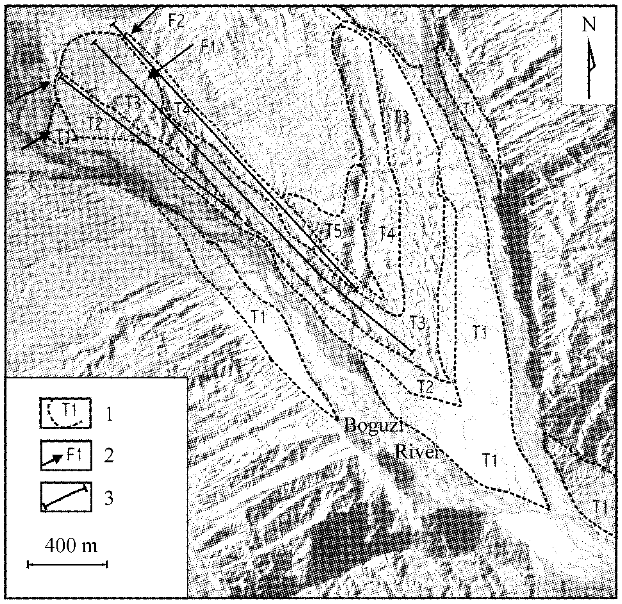

Fig. 2. The air-photography of the terraces of the Boguzi River across the Artushi anticline and the surveying route. 1, Boundary of terrace; 2, position of fault; 3, surveying route.

Table 1 The results of the quantitative study on the deformed terrace of Artushi anticline

No. of terrace	Magnitude of warping up	Crust shortening/m	Age of terrace/ kaBP	Warping up rate/mm • a^{-1}	Crust shortening rate/mm • a^{-1}
T2	20	21	6.08±0.47	3.5	3.5
T3	61	70	11.7±0.9	5.2	6
T4	78	90	16.9±1.3	4.7	5.3

3 Ages of the deformed terraces and crust shortening rate

(i) Ages of the deformed terraces. Besides the amount of the crust shortening, the ages of the deformed terrace are also the key element to estimate the crust shortening rates.

All terraces of the Boguzi River are substrate terraces. The substratum is Neogene fine sand stone, silty clay, and the Lower Pleistocene gravel bed. The deposit is 1—2 m-thick gravel bed (most gravel is limestone cobble with the radio of 2—10 cm), inbedded partially by silt and fine sand lens beds. No organic carbon was found. Even though there are many methods to date the young geological or geomorphological body, the only dating method available for these terraces is the thermal-luminoferous (TL), because this method can be used to date the burial age of the fine sand and the silt to represent the age of these terraces.

We collected the TL samples in the deposits of T2—T4 terraces and processed them at the TL Laboratory of the Institute of Geology of China Seismological Bureau. The samples have high signals. The dating results are reliable. The ages of T2, T3 and T4 terraces are (6.08±0.47) ka, (11.7±0.9) ka and (16.9±1.3) ka, respectively. We calculated the warping up rate and crust shortening rate of each terrace from the deformation magnitudes and the ages of terraces. The average crust shortening rate is around 5.3 mm/a since late Pleistocene, 6 mm/a since early Holocene and 3.5 mm/a since middle Holocene (table 1).

(ii) Error estimation. There are errors in the surveying of deformed terraces, the calculation of the deformation, the collection and procession of dating samples. The error of the procession dating samples is about 8%. The site of the samples and the condition of the samples also make a little error, up to 10%—20%. Considering the errors in the relief surveying and calculation in the crust shorting, the total error may reach 30%. Therefore, the average crust shortening rate is about (5.3±1.6) mm/a since late Pleistocene, (6.0±1.8) mm/a since early Holocene and (3.5±1.0) mm/a since middle Holocene. Obviously, the rate was higher in late Pleistocene and early Holocene, but it slowed down since middle Holocene.

4 Results and discussion

The Artushi anticline belt we studied is only one of the tectonic belts between the northwestern Tarim Basin and the southwestern Tianshan. From the satellite images and air-photographs, the field observation and the results of other researchers on this area, the late Quaternary tectonic movement of the Keketamu anticline belt and the Tuotegongbazi-Arpaleike active fault in the north of the Artushi anticline belt is not weaker than that of the Artushi anticline belt. There occurred the 1902 Artushi M=8.3 earthquake. The terraces across the Keketamu anticline belt and the Tuotegongbazi-Arpaleike active fault have also warped up. However, the poor reservation of the terraces makes it very difficult to carry out the accurate quantitative study. We have not extended the surveying to this belt. Nevertheless, according to the magnitude of geological and geomorphological deformation, we estimated that the crust shortening rate in late Quaternary of this tectonic belt is no smaller than that of the Artushi anticline belt. Thus, the crust shortening rate, made by the thrust faulting and folding, between the northwestern Tarim Basin and southwestern Tianshan is no less than 10 mm/a.

The average crust shortening rate since middle Holocene is obviously smaller than that since late Pleistocene. There are two possibilities. One is that the average crust shortening rate has been slowed down since middle Holocene. The other is that the some elastic deformation has not been converted to permanent deformation by the strong earthquakes, because the observed deformation on the surface is mostly performed by intermittent strong

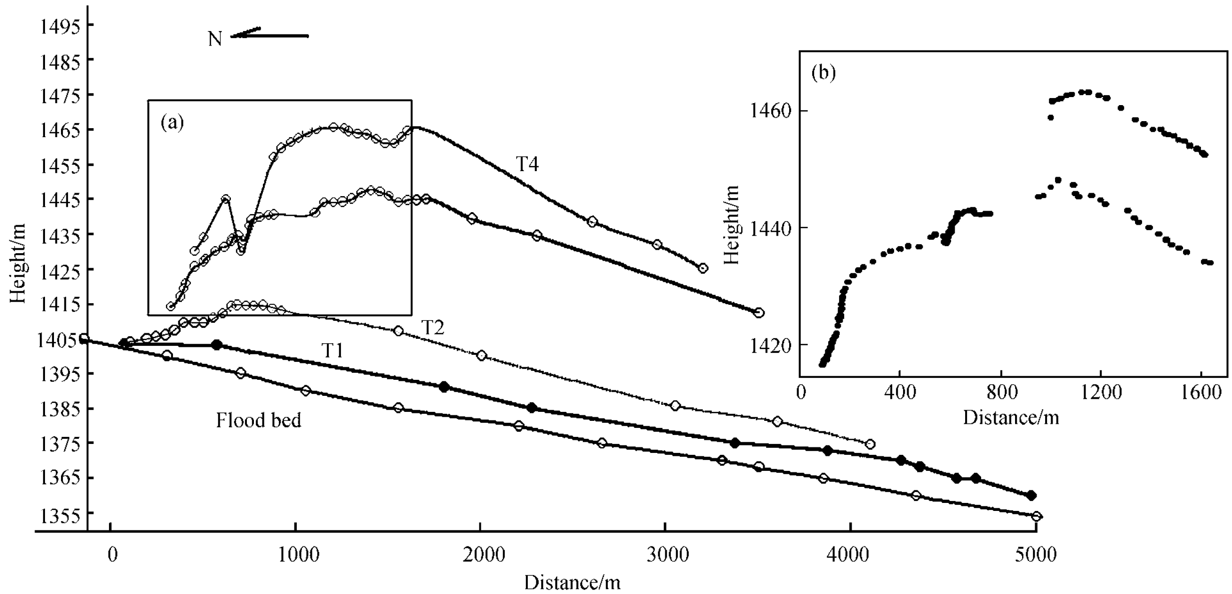

Fig. 3. The surveyed relief profiles of the deformed terraces of the Boguzi River. (a) Profiles surveyed by level and meter; (b) profiles surveyed by differential GPS.

earthquakes. Deficiency of crust shortening indicates that some of the elastic strain has not been released to the visible deformation by strong earthquakes. If a strong earthquake occurred in the near future and about 10 m crust shortening was made, the average crust shortening rate since middle Holocene would be the same as that since late Pleistocene. Normally, the magnitude of the tectonic movement does not change in a relatively short period. The lower rate of crust shortening since middle Holocene indicates that a large amount of elastic energy has stored, and there is a high risk of strong earthquake in the Artushi thrust-anticline belt.

The geophysical sounding of Jiashi project and the petroleum prospecting reveal that the movement between different depths of the crust of the Tarim Basin is not coordinate. Under the compression from south to north, the basement of the Tarim Basin, with high density, is subduction northward into the front of Tianshan, while the cover layers of the basin, with lower density, have formed the two thin-skin thrust. One is the Artushi anticline belt and Kashi anticline belt. It is thrusting northward. The other is Keping Thrust, which is composed of 4—5 thrust fault-anticline belts. It is thrusting southward. Detachment occurred between lower crust and upper crust. Nevertheless, the subduction rate of the Tarim Basin toward the Tianshan should coordinate with the crust shortening rate of the cover layers of the Tarim Basin, and the rate is no less than 10 mm/a.

Acknowledgements This work was supported by the National Natural Science Foundation of China (Grant No. 49834005), the Commission of Science and Technology of China (Grant No. 96-913-07-01) and the Key Project of the Earthquake Joint Foundation (Grant No. 9507438).

References

1. Burtman, V. S., Molnar, P., Geological and geophysical evidence for deep subduction of continental crust beneath the Pamir, Geol. Soc. Am., 1993, Spec Pap 281: 1.
2. Liu Xuefeng, Chen, L., Xiao, A. et al., The characteristics of Cenozoic deformation of the western Tarim Basin during the India-Asia collision, Oil and Gas Geology (in Chinese), 1995, 16(3): 234.
3. Sobel, E. R., Dumitru, T. A., Thrusting and exhumation around the margins of the western Tarim Basin during the India-Asia collision, Journal of Geophysical Research, 1997, 102(B3): 5043.
4. Chen Jie, Qu, G., Hu, J. et al., The basic characteristics and present seismicity along the eastern segment of the arcuate thrust tectonics in the north edge of Pamir, Seismology and Geology (in Chinese), 1997, 19(4): 301.
5. Allen, M. B., Vincent, S. J., Late Cenozoic tectonics of the Kepingtage thrust zone: Interaction of the Tien Shan and Tarim Basin, Northwest China, Tectonics, 1999, 18(4): 639.
6. Yin, A., Nie, S., Craig, P. et al., Late Cenozoic evolution of the southern Chinese Tian Shan, Tectonics, 1998. 17(1): 1.
7. Bai Meixiang, Ge, S., 1902 Artushi M=$8^1/_4$ earthquake (ed. Ma, Z.), The Study on the Huge Earthquake of China (1) (in Chinese), Beijing: Earthquake Press, 1988, 143—170.
8. Feng Xianyue, The rupture zone of Wuqia earthquake. (ed. Active Fault Research Edition Committee), Active Faults Research (3) (in Chinese), Beijing: Earthquake Press, 1994, 45—55.
9. Abdrakmatov, K. Ye., Aldazhanov, A., Hager, B. H. et al., Relatively recent construction of the Tian Shan inferred from GPS measurements of present day crustal deformation rates, Nature, 1996, 384: 450.
10. Avouac, J. P., Tapponnier, P., Bai, M. et al., Active thrusting and folding along the North Tian Shan, and Late Cenozoic Rotation of the Tarim relative to Dzhungaria and Kazakhsta, J. Geophys. Res., 1993, 98(B4): 6755.
11. Yang Xiaoping, Deng, Q., Zhang, P. et al., Study on the late Pleistocene folding features of the Tugulu thrust fault-anticline belt in north Tian Shan (ed. Active Fault Research Edition Committee), Active Faults Research (5) (in Chinese), Beijing: Earthquake Press, 1996, 42—53.
12. Qu Guosheng, Chen, J., Chen, X. et al., The preliminary study on the Jiashi moderate-strong earthquake swarm and the future seismic trending (ed. Institute of Geology of China Seismological Bureau), The Study on the Earthquake Risk Prediction (1999) (in Chinese), Beijing: Earthquake Press, 1998, 158—168.
13. Luan Chaoqun, Bai, M., Xiang, Z., The evaluation on the seismogenic tectonics of the Artushi region, Xinjiang, Geology of Xinjiang (in Chinese), 1998, 16(1): 76.

(Received October 19, 2000)