Q value structure of geoscience transect from Korla to Jimsar and its geodynamic implication

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Abstract In this paper, the methods for *Q* value inversion in 2-D lateral inhomogeneous medium have been introduced. The 2-D *Q* value inversion has been conducted using seismic wide-angle reflection/refraction data of the profile from Korla to Jimsar. The result shows that the 2-D *Q* value structure of the transect from Korla to Jimsar is characterized by vertical stratifying and lateral zoning. Vertically, the crust can be divided into upper crust, middle crust and lower crust with the *Q* value increasing downwards. Horizontally, the total transect can be classified as three regions——the northern margin of the Tarim Basin, the Tianshan orogenic belt (TOB) and the southern margin of the Junggar Basin. At the northern margin of the Tarim Basin the *Q* value increases northwards, indicating a northward subduction of the Tarim Basin (TB) into the TOB. The *Q* value within the TOB jumps near Kumux, making a stage-like difference in *Q* value. The *Q* value distribution at the southern margin of the JB suggests a southward subduction of the Junggar Basin (JB) into the TOB.

The double subduction pattern of the TB and JB into the TOB revealed by the transect from Korla to Jimsar has a big difference from the model " lithospheric subduction with intrusion of the layers into the crust" developed according to the results of the geoscience transect from Xayar to Burjing. The differences between the two provide some dynamic evidence at lithospheric scale for the segmentation of the TOB.

Keywords: *Q* value structure, Tarim Basin, Tianshan orogenic belt, Junggar Basin, subduction, geodynamics.

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The TOB is one of the youngest and highest intracontinental orogenic belts in Middle Asia. It plays a very important role in accommodating the convergence between Indian Continent and the Siberian Continent, and therefore, it is widely noticed by geoscientists worldwide.

Up to now, several geoscience transects crossing the TOB have been carried out. They are natural earthquake profile from Karakorm to Ferghana[1], seismic reflection/refraction profile from Xayar to Burjing1) and the profile from Koktokay to Aksay2). The overseas research shows that the Ferghana Basin subducts southwards into the southern Tianshan at the depth of about 200 km. In

1) Zhang Xiankang, Zhang Chengke, Jia Shixu et al., A summary report on exploration and research on GGT (in Chinese), 1999.

2) Xu Xinzhong, A summary report on the results of seismic exploration on the comprehensive geophysical profile from Kktuohai to Aksai (in Chinese), 1990.

the western segment of the TOB in China the comprehensive geophysical profile from Xayar to Burjing shows a lithospheric subduction of the TB into the upper mantle of the TOB at the depth of about 180 km with some intrusion layers into the crust[2—6]. The transect from Koktokay to Aksay reveals that there are not obvious subductions at the boundaries between JB and TOB and between the TB and TOB. That means that the TOB extending about 3000km has different tectonic features at different segments.

Based on the research mentioned above, the study of "3-D Deep Structure of the Typical Superposed Basins in China" suppotred by the National Research 973 (Grant No. 1999043301) has been conducted. The comprehensive exploration and research of the geoscience transect from Korla to Jimsar are part of this project.

Starting at Karquge, Yuli at the northern margin of the TB (85°22′13.7″E, 40°57′46″N) and ending at Jimsar (88°57′47″E, 44°50′58.6″N) at the southern margin of the JB, the transect with a length of 597.2 km crosses the northern margin of the TB, the TOB and the southern margin of the JB. Along the profile chemical explosions at Yuli, Heshuo, Kumux, Toksun and Jimsar with TNT of 2T for each have been carried out, and 204 receivers of DAS-1 and DAS-2 modes have been used to record the energy. All the receivers with a spacing of 3km in average and 1.5km in some complicated tectonic regions were positioned by GPS. The observational system is shown as fig. 1.

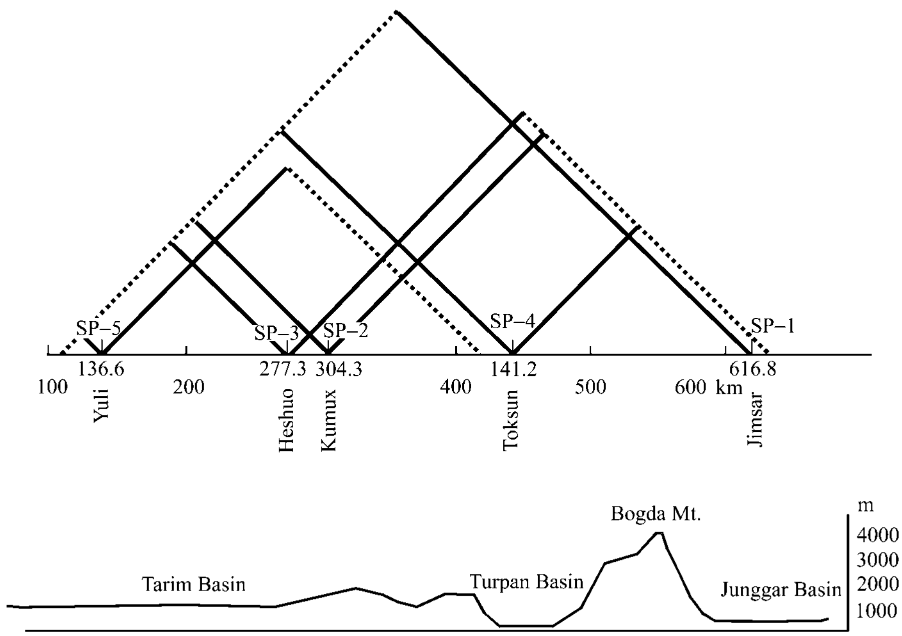

Fig. 1. Observational system for seismic wide angle reflection/refraction profile.

Based on the 2-D velocity structure, 2-D density structure and 2-D magnetic structure, this paper deals mainly with Q value structure of the transect by using seismic data to present dynamic parameters for the research of the lithospheric structure and the tectonic segmentation of the TOB, and for the creation of the comprehensive geodynamic model of northwestern China.

1 Method for *Q* value inversion in 2-D lateral inhomogeneous medium

The *Q* value describes the non-complete elasticity, which causes the energy attenuation of the seismic waves in propagation. The micro mechanism of the energy attenuation is rather complex, but macroscopically, it can be summarized in three types such as solid attenuation by "inner friction", mechanical structure effect by coupling between layers and diffusing by inhomogeneity. The total effect of these three attenuations is embodied by *Q* value, a quality factor of the medium.

1.1 Calculation of observed differential attenuation t^*_{obs}

The quality factor *Q* of the earth medium shows the transportation power of the medium to seismic waves. The larger the *Q* value is, the stronger the transportation power of the medium to seismic waves will be; otherwise, the power would be weak. The definition[7] is as follows:

$$\frac{1}{Q(\omega)} = \frac{1}{2\pi}\frac{\Delta E}{E}, \tag{1}$$

where ΔE is the energy attenuation of seismic waves in one period (time domain) or one wavelength (space domain), E is the maximum energy of a wave. Generally, *Q* value is the function of frequency ω and position.

We know from exponent attenuation term $e^{-\pi f t^*}$ that t^* is an important physical parameter, which shows an exponent attenuation law to the seismic waves. It is usually a function of frequency and position. For solid body both the laboratory experiment and the field seismic practice indicate that *Q* value does not depend on frequency basically within an observed frequency band. After neglecting dispersion and adopting constant *Q* model the differential attenuation t^* can be written as

$$t^* = \int_{r(x,z)} \frac{1}{Q(x,z)} \bullet \frac{1}{V(x,z)} \mathrm{d}r(x,z), \tag{2}$$

where *Q* is an apparent quality factor, $1/Q$ is an apparent attenuation, including inherent attenuation $1/Q_i$ and diffusion attenuation $1/Q_s$. Here Q_i is a quality factor related with effect of inner friction coupling between layers. Q_s is a quality factor related with diffusion; $V(x, z)$ is velocity of the waves. At present, it is difficult to distinguish the diffusion attenuation caused by inhomogeneous medium from the inherent attenuation caused by inner friction. So, the obtained attenuation is called apparent attenuation or total attenuation.

For artificial source, the amplitude attenuation caused by propagation along the path, absorbed by medium and by diffusion follows exponent law. Haskell[8] calculated spectral response of P wave, SV wave and SH wave to any layered crust structures. The result shows that the total response of the waves with different periods, and different incident angles on surface and in the crust is between 1 and 2. We usually take 2, when neglecting the layered crustal structure.

Studies[9] show that t^* bears little variation with the length of a window function. The length of the window is taken as 1.5—3.0 s for P wave and 2.5—5.0 s for S wave. In our research it is taken as 1.0—3.0 s.

1.2 The inverse problem of *Q* value

The forward calculation of *Q* value is mainly to calculate theoretic t^* using 2-D ray tracing through formula (2). The velocity *V* is obtained by seismic CT to 2-D traveling time, which will keep unchanged in the processes of *Q* value inversion. This means that the *Q* value decouples from ray path and the t^* value is only related with the disturbance of the *Q* value.

The disturbance of seismic wave t^* caused by the disturbance of *Q* value at any node points of a 2-D network is

$$\delta t^* = \sum_{l=1}^{N_l} -\frac{\Delta S_l}{2}\left(\frac{1}{V_{l-1}Q_{l-1}^2} \sum_{\substack{m=i \\ n=j}}^{\substack{j+1 \\ i+1}} \frac{\partial Q_{l-1}}{\partial Q^{m,n}} \delta Q^{m,n} + \frac{1}{V_l Q_l^2} \sum_{\substack{m=i \\ n=j}}^{\substack{j+1 \\ i+1}} \frac{\partial Q_l}{\partial Q^{m,n}} \delta Q^{m,n} \right). \quad (3)$$

The inverse problem of *Q* value can be attributed to solve the nonlinear system of equations by iteration

$$\boldsymbol{A}\Delta\boldsymbol{m} = \Delta\boldsymbol{\gamma}, \quad (4)$$

where $\boldsymbol{A}$ is a partial derivative matrix composed of $\partial t^* / \partial Q$. $\Delta\boldsymbol{m}$ is a model vector composed of residual of *Q* value, and $\Delta\boldsymbol{\gamma}$ is a residual vector composed of observed t^*_{obs} and calculated t^*_{cal}.

2 Data processing and the results

The data processing can be roughly divided into four steps. The first is to determine the seismic phases of Pg and Pm, and the time window for spectrum analysis. The second is to conduct the spectrum analysis and to obtain amplitude spectrum. The third is to obtain t^*_{obs} by fitting of measured amplitude spectrum with theoretic amplitude spectrum. The last is to realize *Q* value inversion.

In our study we use some digital recorders with sample rate of 200 points per second. The highest frequency is 100 Hz and the lowest one is 0.2 Hz. The highest frequency spectrum resolution is 0.2 Hz and the lowest one is 0.33 Hz. A Hanning window with a lower spectrum resolution has been adopted to decrease the spectrum “leakage”. The length of this window function should be integral multiple of a signal period in order to avoid at the greatest degree the man-made frequency components.

The calculated spectrum should be corrected in both freedom surface and frequency feature of the instruments based on the displacement spectrum of the remote fields, including such factors as inherent attenuation, diffusion attenuation, geometric divergence and source radiation, etc. The fitting of the calculated theoretical amplitude with corrected observed amplitude is conducted by means of nonlinear least square solution.

For the same shot a unified f_c has been taken to further reduce uncertainty of the t^*_{obs} and to increase the accuracy, because there exists only one corner frequency for each shot. The error range of t^*_{obs} is 0.004—0.0018 s, with the most being about 0.001s. Some amplitude fittings are shown in figs.2 and 3.

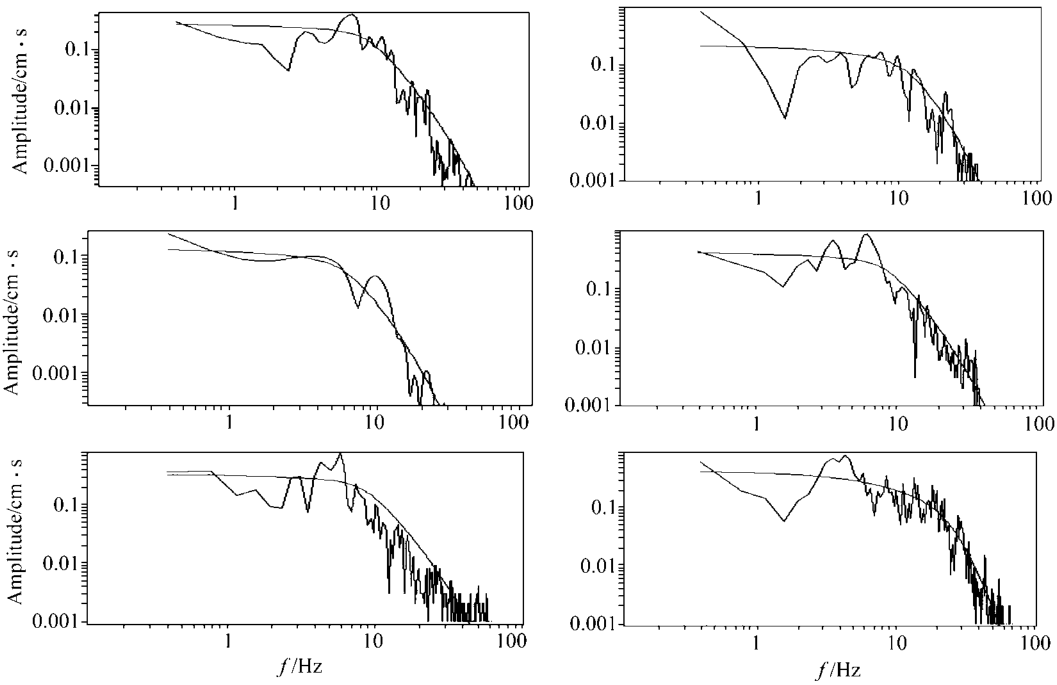

Fig. 2. Some amplitude fittings of Pg waves from shot point Yuli (SP 136.55).

After obtaining t^*_{obs} the t^* fitting by nonlinear least square method with dump has been conducted using 2-D ray tracing program modified by us. Just as the way of travel time inversion, the travel time inversion is to calculate theoretical travel time by forward modeling when the initial velocity model is given and then to fit observed travel time t_{obs} with theoretical travel time t_{cal} by using inversion program, while the Q value inversion is to obtain theoretical t^*_{cal} by ray tracing and forward modeling under a given velocity model (unchanged in the processes of inversion) and Q value model, and by fitting theoretical t^*_{cal} with observed t^*_{obs} (t^* obtained by amplitude fitting) by means of inversion program to get a Q value model. The resolution of the Q value model is 0.6—0.7 in dense ray regions and less than 0.6 in thin ray regions. Some fittings of t^* are given in figs. 4 and 5 and the 2-D Q value structure is shown in fig. 6.

3 *Q* value structure of the profile from Korla to Jimsar and its geodynamic analyses

According to fig. 6, the 2-D lithospheric Q value structure of the transect from Korla to Jim-

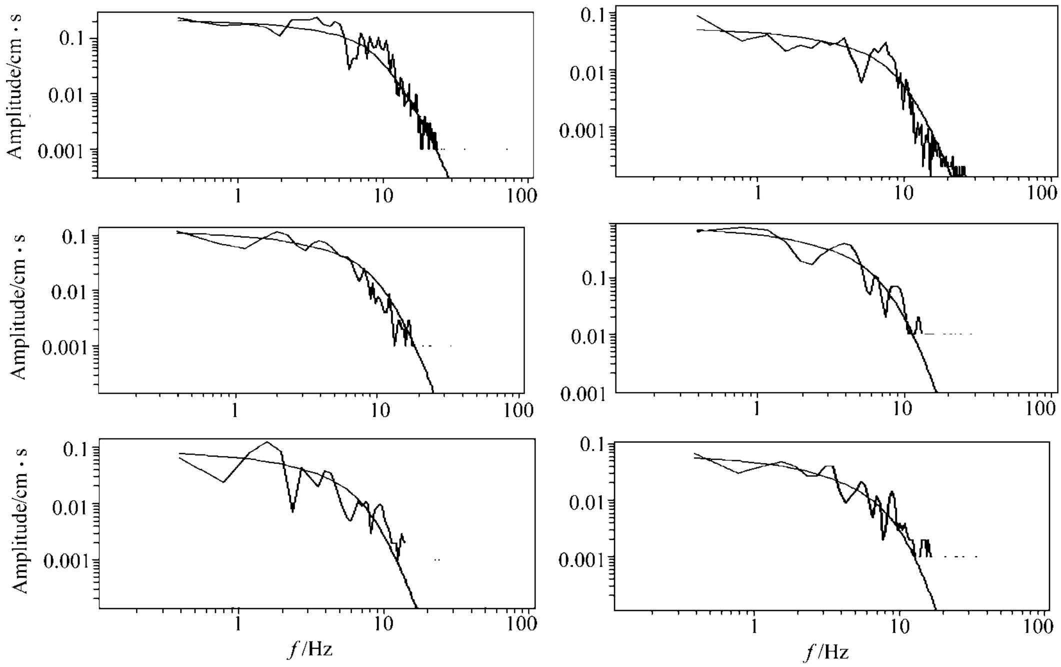

Fig. 3. Part amplitude fitting of Pm waves from shot point Toksun (SP 477.29).

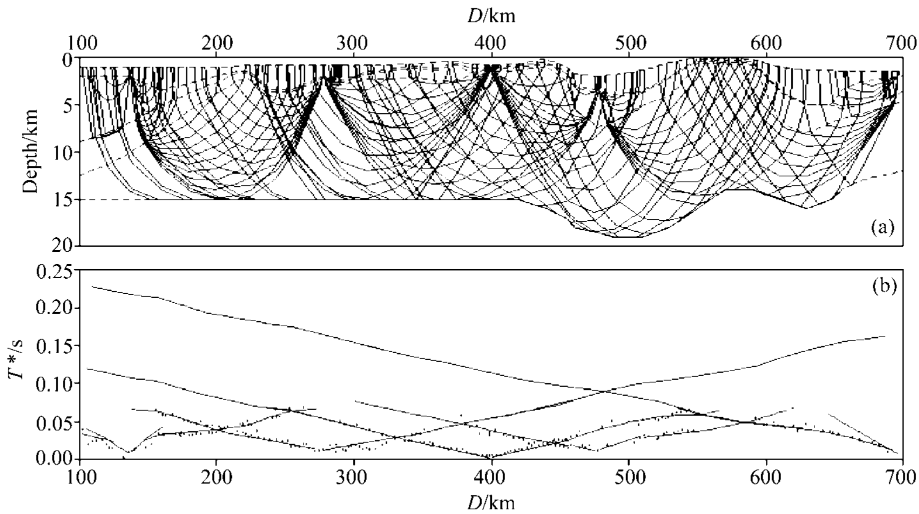

Fig. 4. t^* fitting of Pg waves in transect from Korla to Jimsar. (a) Path of the rays, (b) T^* fitting of Pg waves.

sar is characterized by vertical stratifying and lateral zoning. Vertically, the crust can be divided into upper crust, middle crust and lower crust. Laterally, the transect can be classified as the northern margin of the TB, the TOB and the southern margin of the JB, while the TOB can be further divided into several sub-regions.

3.1 *Q* value distribution in the upper crust

With a thickness of about 20 km, the upper crust can be further divided into sedimentary

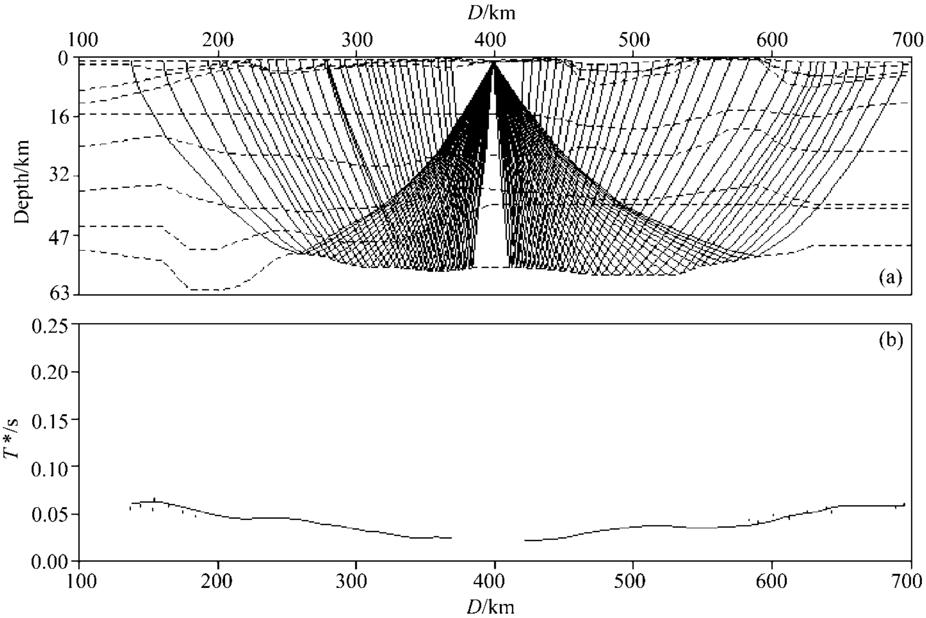

Fig. 5. Selected t^* fitting of Pm waves in transect from Korla to Jimsar. (a) Path of the rays, (b) T^* fitting of Pm waves.

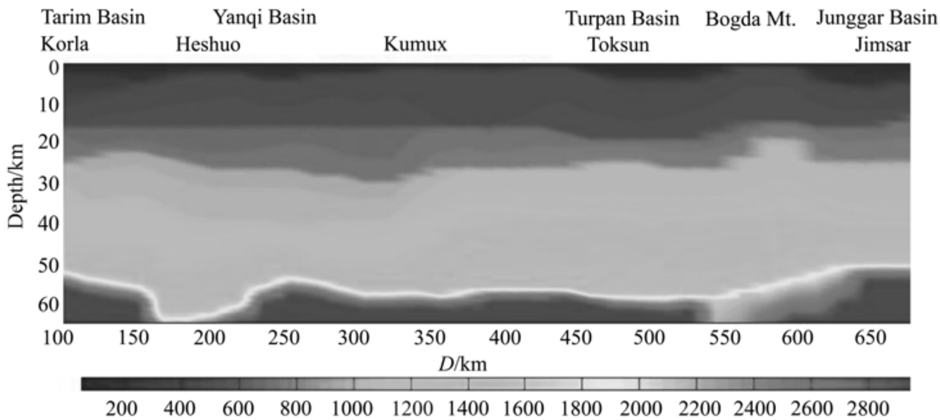

Fig. 6. 2-D *Q* value structure of the transect from Korla to Jimsar.

cover, the upper layer of the upper crust and the lower layer of the upper crust. The thickness of the sedimentary cover along the transect changes obviously. The thickness of the northern margin of the TB, the southern margin of the JB, the Turpan Basin and the Yanqi Basin is relatively large, while that of the Bogda Mt. and the north of Toksun is relatively thin, even the basement is outcropping.

Generally, the *Q* value of the sedimentary cover is relatively low, especially in some basins mentioned above, with the *Q* value being about 200. From Korla to Heshuo at the northern margin of the TB, the thickness of the sedimentary cover becomes thinner. The thickness of the sedimentary cover in the TOB is the thinnest with the basement exposed to the surface at most parts. Entering the Turpan Basin the thickness of the sedimentary cover increases again with *Q* value decreasing. The crystalline basement of the Bogada Mt. exposes to the surface with *Q* value increasing. At the southern margin of the JB the thickness of the sedimentary cover increases with *Q* value decreasing.

The *Q* value of the upper layer of the upper crust is about 400, while that of the lower layer of the upper crust is about 600. The *Q* value distribution in the upper layer of the upper crust is relatively stable and its thickness changes little. The thickness of the lower layer has a jump near Toksun, i.e. to its south the thickness is relatively large, with a relatively low *Q* value; to its north the thickness is relatively small, with a relatively high *Q* value. A high *Q* value falls at the lower layer of the upper crust of the Bogda Mt., indicating a harder medium, which corresponds to a higher seismic velocity and is consistent with highly uprising Bogda Mt. Besides, the *Q* values at the northern margin and to the north of Toksun are relatively high, showing an inhomogeneity of the medium.

3.2 *Q* value distribution in the middle crust

The thickness of the middle crust is relatively small and so is its variation. The local uplift of the middle crust occurs between Korla and Heshuo, in the north of Tuokxun and at Bogda Mt. etc., with *Q* value as high as about 1000. At the northern margin of the TB and the southern margin of the JB the middle crust tips to the TOB at the boundaries between the basin and the range, suggesting an intrusion of the layers into the crust of the TOB.

3.3 *Q* value distribution in the lower crust

The thickness of the lower crust is about 12—20 km with *Q* value of 1200—1600. The thickness increases at the boundaries between JB and TOB and between TB and TOB. At the northern margin of the TB and the southern margin of the JB the lower crust tips to the TOB, indicating the intrusion of the layers into the TOB and even subduction.

3.4 *Q* value distribution at the top of the upper mantle

The top part of the upper mantle of the TOB is relatively smooth. At the northern margin of the TB and southern margin of the JB the Moho tips to the TOB. A double-layered Moho has been found at the boundaries between the basin and the range, presenting us with a clear image of subduction of the TB and JB to the TOB. At the northern margin of the TB, *Q* value decreases southwards, which corresponds to the subduction of the TB to the TOB; the *Q* value distribution in the inner TOB is smooth, suggesting a relative homogeneity of this layer of the TOB. The *Q* value distribution at the southern margin of the JB shows that the JB is subducting to the Bogda Mt.

At present, several GGTs, such as focal profile from Karakorum to Ferghana[1], seismic wide angle reflection/refraction profile from Xayar to Burjing, the comprehensive geophysical profile from Korla to Jimsar1) and the profile from Koktokay to Aksay, have been finished. The results

1) Zhao Junmeng, Zhang Xiankang, Wang Shangxu et al., A summary report on geodynamic studies of the Junggar Basin, the Tianshan orogenic belt, the Tarim Basin, the Altun orogenic belt, the Qiadam Basin and the Kunlun orogenic belt (northern margin), 2001.

show that at the western part of the TOB the Ferghana Basin subducts southwards into the southern Tianshan at the depth of near 200 km; In China, the transect from Xayar to Burjuing indicates that a lithospheric subduction with intrusion of the layers into the crust has occurred at the northern margin of the TB; the northern margin of the TB has subducted to the TOB at the depth of about 180 km, while the 2-D *Q* value structure of the transect from Korla to Jimsar shows that both TB and JB subduct to the TOB. This double subduction revealed by the trabsect from Korla to Jimsar is quite different from the model “lithospheric subduction with intrusion of layers into the crust” revealed by transect from Xayar to Burjing, which shows that the TB intrudes into the crust and subducts to the upper mantle, and JB and TOB have a sliding contact. This presents the research on the formation, evolution, and the segmentation of the east and west Tianshan with some geodynamic evidence of lithospheric scale.

The comprehensive geophysical exploration in the JB carried out recently revealed several faults with SN direction in the JB. The Delunshan-Shixi-Hutubi fault is one of them, which divides the JB into two parts, the west part and the east one. With a high angle the fault is a lithospheric fault. However, there are no obvious vertical dislocation for the structure and tectonic surface within the crust, suggesting a lateral EW extension under the SN compression. The basic and ultrabasic rocks located at the fault and its adjacent region have been found by using the relationship between density and velocity of the basement, suggesting a migration of the medium of the upper mantle into the crust along the fault. Maybe this is the reason why a higher average velocity, higher density and higher magnetism occur in the JB compared with those in the TB and Qiadam Basin (QB).

The Moho of the western part of the JB can connect smoothly with the Moho of the TOB, even though the latter has a larger depth. In the western part of the JB the Moho keeps even in SN direction, while the Moho in the eastern part of the JB cannot connect smoothly with those of the Bogda Mt., because the former undergoes beneath the latter, forming an overriding region and suggesting a subduction of the lithosphere in the eastern part of the JB into the Bogda Mt.[1)] At the same time, the Moho in the eastern part of the JB bears a convex pattern in SN orientation. The big difference between the Moho in the western part of the JB and that in the eastern part of the JB not only explains the uprising of the Bogda Mt. situated in the eastern section of the TOB where the tectonic activities are relatively weak, but also suggests that the east-west segmentation of the TOB and the east-west partition of the JB may have a unified tectonic setting in lithospheric scale. About the exact boundaries of the east-west segmentation of the TOB and the east-west partition of the JB will be discussed in another paper.

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1) The Geoscience Transect IV-IV in the Junggar Basin (eds. Zhao Junmeng, Xu Jie), 2001.

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