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# Crustal structure across the Dabie–Sulu orogenic belt revealed by seismic velocity profiles

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**Abstract**
The Tan-Lu fault (TLF) separates the Dabie and Sulu orogenic belts, well known for their ultra high pressure (UHP) metamorphic rocks in eastern China. We reinterpret one of the wide-angle seismic profiles traversing the TLF using traveltime tomography methods, and compare the results with the interpretation of three other seismic profiles across the TLF, to enable us to study the relationship of the five tectonic units comprising the North China plate (NCP), the Yangtze plate (YTZP), the TLF, the Dabie–Sulu orogenic belt (DSOB), and the ultra-high pressure metamorphic belt (UHPMB) that is exposed within the DSOB. The results demonstrate that there is strong lateral heterogeneity within the studied area. The TLF's penetrating depth deepens along a S–N direction. In the central section of the fault, the TLF can be traced to the middle crust but in the northern section it penetrates to the Moho. The average $P$-wave velocity in the UHPMB and DSOB is 0.1–0.4 km s$^{-1}$ faster than that of the YTZP, NCP and TLF for upper crusts with depths $<$13 km, and 0.1–0.6 km s$^{-1}$ slower for middle and lower crusts with depths $>$13 km. The bottom borders of the middle and lower crusts of the UHPMB and DSOB are apparently deeper than the other three tectonic units, and the Moho beneath UHPMB around Dabieshan may be deeper than 40 km. The general similarities of the crustal velocity structures between the Dabie and Sulu UHPMB may suggest a similar exhuming mechanism of UHP metamorphic rocks, before the large-scale TLF strike slip, driven by the subduction of the Yangtze block. The velocity gradient of the crust–mantle transition beneath the Sulu UHPMB implies the intrusion of basaltic melts from the upper mantle.

**Keywords:** traveltime tomography, deep seismic sounding profile, crustal structure, Tan-Lu fault, ultra-high pressure metamorphic belt (UHPMB)

## 1. Introduction

The Dabie–Sulu orogenic belt (DSOB), as shown in figure 1, which resulted from the continental collision between the Yangtze and North China Plate and reactivated the long-lived Tan-Lu fault (TLF) in eastern China, has attracted wide interest with the discovery of coesite, micro-diamond and other ultra high pressure minerals (e.g. Okay *et al* (1989), Xu and Ma (1992), Liu *et al* (2004), Leech *et al* (2006), Webb *et al* (2006)). One of the arguments is whether the Dabie and Sulu belts can be grouped into the same orogenic belt. In this paper, we attempt to reveal the similarities and differences of the crustal velocity structure in the Dabie orogenic belt, Tan-Lu wrench fault and Sulu orogenic belt.

Since the 1980s numerous deep seismic sounding profiles have been conducted across the DSOB. Four of these profiles, shown in figure 1, include: (1) the Fuliji–Fengxian profile acquired in 1984 (Zhang *et al* 1988, Chen *et al* 1992), (2) the Zhanggongdu–Zhuangmu profile acquired in 1995 (Wang *et al* 1997, Zhang *et al* 2000, Li *et al* 2002), (3) the Suixian–Maanshan profile acquired in 1979–1981 (Zheng and Teng

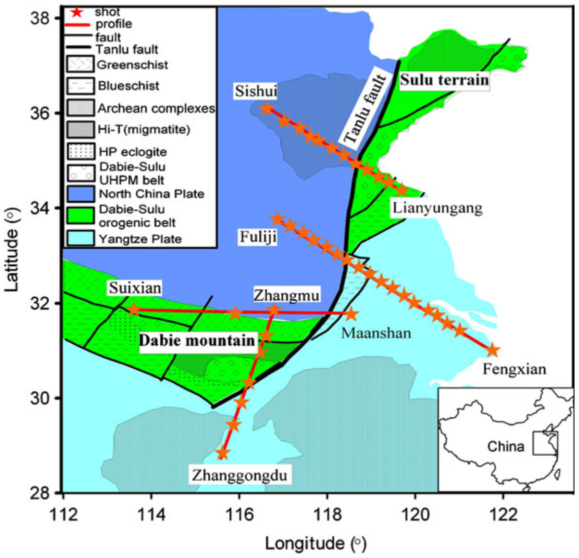

**Figure 1.** Tectonic setting. Four deep seismic sounding profiles of the DSOB area traverse the Tan-Lu fault (TLF). The inset in the lower part indicates the location of the study area with respect to the rest of China. The geological setting is modified from the figures given by Liou *et al* (1996).

1989) and (4) the Sishui–Lianyungang profile acquired in 1980 (Liu *et al* 1987). In this paper, we reinterpret the Fuliji–Fengxian (FLJ–FX) profile using traveltime tomography methods, and then compare its velocity structure with the other three profiles. By comparing these four velocity profiles, we summarize the structural characteristics along the TLF, and analyse the similarities and differences of different tectonic units around the TLF.

## 2. Traveltime tomography of Fuliji–Fengxian (FLJ–FX) profile

The FLJ–FX profile between Fuliji in the Anhui Province and Fengxian in Shanghai City, China, has a total length of 570 km. It consists of 37 shot points with explosive sources. For each shot, 150 channel digital seismographers were deployed at 1 km intervals. In total, there are 4633 seismic traces recorded with a high S/N ratio. The project was jointly carried out in 1984 by China's Ministry of Geology and Mineral Resources, the Chinese Bureau of Seismology, and Changchun College of Geology. In this paper we present one seismic shot (at Fuliji) shown in figure 2, which is the vertical component of the *P*-wave, reduced with a *P*-wave reduction velocity of 6.0 km $s^{-1}$.

Zhang *et al* (1988) and Chen *et al* (1992) interpreted this deep seismic sounding dataset with a homogeneous model, and obtained a 1D crustal velocity model with 2D interface geometry (figure 3(*a*)). In this paper, to reconstruct a 2D fine velocity model along this profile, we reinterpreted the seismic data set based on the same seismic reflection/refraction events, as shown in figure 2: Pg as the first arrival from the crystalline basement, $P_2$, $P_3$, and $P_4$ as reflections from the discontinuities within the crust, and Pm as the reflection from the Moho. However, we reinterpreted this dataset with a tomographic inversion approach, in which we used the finite-difference inversion method (Vidale 1988, 1990, Hole 1992) for the upper crust velocity structure and the RayInvr technique (Zelt and Smith 1992) for the deep velocity and boundary structure.

Firstly we reconstructed the upper crust velocity structure (with a mean bottom depth of 12.7 km) with the finite-difference inversion code provided by Hole (1992). We tested a number of combinations of velocity parameters in order to determine an optimal initial model. By considering the fit of the observed data and the adequacy of ray cover, we set a 1D model constraint with a velocity value of 3.35, 5.50, 6.12, 6.18 and 6.25 km $s^{-1}$ at depths 0, 2, 5, 10 and 16 km respectively. In the forward modelling for the traveltime calculation, we divided the upper crust into 1 × 1 $km^2$ cells. But for the inversion which updates the model parameters based on the traveltime residual, we employed rectangular cells of 4 × 2 $km^2$ (4 km horizontal and 2 km vertical) and a total of 2100 traveltime picks of the Pg arrival. After five iterations,

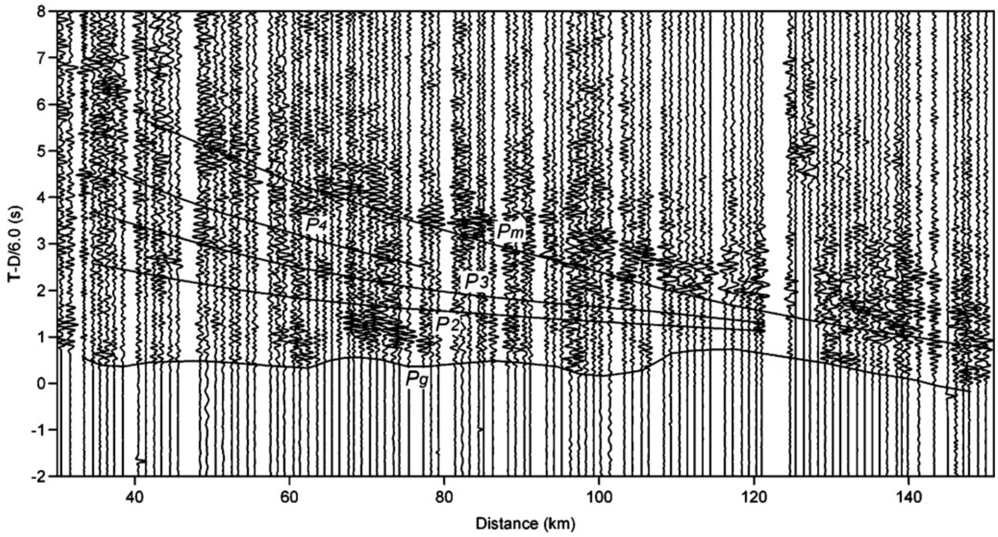

**Figure 2.** An example shot gather at Fuliji. The vertical component of the *P*-wave seismic section with *P*-wave reduction velocity of 6.0 km $s^{-1}$.

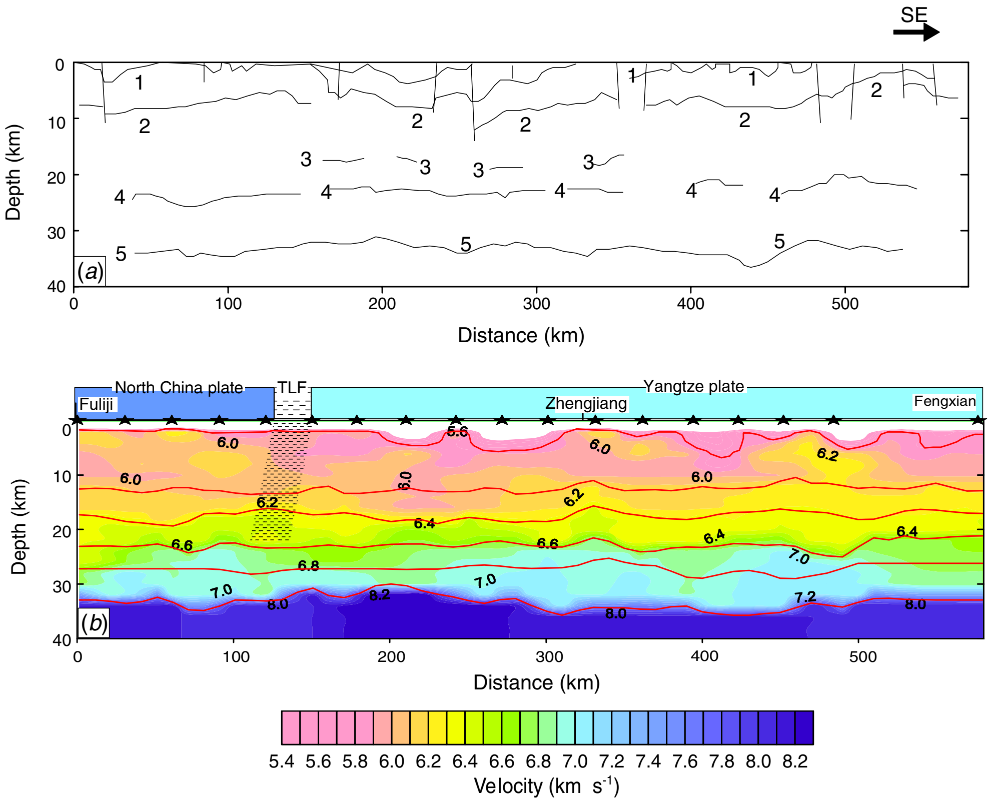

**Figure 3.** (*a*) A published crustal velocity model along the Fuliji–Fengxian profile given by Zhang *et al* (1988). 1: top interface of the Precambrian layer; 2: bottom interface of the crystalline basement; 3: upper boundary of the crustal middle layer; 4: bottom boundary of the crustal middle interface; 5: Moho interface. (*b*) The crustal velocity model along the Fuliji–Fengxian profile obtained by our traveltime tomography. Areas filled with dashed lines show the location of the TLF.

we obtained the final upper crust velocity model, for which the *rms* residual of traveltimes is decreased to 0.17 s and the number of rays in most cells is more than 13.

We then reconstructed the middle and lower crust models (with mean bottom depths of 23.3 and 32.9 km respectively) based on other events' traveltimes. We used the RayInvr technique and layer-stripping procedure in the inversion (Zelt and Smith 1992). We set the initial model as homogenous layers beneath the upper crust. In the inversion for each layer, we interactively calculated the velocity distribution using RayInvr, and then determined the reflector depth within a total of 4280 traveltime data. After five iterations we obtained the velocity model of the middle and lower crusts, and the *rms* residual of traveltime data of 0.21 s.

Figure 3(*b*) displays the resultant crustal velocity model. It reveals that the Moho depth is within a range of 30–36 km and is featured with a topography uplift of 4–5 km at the segment 100–300 km. The velocities within the upper crust (with a bottom depth of 12.7 km) decrease from NW to SE abruptly at ∼110 km, while the velocity distribution in the middle crust (with a mean bottom depth of 23.3 km) is relatively uniform. In the lower crust with a bottom depth of 32.9 km, the main feature is the slower velocity anomaly above the uplifted Moho. The *P*-wave velocity at the topmost mantle is 8.06–8.30 km s$^{-1}$.

## 3. Crustal structure along the Tan-Lu fault (TLF)

In addition to figure 3(*b*), figure 4 presents three more velocity structures of wide-angle seismic profiles. All four profiles traverse different parts of the TLF. The apparent resolution of velocity profiles shown in figure 4 is lower than that in figure 3(*b*). This is due to the shot spacing interval being about two to four times as big as that in figure 3(*b*), and the receiver interval is more than three times larger than that in figure 3(*b*). Therefore, the ray coverage of the profiles in figure 4 is about 6–12 times less than that in figure 3(*b*). Nevertheless, the acquisition geometry of these three profiles is still acceptable in conventional exploration for probing deep crustal structure.

The southern section of the TLF locates at the transition between uplift and depression as shown in the crustal velocity models of the Zhanggongdu–Zhuangmu and Suixian–Maanshan profiles (figures 4(*a*), (*b*)). There is a significant lateral velocity variation in the middle crust (with a bottom depth 20.6–24.0 km). It is inferred that the southern part of the TLF had been a channel for the upwelling of mantle material (Zheng and Teng 1989).

The middle part of the TLF is located upon the western side of the Moho uplifting shown in the Fuliji–Fengxian profile (figure 3(*b*)). The crust thickness changes abruptly, and the velocity at the top mantle is the fastest at 8.3 km s$^{-1}$. In

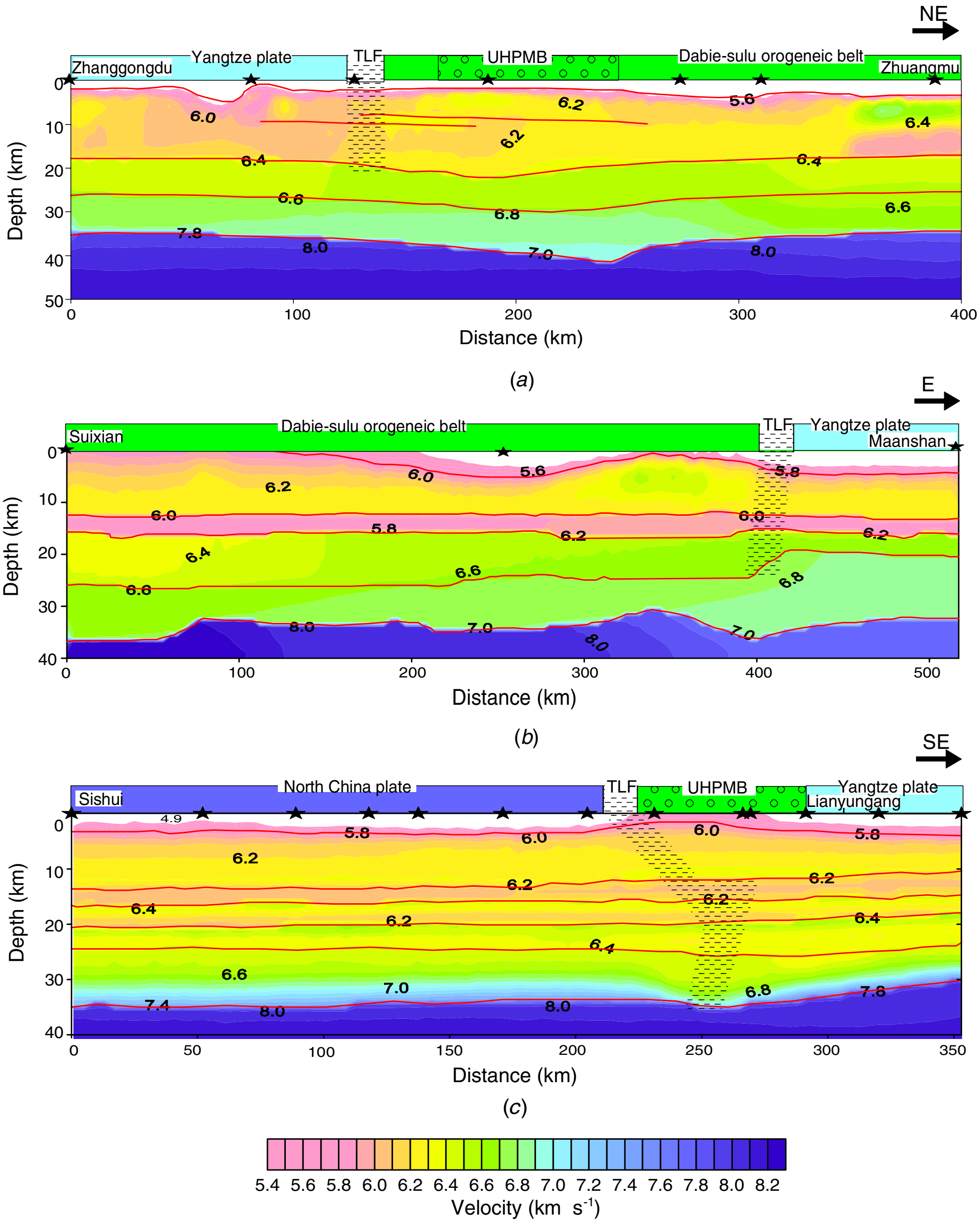

**Figure 4.** Three more crustal velocity profiles in the DSOB area in figure 1. (*a*) The Zhanggongdu–Zhuangmu profile, (*b*) the Suixian–Maanshan profile, (*c*) the Sishui–Linyi profile.

the upper crust at a depth $<16$ km, the TLF is featured with a velocity gradient belt between a fast and slow velocity anomaly, and a large slow-velocity zone lies to the east of it. In the lower crust with a bottom depth of 30.5–35.6 km, there is no obvious evidence of variations of velocity distribution and interface geometry on both sides of the TLF. Xu and Zhao (2004) discovered a similar velocity feature, and showed that the $P$-wave velocity slice had clear features corresponding to the TLF on the middle-upper crust but no such features within the lower crust.

For the northern section of the TLF crossed by the Sishui–Lianyungang profile, the TLF is inferred to the crustal scale. It is located upon the strong undulated Moho at a depth of 33–35.6 km (figure 4(*c*)).

Obviously, there is a discrepancy about the TLF penetration depth: for the southern and middle sections, the TLF penetrates to the middle crust (with a bottom depth of 21.7–25.3 km); but for the northern section of the fault, it penetrates to the Moho. The discrepancy could be interpreted in two ways. First, the TLF was produced from the tension of mantle uplifting and cut only through the middle-upper crust (with a bottom depth 20.20–25.35 km), as proposed by Zhang *et al* (1988). Second, the TLF had cut through the whole crust while the fault in the lower viscid crust had gradually disappeared balancing the orogenic extension and the material intrusion from the upper mantle. We infer from the discrepancy that the fault's penetrating depth deepens along the S–N direction; it may partly be a result of the counter-clockwise rotation of the North China block since the late Triassic period. The middle and southern sections of the fault act as the axis centre and the North China block rotates around this centre, resulting in the deepening of the TLF. The

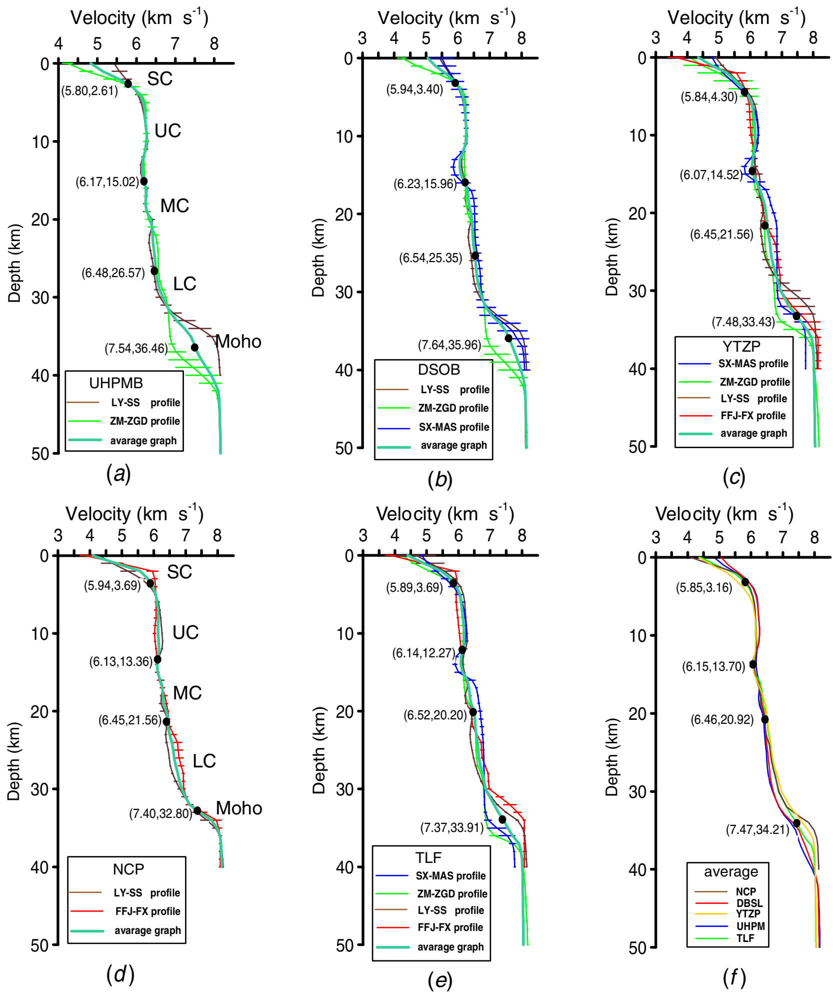

**Figure 5.** The average velocity–depth relationship derived from the four velocity profiles across five different tectonic units: (*a*) ultra-high-pressure metamorphic belt (UHPMB); (*b*) Dabie–Sulu orogenic belt (DSOB); (*c*) Yangtze plate (YTZP); (*d*) North China plate (NCP); (*e*) Tan-Lu fault (TLF); (*f*) comparison of the average velocity–depth function of different tectonic units. SC: sedimentary cover; UC: upper crust; MC: middle crust; LC: lower crust.

evidence of such a rotation can be seen from the paleomagnetic measurements (Wu *et al* 2004), the Mesozoic tectonic lineation and the orientation of sedimentary basins changing over time (Zhang *et al* 2003). Lin *et al* (2004) and Wang *et al* (2005) numerically simulated the Mesozoic lithospheric deformation of the North China block and demonstrated an anti-clockwise rotation of the TLF.

## 4. Crustal structure around the Dabie–Sulu orogenic belt (DSOB)

As shown in figure 1, the four wide-angle seismic profiles cross four main tectonic units, the North China Plate (NCP), Yangtze Plate (YTZP), TLF and Dabie–Sulu orogenic belt (DSOB), as well as the ultra-high pressure minerals belt (UHPMB) that is exposed within the DSOB. To see the similarities and differences of the crustal structure among these five different tectonic units, we calculated the average velocity–depth function for each tectonic unit, as illustrated in figures 5(*a*)–(*e*) respectively. In figure 5(*f*), we also compare different average depth–velocity functions.

The crustal velocity differences are significant among different tectonic provinces. (1) For the upper crust whose bottom depth is less than 13.0 km, the mean velocity of DSOB and UHPMB is 0.1–0.4 km $s^{-1}$ faster than that of the NCP, YTZP and TLF, whereas for the middle and lower crusts with a depth $>$13.0 km, it is 0.1–0.6 km $s^{-1}$ slower. For example, around Dabie Mountain the velocity within the lower crust is 6.6–7.0 km $s^{-1}$, while for the YTZP and NCP it is as high as 7.3 km $s^{-1}$. (2) The bottom borders of the middle and lower crusts of the UHPMB and DSOB are apparently deeper than the other three tectonic units. The average bottom depths of the middle and lower crusts of the UHPMB, 26.57 and 36.46 km respectively, are the deepest among these five tectonic units (figure 4(*a*)). The Moho beneath the UHPMB around Dabieshan Mountain may be deeper than 40 km.

Compared to the Dabie UHPMB, there are some similarities to that of the Sulu terrain. The exposed Sulu UHPMB locates upon a locally fast velocity anomaly in the middle-upper crust (with a bottom depth of ∼20.0 km), and in addition the Moho boundary also takes on a strong bending shape. There exists a fast velocity anomaly within the upper crust (with a bottom depth of about 12.3 km), corresponding to the exposed ultra-high-pressure (UHP) metamorphic rocks beneath the Dabie UHPMB. Wang *et al* (1997) reported that the Moho boundary breaks off here. Li *et al* (2002) argued that the faster Poisson ratio compared to the Yangtze and North China plate suggested a more 'soft' composition, which mainly consisted of granulite. Zhang *et al* (2000) inferred that the zone with strong anisotropy showed a 'chimney' structure, and thus the subduction of the Yangtze plate and the mantle flow of materials played important roles in exhuming the UHP metamorphic rocks of the Dabie orogenic belt. All of these imply a similar mechanism within the UHPMB. Hence similar velocity features may suggest the exhuming history of UHP metamorphic rocks driven by the subduction of the Yangtze block before the first large-scale strike-slip of TLF.

However, the mantle intrusion beneath the Sulu UHPMB is stronger than that in the Dabie block. In the Sulu block, the velocity gradient layer with an obvious lateral inhomogeneity and indistinguishable velocity contrast on each boundary within the crust, can be attributed to the multi-period strong intrusion of mantle magma (Lin and Wang 2005). We may infer that the velocity gradient of the crust–mantle transition under the Sulu UHPMB is from the intrusion of basaltic melts. On the other hand, the phenomenon mentioned above is not always evident in the Dabie block. It implies that the magma activity after continental collision in the Dabie block is far weaker than that of the Sulu terrain. Dabie Mountain would lead to excess pore fluids in the lower crust, which effectively decrease the velocity within the lower crust.

## 5. Conclusions

Based on the investigation in this paper, we can draw the following conclusions:

(1) The TLF's penetrating depth deepens along a S–N direction. It may partly be the result of the counter-clockwise rotation of the North China block since the late Triassic period.

(2) For the upper crusts (shallower than 13 km), the mean velocity of DSOB and UHPMB is 0.1–0.4 km $s^{-1}$ higher than that of the NCP, YTZP and TLF, whereas for the middle and lower crusts (deeper than 13 km), it is 0.1–0.6 km $s^{-1}$ lower.

(3) The bottom borders of the middle and lower crusts of the DSOB and UHPMB are apparently deeper than the other three tectonic units. The average bottom depths of the middle and lower crusts of the UHPMB of 26.57 and 36.46 km respectively, are the deepest among the five tectonic units. The Moho beneath the UHPMB around Dabie Mountain may be deeper than 40 km.

(4) The similarity between the crustal velocity structures of the Dabie and Sulu UHPMB may suggest a similar exhuming history of UHP metamorphic rocks, driven by the subduction of the Yangtze block. The velocity gradient of crust–mantle transition beneath the Sulu UHPMB implies the intrusion of basaltic melts from the upper mantle.

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