Lithospheric structure of East Sea of Korea from teleseismic receiver functions: Seismic evidence of ancient back-arc basin opening

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We investigate lithospheric seismic structure beneath Ulleung back-arc basin in East Sea of Korea, which opened ~28 Ma due to Pacific Plate subduction. Formation of ocean basin in response to subduction typically causes characteristic features such as thinned crust and trench-normal fast-velocity directions in the mantle. Previous seismic studies reported a presence of a thick crust (thicker than normal oceanic crust) and prominent low-velocity anomaly in the lithospheric upper mantle (at ~100 km depth) beneath East Sea. Also, shear-wave splitting and tomography results show trench-normal fast-velocity directions beneath the oceanic basin.
We constrain azimuthal anisotropy of crust and lithosphere of the volcanic islands (Jeju, Ulleung, and Dok islands) by modeling amplitude variations of both radial- and transverse-component receiver functions (RFs) by back-azimuths. Our analysis results show that all islands commonly have thicker crust (more than 20 km). In particular, under Jeju Island, we observe a large variation in crustal thickness (18-26 km). The thinnest part of the crust is observed in the middle of the island along a N-S direction. Modeling of the transverse RFs requires an existence of a dipping Moho and localized anisotropy above the Moho. Also, a presence of paleo-oceanic sediments shifts the arrival time of a direct P wave in the radial RFs by 0.5 s. Crustal structure of Ulleung Island includes a dipping Moho with strike roughly parallel to contour line of the island. Under Dok Island, we observe large variations in amplitudes of the transverse RFs in back-azimuthal domain, suggesting a similar crustal structure as that in Ulleung Island.
Our teleseismic constraints on the structure and anisotropy provide an insight on the opening of the ancient back-arc basin in East Sea. Direction of anisotropy under Jeju Island is along a N-E direction, and is consistent with the constraints from previous body-wave anisotropy studies. Also, this direction is along the mantle shear which might have induced focusing of the magmatism, causing the monogenetic volcanism of the island (Brenna et al., 2012). Also the dipping Moho structure beneath Ulleung Island can be a geophysical evidence of an existence of continental block suggested in geochemical studies (Jolivet et al., 1992; Kim et al., 2008). Variable Moho depths under Jeju Island may be related with the activity of Mt. Halla, the largest shield volcano of the island.

Keywords: Back-arc basin opening, Receiver Function, Seismic anisotropy, Ulleung Basin, Volcanic island

Stress field did not change at 15 Ma in SW Japan: Counterevidence from dike orientations

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The drastic change in dike orientations at 15 Ma in SW Japan has been thought to indicate the termination of the extensional tectonics accompanied by the Japan Sea opening. We found counterevidence to this picture in the Tajima-Myokensan area, northern Hyogo Prefecture, SW Japan—a representative area where previous researchers reported an older ENE-trending eight dikes and a younger NNW-trending 51 ones (Kobayashi, 1979a, b; Tsunakawa, 1983). The host strata lie subhorizontally, which make tilt correction unnecessary. They judged the stress regimes from the faults that were activated before and after 15 Ma. However, it is difficult to determine the timing of faulting, because few syntectonic deposits along faults have been found in SW Japan.

The recent development of paleostress analysis of dilational fractures allows us to determine all the three stress axes, stress ratio and driving pressure of magma from dike orientations. In case dikes were resulted from polyphase tectonics, the technique not only separates the stresses, but also determines the appropriate number of stresses (Yamaji and Sato, 2011).

In this study, we measured the 388 orientations of dikes and sills in the Early to early Middle Miocene strata called the Hokutan Group, and applied the latest technique by Yamaji and Sato (2011) to them. It was found that NE-SW extensional stress with a low stress ratio was found from the group. The base and top horizons are correlated to ca. 20 and 14 Ma, respectively (e.g., Takayasu et al., 1992). We obtained three couples of fission-track ages between ca. 17 and 13 Ma, which was consistent with the youngest fractions of the U-Pb ages of the same samples. Therefore, stress condition did not change at 15 Ma in this area.

Keywords: Miocene, paleostress, Southwest Japan, Japan Sea

Deep focus earthquakes and slab-like structure beneath Northeast China and surrounding regions

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Earthquakes with hypocentral depth >60 km are generally observed only in areas of subduction zone. Northeast China is one of good places for studying deep-focus earthquakes and subducting slabs. The deep seismicity forms narrow, inclined Wadati-Benioff zones which sometimes are continuous throughout the upper mantle and outline the shape of subducting slabs. Consequently, the deep seismicity zones also correlate well with the subducting slabs, as shown in regional/global tomography studies. Two issues are included in this proposition: namely, the mechanisms of deep-focus earthquake and the fate of subducted slab. Note that both of the included issues are debated topics. Three major hypotheses suggested for the mechanism of earthquakes are brittle shear failure in the subducting slab, polymorphic phase transformations, and sudden minerals transformation. The fate of slab whether or not it subducted into the lower mantle remains uncertain. So the relationship between shapes of subduction slabs and deep-focus seismicity zones is not a simple link to each other as mentioned above.
The relationship between slab shape and deep-focus seismicity is variously dependent on several physical mechanisms producing seismicity within Wadati-Benioff zones. Two items are required for earthquake activity, a source of stress and a material undergoing unstable strain localization. In the western Pacific, a reasonable relationship between the slabs and seismicity zones is provided through slab buckling by Myhill study (2013). This mechanical model of deep-focus earthquakes is based on slab buckling. Apperson and Frohlich (1987) supposed that the majority of deep-focus earthquake physical mechanisms are not explained by slab shape in any simple way due to the uncertain role of slab morphology. Another physical mechanism is volume changes within subducting slabs, which providing an alternative to stresses associated with deep-focus seismicity. Inside or around the subducted oceanic lithosphere, that olivine phase transformation has been considered as volumetric reduction, which caused deep-focus earthquake.
Both slab buckling and volume change can explain well the clustering of deep-focus earthquakes observed in depth distributions within subduction zone. Note there is a lack of intense seismicity in the mantle transition zone beneath the Changbaishan volcanic site where oceanic lithosphere was observed by several tomographic studies. Neither slab buckling or volume change can interpret this possible gap in earthquake prone area beneath Changbaishan volcanic site.
In Northeast China area, we derived a 3D P and S velocity model to 800 km depth using P and S joint inversion method. The data used here were recorded by a temporary deployment as well as the permanent stations coexisted during the same period. We constrain an integrated model based on previous and this study, and thus give a possible explanation for few deep-focus seismicities occurring within the subducted oceanic lithosphere and surrounding area beneath Changbaishan volcanic site.
The main conclusions are: 1) not all of the deep-focus seismicities occurred in high-V anomaly zones because of the different physical mechanisms of deep earthquake. 2) A part of the deep-focus seismicities were due to the brittle shear failure in the subducting slab while other part of the deep-focus seismicities stemmed from volume change. 3) The piled up small slab block zones seem to be broader than the known deep seismicity zone because of the horizontal flow.

Keywords: deep focus earthquake, slab-like, tomography

3-D upper mantle structure beneath the Sea of Japan with inter-station surface-wave analysis using multiple seismic arrays

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The Sea of Japan is one of the typical back-arc basins in the western Pacific, comprising three major basins (Japan, Yamato and Tsushima Basins) and Yamato and North Yamato Rises in its center. In addition to such characteristic sea-floor topography, the crustal thickness beneath this marginal sea is variable, reflecting the complex tectonic history of the back-arc spreading, which had occurred from 30 to 10 Ma. Thus, the seismic structure in the crust and upper mantle beneath the Sea of Japan is likely to reflect its complex tectonic history including back-arc spreading and the subsequent formation of the Japanese islands.

The 3-D upper mantle structure around the Japanese islands has been investigated by Yoshizawa et al. (2010, PEPI), based on inter-station dispersion measurements of surface waves primarily using permanent broad-band seismic stations deployed throughout Japan (F-net) and some stations of the Global Seismic Network in east Asia. However, this earlier model had insufficient lateral resolution for most areas in the Sea of Japan, due to the limited ray path coverage. In this study, in addition to the permanent seismic networks in Japan and east Asia, we employ temporary broadband seismic arrays in Northeast China (NECESSArray) with 120 stations from 2009 to 2011, and in Far-east region of Russia with 8 stations since 2005. By combining all these multiple seismic arrays, we are able to collect a large number of inter-station paths across the Sea of Japan, which can be of help in enhancing the horizontal resolution of surface-wave tomography model.

For the inter-station phase speed measurements of this study, we used a fully non-linear waveform fitting technique developed by Hamada & Yoshizawa (2015, GJI). Through the waveform analysis of the combined data sets in the period range between 25 and 130 seconds, we collected about 12000 new measurements of phase speeds using events with moment magnitude greater than 6.0 from 2002 to 2016. With the additional data sets from arrays in Northeast China and Far-East Russia, we are now able to resolve the smaller scale heterogeneity of about 1.5 degrees or less in the Sea of Japan. The updated 3-D upper mantle structure show significant fast shear wave speed anomalies in the top 55-65 km, representing the oceanic-type lithosphere, while the conspicuous slow anomalies are found beneath 70 km depth in most areas under the Sea of Japan. The lithospheric thickness varies slightly from place to place, suggesting relatively thicker lithosphere in the eastern margin of the Japan Basin as well as Yamato Basin. Slow anomalies in the asthenosphere are more enhanced under the Japan Basin, compared with the other basins. This slow anomaly tends to be more enhanced in the western part of the Japan Basin near the continental margin, which may be mixed with the strong local slow anomaly right beneath the Changbaishan Volcano in the border between China and North Korea, mainly due to the smearing effects caused by biased azimuthal coverage of surface wave paths in this region.

Keywords: upper mantle, surface waves, Sea of Japan

Petrological and geochemical features of gabbros and relatively primitive basalts from Nikoro Group, Tokoro belt, eastern Hokkaido: Implications for the geodynamic setting

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The Tokoro belt is a subduction complex located in eastern Hokkaido, Japan. The Tokoro belt was formed by the subduction of Kula plate during the Late Cretaceous and consists of three stratigraphic units: the Nikoro, Yubetsu, and Saroma groups. The Nikoro Group is composed mainly of Late Jurassic to Early Cretaceous igneous rocks intercalated with bedded (or lenticular) chert and limestone. Igneous rocks are made up of basaltic and trachytic pillow lavas, hyaloclastites, dolerite, trachyte dikes, and ultramafic-mafic cumulates. Based on their geological characteristics, whole-rock (WR) major and minor elements, and clinopyroxene (Cpx) major element (MJ) geochemistry, these rocks are presumably derived from fragments of seamounts. In this study, we re-evaluate geochemical features of igneous rocks from the Nikoro Group based on WR and Cpx geochemistry, including trace elements (TEs).

Gabbros show ophitic texture and contain fresh, large oikocrystic Cpx. TE composition of Cpx from gabbros and WR geochemistry of gabbroic rocks are almost identical to the Cpx microphenocrysts of basalts and the WR geochemistry of basalts, respectively. This evidence suggests Cpx-melt partition coefficients for TE remained constant with almost no modification and the gabbroic rocks represent the melt composition. Although these rocks are slightly evolved (Mg# = 0.63), their compositions are among the most primitive rock compositions previously reported from this area. Whole rock TEs show ocean island basalt (OIB) type patterns as well as 'garnet signatures' (e.g., $[Sm/Yb]_N > 1$). These geochemical features support seamount origin. In further detail, gabbros and the relatively primitive basalts show rather flat TE patterns compared to the 'typical' OIB. After correcting the gabbros and basalts (MgO>7 wt%) for the fractionation effect to Mg# = 0.72, composition X_{72} suggests a significantly shallow lithosphere–asthenosphere boundary depth of ~0 km. WR $[Sm/Yb]_N$ ratios also show the same results. These geochemical results constrain the geodynamic setting of the Nikoro Group; the OIBs erupted through very thin lithosphere. Such a tectonic setting is limited to the ridge–hotspot interaction area.

Keywords: Tokoro belt, Nikoro Group, Ocean island basalt (OIB)

Velocity structure of uppermost mantle from Pn tomography beneath the southeastern margin of the Tibetan Plateau

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Since the late Cenozoic, structural deformation and seismic activity of the southeastern margin of Tibetan Plateau have become very strong. The southeastern margin of the Tibetan Plateau is characterized by strong seismicity and crustal deformation. It is an ideal region to investigate the lateral growth of the plateau and southeastward escape of the crustal material. The velocity structure and anisotropy of the uppermost mantle are important constraints on the crustal and mantle rheology.The Pn phases, which propagate along the bottom boundary of Moho, are critical information to study the velocity structure and anisotropy of the uppermost mantle.
In our work we have selected travel times of Pn arrivals as reported in the Annual Bulletin of Chinese Earthquakes(ABCE) and regional seismic network of provinces. A two-dimensional tomography method is employed to find regional variation of Pn velocity in the uppermost mantle beneath the southeastern margin of the Tibetan Plateau. In the most study area 2 degrees are well resolved.The main results show the relations of Pn velocity variation to regional tectonic structure, Moho depth and earth’s heatflow. Pn velocity structure is close to the regional tectonic structure: Low Pn velocities are found on the intense tectonic activity area, such as the west of SiChuan-YunNan block . High Pn velocities are on the tectonic stability area,beneath SiChuan Plain. Quantitative analysis result indicates that Pn velocity is positively correlated with crust thickness and negatively correlated with Earth’s heatflow.
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Keywords: Tibetan Plateau, uppermost mantle, Pn tomography

Dissolved helium isotopes in groundwater: Implication for subduction of continental crust in an active arc-continent collision

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Here we use helium isotopes in groundwater from along the Chauchou/Tulungwan fault system in southern Taiwan to evaluate the involvement of the upper mantle in an active arc-continental collision. Helium isotope ratios of sixteen groundwater samples, four bedrock samples, and one hot spring sample, collected along 10 km on the fault, were measured and reported as R_A (relative to an air helium isotope ratio ($^3He/^4He$) of 1.39 ×10^{-6}). Measured groundwater helium isotope ratios, ranging from 0.07 to 1.00 R_A, express a clear mixing model with three endmembers of air (1.00 R_A), crust (0.06 R_A) and upper mantle (8 R_A). Samples from southern part of the fault show normal distribution of crustal signal. By correcting the helium from air-contamination, samples from northern part of the fault with 0.30-0.78 R_A reveal significant upper mantle signal. The Chauchou/Tulungwan fault system, in the area of detected mantle-derived fluids, projects down dip to a zone of ambient tremors and a nearby zone of high conductivity; both features extend to nearly 40 km, which is close to the crust-mantle boundary in this area. These observations suggest that mantle-derived fluids penetrate the crust through the zone of the tremor activity, reaching the surface long the Tulugwan fault zone. This study shows that non-volcanic, mantle-derived fluids can be involved in tectonic processes associated with an active arc-continent collision zone.

Keywords: Chauchou fault, noble gas, active tectonics, mantle-derived fluids

Moho Depth of The South China Sea Basin from Three-dimensional gravity inversion with control points and its characteristic

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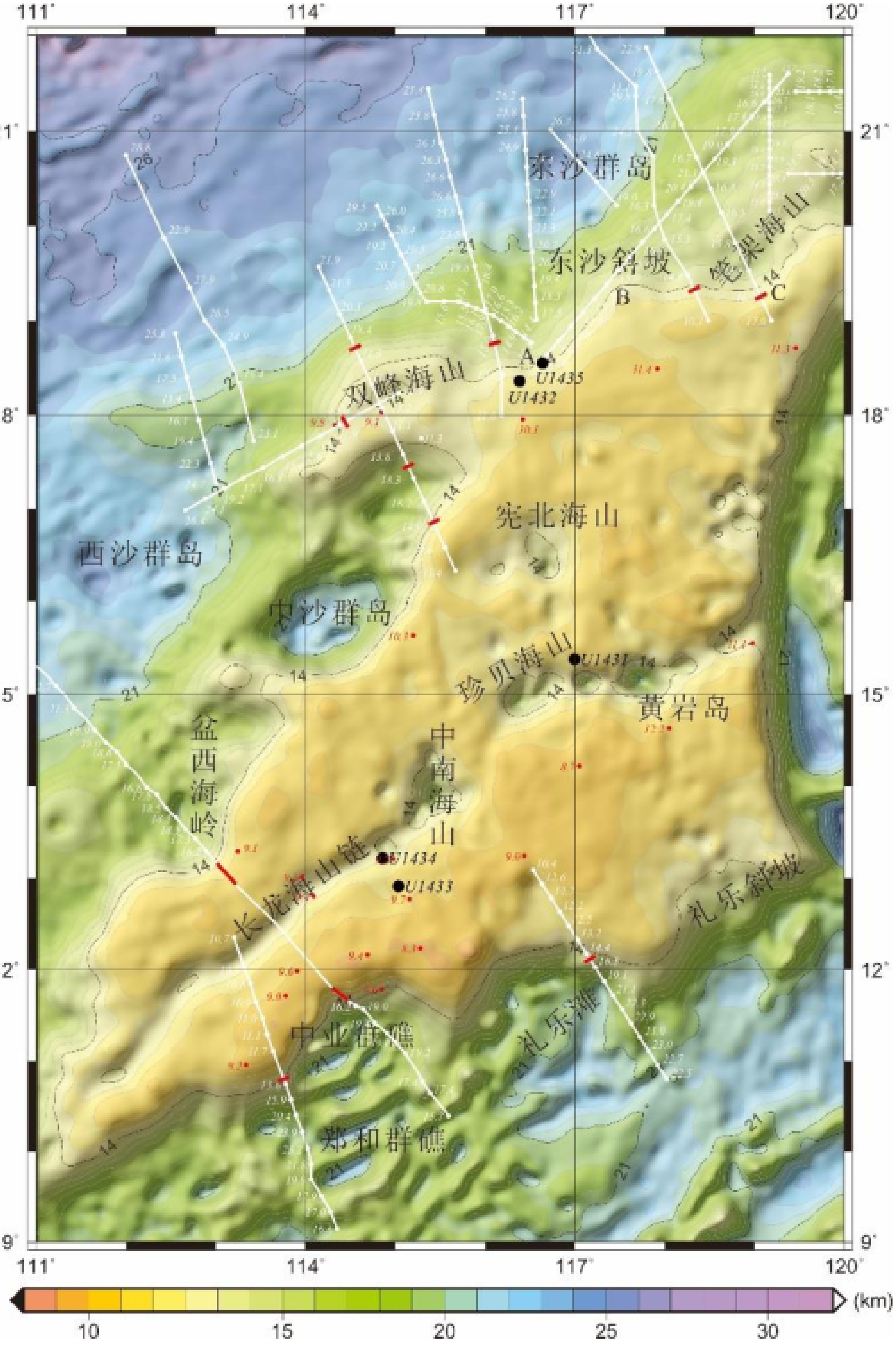
Over most of the South China Sea basin, the Moho depth ranges between 8˜14km, the crustal thickness is 3˜9km.

Keywords: South China Sea Basin, Moho depth, Known control points, Thermal gravity anomaly



东沙群岛
东沙斜坡
笔架海山
双峰海山
宪北海山
西沙群岛
中沙群岛
珍贝海山
黄岩岛
盆西海岭
中南海山
长龙海山链
礼乐斜坡
礼乐滩
中业群礁
郑和群礁
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(km)
10
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The tectonic boundaries of the Jiangnan belt in South China: insights from potential-field anomalies

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The tectonic boundaries of the Jiangnan belt in South China, which developed during the Neoproterozoic, has remained unknown or controversial for decades. A long NW-trending deep seismic reflection profile across the Yangtze and Cathaysia blocks in South China was conducted by the SinoProbe-02 project for the first time in 2010–2012. From the analysis and interpretation of this seismic data, 2-D gravity modeling was proposed, suggesting that both Yangtze and Cathaysia blocks are notably different in crustal structure, and that the northern boundary of the central Jiangnan belt is bounded by Fangjingshan and the southern boundary is bounded by Qidong county. Then the regional gravity and magnetic anomalies were analyzed and interpreted comprehensively, showing that Yangtze and Cathaysia blocks have distinct features of gravity and magnetic anomalies due to various crustal structures and tectonic deformation. The results indicate that the northern boundary of the Jiangnan belt is located in the Shitai–Jiujiang–Dayong–Tongren–Hechi–Baise line, and the southern boundary is located in the Shaoxing–Jiangshan–Pingxiang–Qidong– Yongzhou–Guigang–Nanning line, which possibly represents a Neoproterozoic suture between Yangtze and Cathatsia blocks.

Keywords: South China, crustal structure, tectonic boundary, gravity and magnetic

Lithospheric rebuilding of the Alashan and ordos by upper mantle upwelling: evidence from multiscale teleseismic tomography

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Between 2013 and 2015, The China Seismic Array-2 experiment operated 670 broadband seismic stations with an average station spacing of 35km. This seismic array located in northeastern Tibet and covered the Qilian Mountains, Qaidam Basin, and part of Songpan-Ganzi, Gobi-Alashan, Yangzi, and Ordos terrane. ~90,000 P-wave relative travel times from ~300 teleseismic events were picked by cross-correlation method. A new multiscale seismic traveltime tomography technique with sparsity constrains were used to map the upper mantle P-wave velocity structure beneath northeastern Tibet. The seismic tomography algorithm employs sparsity constrains on the wavelet representation velocity model via the L1-norm regularization. This algorithm can efficiently deal with the uneven-sampled volume, and give multiscale images of the model.

Our preliminary results can be summarized as follows: 1) in the upper mantle down to 200km, significate low-velocity anomalies exist beneath the northeastern Tibet, and slight high-velocity anomalies beneath the Qaidam basin; 2)under Gobi-Alashan, Yangzi, and Ordos, high-velocity anomalies appear to extend to a depth of ~250km, this high-velocity may correspond to the lithosphere; 3) there exist relative high-velocity anomalies at depth of 250km-350km underneath north Tibet, which suggests lithospheric delamination; 4) there exist low-velocity anomalie from depth of 500km under Qinlin extented to uppermantle of the north part of Ordos and eastern margin of Gabi-Alashan terrane, which implied the upper mantle upwelling transform and rebuild the lithosphere of Gabi-Alashan and Ordos.

Keywords: upper mantle upwelling, Alashan, Ordos, multisacle seismic tomography

