Crustal structure beneath the Dabie orogenic belt from ambient noise tomography

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A B S T R A C T

The Qinling–Dabie–Sulu orogenic belt in east-central China is the largest high and ultrahigh pressure (HP and UHP) metamorphic zone in the world. The Dabie Mountains are the central segment of this orogenic belt between the North China and Yangtze cratons. This work studies the nature of the crustal structure beneath the Dabie orogenic belt to better understand the orogeny. To do that, we apply ambient noise tomography to the Dabie orogenic belt using ambient noise data from 40 stations of the China National Seismic Network (CNSN) between January 2008 and December 2009. We retrieve high signal noise ratio (SNR) Rayleigh waves by cross-correlating ambient noise data between most of the station pairs and then extract phase velocity dispersion measurements from these cross-correlations using a spectral method. Taking those dispersion measurements, we obtain high-resolution phase velocity maps at 8–35 second periods. By inverting Rayleigh wave phase velocity maps, we construct a high-resolution 3D shear velocity model of the crust in the Dabie orogenic belt.

The resulting 3D model reveals interesting crustal features related to the orogeny. High shear wave velocities are imaged beneath the HP/UHP metamorphic zones at depths shallower than 9 km, suggesting that HP/UHP metamorphic rocks are primarily concentrated in the upper crust. Underlying the high velocity HP/UHP metamorphic zones, low shear velocities are observed in the middle crust, probably representing ductile shear zones and/or brittle fracture zones developed during the exhumation of the HP/UHP metamorphic rocks. Strong high velocities are present beneath the Northern Dabie complex unit in the middle crust, possibly related to cooling and crystallization of intrusive igneous rocks in the middle crust resulting from the post-collisional lithosphere delamination and subsequent magmatism. A north-dipping Moho is revealed in the eastern Dabie with the deepest Moho appearing beneath the Northern Dabie complex unit, consistent with the model of Triassic northward subduction of the Yangtze Craton beneath the North China Craton.

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1. Introduction

The Qinling–Dabie–Sulu orogenic belt in east-central China is the largest HP and UHP metamorphic zone in the world (Carswell and Compagnoni, 2003; Coleman and Wang, 1995; Hacker and Liou, 1998; Zheng et al., 2003; Zheng, 2008). The Dabie HP/UHP metamorphic belt was formed by a series of arc–continent and continent–continent collisions between the North China Craton and the Yangtze Craton during the early Paleozoic to early Mesozoic (e.g., Ames et al., 1993; Li et al., 1993; Liou et al., 2000; Ye et al., 2000). Numerous studies of geology and geochemistry on deep continental subduction and exhumation mechanism of HP and UHP metamorphic rocks have been carried out in this region in the past two centuries (e.g., Ernst and Liou, 1995; Hacker et al., 2006; Sun et al., 2002; Wallis et al., 2005; Wang et al., 1989; Xiao et al., 2006; Zheng et al., 2003). Meanwhile, a number of geophysical studies have also been done to characterize the crustal and upper mantle structure beneath the Dabie Orogenic belt, such as Magnetotelluric (MT) sounding (Dong et al., 1993; Xiao et al., 2007), explosive-source seismic profiling, and seismic tomographic imaging (e.g., Wang et al., 2000; Xu et al., 2001, 2002; Yuan et al., 2003; Zhang et al., 2000). For example, Dong et al. (2008) integrated eight wide angle reflection/refraction seismic profiles to map the Moho depth and uppermost mantle velocity across the Dabie orogenic belt.

Most of previous geophysical studies focus on individual profiles, which traverse the Dabie orogen and reveal some details of the 2D crustal structure of the orogen. However, the crustal and upper mantle structure of the Dabie orogen could be very complex and have significant lateral variations as manifested by different blocks of exposed rocks on the surface, due to the complexity of the collision processes. In the past, some large scale 3D tomographic studies covering the Dabie Mountains have been carried out (e.g., Ma and Zhou, 2007; Zheng et al., 2008). The lateral resolution of these large scale 3D models, however, is typically in order of several hundreds of kilometers, which makes it hard to reveal the detailed variation of crustal and upper mantle structure related to the regional collision processes.
A high-resolution 3-D model of crustal and upper mantle structure beneath the Dabie orogen is critical to understanding the behaviors of deep rocks in the collisional orogen, including 3D distributions of exhumated HP/UHP metamorphic rocks, the existence of ductile flow or brittle faults relevant to postcollisional exhumations, the variation of the Moho depth related to the collision, and so on. However, to date, such a model still does not exist due to the lack of dense seismic broadband stations and local earthquakes nearby.

The advantage of ambient noise tomography and the development of dense broadband seismic stations of the Chinese National Seismic Network (CNSN) in the Dabie region have overcome these limitations and provide an opportunity to construct a high-resolution model of crustal and uppermost mantle structure. Ambient noise tomography is based on the theory that the full Green’s function between two receivers can be extracted by cross-correlating continuous ambient seismic noise recorded at the two receivers (Lobkis and Weaver, 2001; Snieder, 2004). Ambient noise cross-correlation can retrieve short-period (<20 s) surface waves from ambient noise and thus constrain crustal structure without the need to use any earthquake surface-wave data in tomography. Since Shapiro et al. (2005) applied this method to southern California, ambient noise tomography has recently become a well-established seismic method to study crustal structures. A number of ambient noise tomographies have been performed in the Chinese continent (e.g., Fang et al., 2010; Li et al., 2009, 2010; Yang et al., 2010; Yao et al., 2006, 2008, 2010; Zheng et al., 2008).

In this study, we employ ambient noise tomography to construct a high-resolution 3D model of crustal structure beneath the Dabie orogen and surrounding regions. We collect continuous ambient noise data recorded at 40 stations from the Chinese National Seismic Network between January 2008 and December 2009 and retrieve Rayleigh waves from cross-correlations of these noise data between station pairs. Then, we measure phase velocity dispersion curves at periods from 8 s to 35 s using a spectral method (Ekström et al., 2009) and perform surface wave tomography to obtain high-resolution phase velocity maps. Finally, we construct a 3D model of shear velocity beneath the Dabie orogenic belt by inverting the resulting Rayleigh wave phase velocity maps. This high-resolution 3D model provides important constraints on understanding of the continent–continent collision processes in the Dabie orogenic belt.

2. Geological settings

The Qinling–Dabie–Sulu orogenic belt was formed by the Triassic subduction of the Yangtze Craton beneath the North China Craton (e.g., Ames et al., 1993; Li et al., 1993; Liou et al., 2000; Ye et al., 2000). The timescale of continental subduction and exhumation of the HP/UHP metamorphic zones in the Dabie Mountains is from ~245–240 Ma to ~225–220 Ma (Li et al., 2005). Two stages of exhumation, an early rapid exhumation from mantle depths to mid-crustal levels and a late slow exhumation from the middle crust to the surface, have been proposed for the exposed HP/UHP metamorphic rocks (e.g., Hacker et al., 1995).

The Dabie Mountains are the central segment of the Qinling–Dabie–Sulu orogenic belt between the North China and Yangtze cratons (Fig. 1a; simplified geological map of the Dabie orogenic belt modified after Zhang et al., 2002). The Dabie orogenic belt is divided by the Shangcheng–Macheng fault (SMF) into the eastern and western Dabie; the latter is often termed as the “Hong’an Block.” Tectonically, the eastern Dabie orogenic belt is further divided, from north to south, into four units: the north Huaiyang (NHY) unit, the Northern Dabie complex (NDC) unit, the HP metamorphic unit, and the UHP metamorphic unit. The NHY unit is bounded by the Xiaotian–Mozitan fault (XMF) in the north, and composed of low-grade metamorphic flysch. This unit is considered to be the southern margin of the North China Craton based on its Paleozoic sedimentary sequences, which are typical of the North China Craton. The NDC unit is bounded by the XMF in the north. The NDC consists of orthogneiss with minor amphibolite, marble, mafic, and felsic granulites. The HP metamorphic unit is traditionally called the Susong Group, consisting of muscovite–albite gneiss and two-mica gneiss with minor eclogite, amphibolite, marble, metaporphoite layer, and blueschist. The metamorphic grade apparently decreases from north to south. The UHP metamorphic unit consists mainly of gneiss with frequent and retrograded eclogites (garnet-bearing amphibolite), garnet-bearing peridotite, jadeite quartzite, and marble. This unit is characterized by occurrence of the UHP metamorphic rocks such as coesite-bearing eclogites (Okay et al., 1989; Wang et al., 1989) and rare microdiamond-bearing eclogites (Xu et al., 1992).

Fig. 1. (a) Simplified geological map of the Dabie Mountains. Inset shows the location of the study area (modified after Zhang et al., 2002). XSF = Xinyan–Shucheng Fault; XMF = Xiaotian–Macheng Fault; SMF = Shangcheng–Macheng Fault; TLF = Tancheng–Lujiang Fault; XGF = Xiangfang–Guangji Fault; HP = high pressure; UHP = ultrahigh pressure. The blue lines represent locations of three vertical cross-sections along longitude 114.2°E (AA′), 115.4°E (BB′), and 116.3°E (CC′) with shear velocities plotted in Fig. 9. (b) Locations of 40 stations (black triangles) around the study region. The solid blue and red lines represent raypaths between stations HAXY and AHANQ (blue line) and between stations HBSZH and HBWHN (red line) with their dispersion curves plotted in Fig. 3. The three points identify the locations in the eastern Dabieshan UHP area (blue point), the “Hong’an Block” UHP area (green point), and the NDC area (red point) for Fig. 6 to illustrate the inversion results.
3. Data processing

We collect two years of continuous vertical-component seismic data recorded by 40 stations from CNSN between January 2008 and December 2009. The locations of these stations are plotted in Fig. 1b. Most of these stations are equipped with broadband seismometers, with a few exceptions in which short-period instruments are in operation. As demonstrated by other ambient noise studies (Arroucau et al., 2010; Yang et al., 2011), intermediate-period surface waves up to 20–30 s can still be extracted from ambient noise recorded at short period stations. Thus, we use the ambient noise data from those short-period stations in this study.

The procedures for ambient noise data processing applied here are similar to those described in detail by Bensen et al. (2007). Using only vertical components of ambient noise means that the cross-correlations merely contain Rayleigh wave signals. Continuous data are first decimated to one sample per second and then filtered in the period band from 3 to 50 s. Instrument responses are removed from the continuous data because different types of seismic sensors are equipped among the stations. Spectral whitening is applied to flatten spectra over the entire period band (3–50 s) to obtain broadband dispersion curves. A time-domain normalization method named as running-absolute-mean normalization (Bensen et al., 2007) is then taken to suppress the influence of earthquake signals and other irregularities, such as glitches and spikes. This normalization method computes the running average of the absolute value of a seismic waveform in a normalization time window of fixed length (about 50 s) and weights the seismic waveform at the center of the window by the inverse of this average (Bensen et al., 2007). After these processes are completed, cross-correlation is performed on the daily segments of continuous noise data in the period band of 3–50 s and daily cross-correlations are then stacked over the two year period from January 2008 to December 2009. Fig. 2 plots the record section of these two-year cross-correlations. Apparently, high quality Rayleigh waves have been obtained as indicated by the two inclined dashed lines. To boost SNR, positive and negative time lags of each cross-correlation are stacked to form the so-called symmetric component for dispersion analysis.

4. Phase velocity measurements and surface wave tomography

In order to identify and reject bad measurements and get a reliable topographic result, we use signal-to-noise ratio (SNR) and phase travel time residual in tomography as criteria to select data. Period dependent SNR of Rayleigh waves is defined as the ratio of the peak amplitude in the window of the Rayleigh wave signal to the root-mean-square (RMS) of the trailing noise for each narrow-bandpass filtered cross-correlation waveform. The time window of Rayleigh wave signal is calculated by the inter-station distance divided by a phase velocity range of 2.5–4.5 km/s. We only retain those cross-correlations with SNR > 10. During tomography as described in following paragraphs, we further discard phase velocity measurements with travel time residuals larger than 4 s. After selection of measurements, the numbers of retained paths at periods of 12 and 25 s are 512 and 528, respectively; and the numbers of paths at other periods are also similar.

Phase velocity dispersion curves of Rayleigh waves are measured from the selected cross-correlations using a slightly revised spectral method (Ekström et al., 2009). As demonstrated by Ekström et al. (2009), the spectral method overcomes the limitation that inter-station distances must be longer than three wavelengths as required by the time-domain method (Bensen et al., 2007). In the spectral method, phase velocity measurement of each inter-station cross-correlation is performed in two steps: identification of zero crossings in the real part of the cross-correlation spectrum and interpretation of zero crossings in terms of phase velocities. The reason why we only measure phase velocities at zero crossings of the real part of cross-correlation spectrum is because the zero crossings of the real part spectrum are likely to be insensitive to the power spectrum of the background noise and the non-linear data processing of the original signals, while the amplitude of the real part is not (Ekström et al., 2009).

The more details of this method are described by Ekström et al. (2009). One may also note that the spectral method of Ekström et al. (2009) directly calculates station-pair cross-spectrum functions. Whereas, our revised method first calculates daily time-domain cross-correlation functions and stacks all of them to form the final stacked cross-correlation functions, which are then Fourier-transformed to obtain cross-spectrum functions. To investigate whether these two different data processing procedures result in the same phase velocity measurements, we compare the real parts of the spectrum functions obtained using the two different data processing procedures and find that they are almost same and have identical zero-crossings (Fig. 3a), which guarantees phase velocity measurements based on our data processing procedures are the same as those exactly based on the spectral method of Ekström et al. (2009).

Fig. 3 shows two examples of measured phase velocity dispersion curves. The path between stations HAXY and AHAQN (blue symbols) passes through the Dabie Mountains, while the path between stations HBSZH and HBWHN (red symbols) passes through the Jianghan Basin (Fig. 1b). Phase velocities of the HAXY–AHAQN path (blue symbols) are significantly higher than those of the HBSZH–HBWHN path, indicating generally higher seismic velocities in the Dabie Mountains than in the Jianghan Basin.

A generalized 2-D linear inversion program developed by Ditmar and Yanovskaya (1987) and Yanovskaya and Ditmar (1990) and named Surface Wave Tomography (SWT) is adopted to generate phase velocity maps at 8–35 second periods by using all the estimated phase velocity dispersion measurements. This method is a 2D generalization of the classical 1-D method developed by Backus and Gilbert (1968) and is based on the geometric ray approximation which assumes that the travel time of a surface wave is only sensitive to the media along the great circle path of surface wave propagation. On the basis of a series of numerical tests, we parameterize the study region into a grid with a cell size of 0.3°×0.3° and choose the proper regularization and set all damping parameters as the same to obtain relatively smooth maps and meanwhile achieve small data misfits.

![Fig. 2. Two-year cross-correlations filtered between periods of 6–40 s. The gray dash lines display a velocity move-out of 3 km/s.](image-url)
in detail the observed variations of the phase velocity maps because these phase velocity maps are inverted for a 3D Vs model, which we will discuss thoroughly later.

In addition to phase velocity maps, SWT also provides corresponding resolution information at each period. Resolution of surface wave tomography depends primarily on the coverage and azimuthal distribution of inter-station paths. Yanovskaya (1997) and Yanovskaya et al. (1998) proposed to use the mean size of an averaging area to estimate the lateral resolution. For a 2-D tomography problem, a function $S(x, y)$ for different orientations of the coordinate system is used in order to determine the sizes of the averaging area along different directions (Yanovskaya et al., 1998). The "averaging area" which gives us an idea of the obtained resolution can be approximated by an ellipse centered at a point, with axes equal to the largest $S_{\text{max}}(x, y)$ and to the smallest $S_{\text{min}}(x, y)$ values of $S(x, y)$. The smallest $S_{\text{min}}(x, y)$ and largest $S_{\text{max}}(x, y)$ axes of the ellipse are calculated, and the resolution at each point is given by a single number, the mean size of the averaging area $L = [S_{\text{min}}(x, y) + S_{\text{max}}(x, y)]/2$. Examples of resolution maps and associated path coverages at 12 and 25 second periods are plotted in Fig. 4. The resolution of phase velocity maps at 8–35 second periods is estimated to be about 30 km in the Dabie orogenic belt, where the path coverage is best, and gradually degrades towards the fringes, where the path coverage becomes sparse. Thus, we only plot and discuss seismic velocities within the region as shown in Fig. 1a, where resolution is approximately higher than 45 km.

5. Construction of a 3D shear velocity model

To construct a 3D Vs model from the resulting phase velocity maps, we adopt an iterative linearized least-square inversion scheme of surf96 (Herrmann and Ammon, 2004) to invert each local dispersion curve at each node across the 0.3° × 0.3° grid for a 1D Vs profile. The local dispersion curves are extracted from the phase velocity maps at 8–35 second periods. Surface waves are mainly sensitive to shear velocities. In the linearized inversion, the choice of a proper starting Vs model is important. In particular, a smooth variation in shear wave velocity with depth is necessary in the deeper part of the model in order to prevent oscillations and edge effects. We obtain the starting model of $V_p$, Vs, and density by referring to the results of deep seismic refraction profiling (Wang et al., 1997a, 1997b, 2000; Yuan et al., 2003). We use the same starting model with a Moho depth of 30 km for each grid node in the study area, which is plotted in Fig. 6b. According to our tests, variations, like 10–15%, in the starting model do not affect the inverted Vs model noticeably. Depth-dependent shear wave velocities are parameterized as 23 layers from the surface to a depth of 45 km. Each layer is 2 km thick except the top layer which is 1 km thick (Fig. 6b). During the inversion, the model parameters are smoothed by adding off-diagonal terms to the model co-variance matrix so that shear velocities at adjacent layers are smoothed vertically in order to reduce the likelihood of strong vertical oscillations in the model.

Examples of local dispersion curves at three points, respectively located in the eastern Dabie UHP area, the "Hong'an Block" UHP area, and the NDC area, are shown in Fig. 6a. Phase velocities in the "Hong'an Block" UHP area (green line) are higher in the whole period range; phase velocities in the eastern Dabie UHP area are similar with those in the NDC area at long periods but higher at short periods (<15 s). Inverted vertical Vs profiles beneath these three locations are shown in Fig. 6b with corresponding colors as local phase velocity curves. In the inversion, each Vs profile is damped vertically to ensure that Vs differences at neighboring layers are minimal. Thus, strong velocity contrasts over depths such as the velocity jump over the Moho are smoothed out in the inverted Vs profiles. The final 3D Vs model is constructed by assembling all inverted 1D Vs profiles.

Because the tomography method of this study does not produce meaningful error estimates of local dispersion curves, we cannot directly estimate the uncertainties of our 3D Vs model. In principle,
Fig. 4. Raypath coverage (a), resolution (b) and histograms of data misfit maps (c) at periods of 12 and 25 s.
reliable errors from ambient noise tomography can be estimated using eikonal tomography (Lin et al., 2009) if the distribution of stations is dense and nearly uniform such as the USArray. But the station coverage in this study is too sparse and irregular for eikonal tomography. Thus, adopting an alternative way, we use misfits of extracted local phase velocity dispersion curves from tomography maps relative to the dispersion curves computed from the inverted 3D Vs model to approximately evaluate the quality of local dispersion measurements. The period-averaged misfits of local phase velocity dispersion measurements are plotted in Fig. 7. The misfits vary in a range of about 10–20 m/s across most of the study area and increase towards the four corners of the study region where path coverage is quite sparse. The period-averaged misfits (~10–20 m/s) in this study are slightly higher than those, about 10–15 m/s, in western US where ambient noise tomography is performed by Yang et al. (2008) using data from the USArray/Transportable Array. Yang et al. (2008) estimate the uncertainties of their Vs model are about 1% in the crust based on a Monte-Carlo inversion method. Given the misfits of our local dispersion measurements are slightly higher than those in western USA, the average uncertainties of our Vs crustal model should be slightly higher than but very close to 1%. Because of the trade-off between the Moho depth and the velocity in the lower crust, the uncertainty of Vs in the lower crust is typically larger than that in the middle or upper crust, which is also the case in Yang et al. (2008).

6. Results and discussion

The resulting 3D Vs model is presented as maps at depths of 8, 18, 25 and 35 km and three transects in Figs. 8 and 9, respectively. In the crust, the most pronounced velocity features are high shear wave velocities in the Dabie orogenic belt and low velocities in the Jianghan, Huabei and Hefei basins (Fig. 8a). The low velocities in the Jianghan, Huabei and Hefei basins are due to the thick sedimentary layers. The high velocities imaged at the shallow depths in the Dabie orogenic belt (Fig. 8a) are coincident with the areas with HP/ UHP metamorphic rocks (Fig. 1a) exposed at the surface, consistent
with previous results of reflection/refraction studies (Wang et al., 2000; Yuan et al., 2003). As revealed by the laboratory study (Ji et al., 2007), HP and UHP metamorphic rocks usually have higher seismic velocities than other upper crust rocks. The observed high velocities are mostly concentrated in the upper crust at depths shallower than 9 km as shown in the vertical Vs transects (Fig. 9a, c), suggesting that HP/UHP metamorphic rocks are primarily concentrated in the upper crust. Underlying the high velocity HP/UHP metamorphic zones, low velocities are imaged in the middle crust (Figs. 8b, 9a, c). One may suspect the variation pattern of Vs from high velocities in the upper crust to low velocities in the middle crust to high velocities again in the lower crust (Fig. 9a, c) could be an artifact of oscillation introduced in the version. However, by checking the local dispersion curve in the eastern Dabie UHP unit, with its location denoted in Fig. 1 and its dispersion curve and inverted Vs plotted as blue lines in Fig. 6, we observe that phase velocities of the local dispersion curve decrease with increasing periods at ~8–12 second periods, undoubtedly indicating the presence of low velocity zone in the middle crust (blue line in Fig. 6b).

Even after intensive studies over the past two decades, the exhumation mechanism of the HP/UHP terranes in the Dabie orogenic belt still remains hotly debated (Wang et al., 2008). Several exhumation models have been suggested, such as corner flow (Cloos and Shreve, 1988), buoyancy (Ernst et al., 1991), extension (Platt, 1993), erosion (Yin and Nie, 1993), extrusion wedge (Maruyama et al., 1994), and slab break-off (Davies and von Blankenburg, 1998). Our seismic results suggest that the high velocity HP/UHP metamorphic rocks are mostly likely concentrated in the upper crust, which is consistent with the buoyancy and corner flow controlled two-stage exhumation model (Suo et al., 2000; Wang et al., 2008; Yang, 2003). At the very beginning of the Triassic, the Yangtze Craton collided with the North China Craton and subsequently subducted underneath it. During this process, the crustal rocks were driven to the upper mantle and could reach up to 100 km depth, where HP or UHP metamorphism occurred depending on the exact depths (Wu et al., 2009). Due to the lower density of crustal rocks compared with mantle rocks, the deeply subducted HP/UHP slices were brought upward to mid-crustal levels driven by buoyancy and corner flow along the subducting channel and eventually brought to the Earth’s surface by the continuing compression of the Yangtze Craton and underthrusting after geodynamic regime reorganization (Wang et al., 2008). The low velocity zones underlying the high velocity HP/UHP blocks may represent ductile shear zones or brittle fracture zones developed during the exhumation of the HP/UHP metamorphic rocks (Liu et al., 2003; Zhong et al., 1999). The existence of the low velocity zones in the middle crust may facilitate the exhumation of HP/UHP metamorphic rocks from the middle crust to the surface.

In the middle crust, another prominent feature is the high velocity anomaly beneath NDC (Figs. 8b, 9b, c). Studies of crustal seismic reflections and surface geology (Hacker et al., 2000) also suggest that there is a crustal-scale high velocity dome beneath NDC between the XMF and the XGF. The formation of the high velocity dome may be related to the post-collisional lithosphere delamination and subsequent magmatism (Li et al., 2005). When the Yangtze Craton collided with the North China Craton northward, the lithosphere in the Dabie orogenic belt was thickened significantly, which could lead to post-collisional delamination of the thickened lithosphere. The delamination of lithosphere would induce mantle to upwell and replace the room left by the delaminated lithosphere. Subsequently, the upwelling mantle became partially
melted, and magma rose and intruded/underplated the overlying crust. The declamation of the thickened lithosphere is invoked by Li et al. (2005) to explain the rising of the Dabie dome and post-collisional magmatic intrusion in the Dabie orogenic belt, occurring in both periods of 180–170 Ma and 130–110 Ma according to the studies of Geochronology and Geochemistry (Li et al., 2005; Wang et al., 2008). The high velocities beneath NDC might represent intrusive and underplated igneous rocks, melting at the base of collision-thickened orogen and rising to the middle crust from the upper mantle and finally cooling and crystallizing in situ (Zhao and Zheng, 2009).

As it is known, surface waves cannot constrain strong velocity jump over vertical velocity boundary such as the Moho. However, given the strong gradient of seismic velocity over the Moho, if we can determine the highest velocity in the crust, we can approximately constrain the depth of Moho by tracing the depth of this maximum velocity. Previous seismic refraction studies by Wang et al. (2000) and Dong et al. (2008) indicate that the P-wave velocity ranges from 6.6 to 6.9 km/s and the Poisson’s ratio ranges from 0.26 to 0.29 in the crust. Thus, by taking the highest P-wave velocity of 6.90 km/s and the lowest Poisson’s ratio of 0.26, we calculate the possible maximum Vs in the crust is about 3.93 km/s. Thus, we use 3.93 km/s Vs to approximately mark the depth of Moho (Fig. 9). Because the Moho interface usually marks the big velocity jump from the lower crust to the uppermost mantle, in an alternative way, we also use the largest positive peak of velocity–depth gradient to estimate the depth of Moho by calculating velocity–depth gradients (dVs/dz) beneath each geographic point. We find that the depths of the 3.93 km/s Vs contour are very similar with the Moho depths determined based on velocity–depth gradients. Here, we have to acknowledge that the estimation of the depth of Moho using surface wave dispersion curves is merely an approximate way and caution needs to be taken in interpreting the depth of Moho. Nevertheless, the shape of the 3.93 km/s Vs contour of the Vs model correlates well with the Moho shape of two profiles estimated from deep

Fig. 8. Maps of shear velocities at depths of 8, 16, 25, and 35 km.
seismic refraction profiling (Wang et al., 2000) and seismic reflection profiling (Yuan et al., 2003). The depth of the 3.93 km/s Vs is, however, about 0–3 km shallower than the two explosive profiles, which is quite small given the distinct techniques used in determining the depth of Moho.

The most pronounced feature of the Moho in the eastern Dabie orogenic belt is that the depth of Moho becomes deeper and deeper from south to north and reaches deepest in the NDC unit. The observed variation of Moho depth is consistent with previous results of reflection and refraction profiles (Dong et al., 2008; Wang et al., 2000; Yuan et al., 2003), and also consistent with the observation of a low Bouguer gravity anomaly in the central Dabie (Liou et al., 1996). The strong low velocity observed in NDC in the Vs map of 35 km depth (Fig. 8d) is because the crust is more than 35 km thick beneath NDC; while the crust in other regions is less than 35 km thick. In other words, the map of 35 km depth exhibits crustal velocities in the NDC but exhibits mantle velocities in other regions. Beneath the Hong’an HP and UHP belts (Fig. 9a), the Moho does not show north-dipping pattern (Fig. 9a), which implies there could be a different suturing type of collision between the Yangtze Craton and the North China Craton in the western Dabie. The reason for this could be that the Hong’an block escaped from the thermal and structural overprint during early Cretaceous intrusions of massive granites and granodiorites (Eide and Liou, 2000).

Fig. 9. (a)–(c) Transects of shear velocities along longitude 114.2°E, 115.4°E, and 116.3°E, correspondingly (see Fig. 1a for the locations of these transects). Black lines in (a–c) represent 3.93 km/s Vs velocity contours. Major geological blocks and features are identified at the top of each transect with the abbreviations listed in the caption of Fig. 1a.
7. Conclusions

In contrast to most previous geophysical studies focusing on individual linear profiles, which traverse the Dabie orogen from north to south and only reveal 2D crustal structures of the orogen, this study constructs a high-resolution 3D crustal structure of the Dabie orogenic belt using ambient noise tomography. The high-resolution 3D model reveals significant lateral and vertical variations of seismic velocities relevant to the complex Dabie orogeny. In the upper crust, the distribution of shear velocities is closely correlated with the surficial geologic features. Low velocities are observed in the Jianghan, Huabei and Hefei basins, due to the presence of sedimentary layers. High velocities are imaged in HP and UHP metamorphic zones where HP and UHP metamorphic rocks are exposed at the surface. These high velocities are observed to be only concentrated in the upper crust at depths shallower than ~9 km. Underlying the high velocity HP/UHP blocks, low velocity zones appear in the middle crust, probably representing ductile shear zones or brittle fracture zones developed during the exhumation of the HP/UHP metamorphic rocks. In the middle crust, a prominent high velocity feature is imaged beneath the Northern Dabie Complex unit between XMFX and the XGF. This high velocity anomaly may be related to cooling and crystallization of intrusive igneous rocks in the middle crust resulting from the post-collisional lithospheric delaminatation and subsequent magmatism. A north-dipping Moho is observed with the deepest Moho located in the North Dabie Complex unit in the eastern Dabie, consistent with the northward subduction of the Yangtze Craton beneath the North China Craton.

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Dabie, consistent with the northward subduction of the Yangtze Craton subsequent magmatism. A north-dipping Moho is observed with the deepest Moho located in the North Dabie Complex unit in the eastern Dabie, consistent with the northward subduction of the Yangtze Craton beneath the North China Craton.