Multi-scale Structure and Lithospheric Discontinuities

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The continental lithosphere is heterogeneous on a wide variety of scales and apparent seismic discontinuities arise from the interaction of the seismic wavefield with multiple-scale features. In consequence the character of such discontinuities is frequency-dependent. Nevertheless it is possible to track discontinuities within the lithosphere across closely spaced stations exploiting P-wave reflectivity extracted from stacked autocorrelograms at each receiver.
Although most inference of finer-scale structure is indirect, corroborative evidence comes from the geochemistry of xenoliths across southeastern Australia. There is a close correspondence between changes in chemistry and P-wave reflectivity in the neighbourhood of the xenoliths.

Keywords: Lithospheric Heterogeneity, Lithsopheric Discontinuities

Imaging Lithospheric Seismic Discontinuities beneath Cascadia using S-to-P Receiver Functions

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Strong, sharp seismic discontinuities in the 60 –110 km depth range are now frequently imaged and sometimes related to the lithosphere-asthenosphere boundary. However, determining the exact relationship has proven challenging, and interpretations diverge particularly between the continents and the oceans. Here we use S-to- P receiver functions recorded by the Cascadia Ocean Bottom Array and the western most Transportable Array to image crust and upper mantle discontinuity structure beneath the Juan de Fuca and Gorda Oceanic Plates and western North America. We handpick events from epicentral distances 55 –80 degrees away, choosing 5021 waveforms of which 343 are from ocean bottom seismometers. We use an extended time multi-taper technique to deconvolve the waveforms and migrate to depth in 3-D. We image a positive phase, or velocity increase with depth, that corresponds to an oceanic Moho at 6 –7 km depth and a continental Moho at 33 –37 km depth. We also image a negative discontinuity beneath the ocean plate that thickens with age from 25 –45 km depth beneath the oceans in general agreement with expectations from half-space cooling. Waveform and geodynamic modelling indicate that these are defined by melt. This suggests that melt exists at the base of the plate, defining it, and that melt is likely transported along the base of the plate towards the mid-ocean ridge. In addition, we image a deeper discontinuity at 55 –75 km beneath the continental lithosphere also likely related to the lithosphere-asthenosphere boundary.

Keywords: lithosphere-asthenosphere, seismic, receiver function, Cascadia, melt, ocean plate

Moho Depth Variations in the northeastern North China Craton Revealed by Receiver Function Imaging

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The North China Craton (NCC), one of the oldest cratons in the world, has attracted wide attention in Earth Science for decades because of the unusual Mesozoic destruction of its cratonic lithosphere. Understanding the deep processes and mechanism of this craton destruction demands detailed knowledge about the deep structure of the region. In this study, we used two-year teleseismic receiver function data from the North China Seismic Array, which consists of ~200 broadband stations deployed in the northeastern NCC, to image the Moho undulation of this region. A 2-D wave equation-based poststack depth migration method (Chen et al., 2005) was employed to construct the structural images along 19 profiles, and a pseudo 3D crustal velocity model of the region based on previous ambient noise tomography and receiver function study was adopted in the migration. We considered both the Ps and PpPs phases, but in some cases we also conducted PpSs+PsPs migration, analyzed images using different back azimuth ranges of the data, and calculated the theoretical travel times of all the considered phases to constrain the Moho depths. By combining the structure images along the 19 profiles, we got a high-resolution Moho depth map beneath the northeastern NCC. Generally, the Moho depths are distinctly different on the opposite sides of the North-South Gravity Lineament. The Moho in the west are deeper than 40 km and shows a rapid uplift from ~40 km to ~30 km beneath the Taihang Mountain Range in the middle. To the east in the Bohai Bay Basin, the Moho further shallows to ~30-26 km depth and undulates by ~3 km, coinciding well with the depressions and uplifts inside the basin. The Moho depth beneath the Yin-Yan Mountains in the north gradually decreases from ~42 km in the west to ~35 km in the east, varying much smoother than that to the south. Our results broadly consist with the pattern of previous active source studies [http://www.craton.cn/data], and show a good correlation of the Moho depths with geological and tectonic features. We systematically compared our results with other seismic observations and discussed correlations of Moho depths with lithospheric thickness, seismic anisotropy, surface geology, reginal tectonics, and gravity anomaly as well as petrographic and geochemical data in detail. Furthermore, we discussed possible mechanisms accounting for fundamental destruction of the NCC lithosphere in Late Mesozoic.

Keywords: Moho discontinuity, North China Craton, Lithospheric destruction, Receiver function imaging

A Detailed Look at Pn Phases in the Western Pacific: Local Reverberations versus Scattering in the Deeper Lithosphere

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Oceanic Pn or Po phases propagate efficiently in old Pacific lithosphere. Their ability to propagate hundreds of km up a subducting slab and then travel thousands of km horizontally within the lithosphere while retaining their high frequency content indicates that there are strong, semi-horizontal heterogeneities within the plate that scatter and guide the waves (e.g., Kennett and Furumura, 2013). However, it is clear that reverberations within the water column and sediments contribute significantly to the coda of Po. In an attempt to sort out the relative contributions of local reverberations and lithospheric scattering to the coda, we examine in detail the waveforms of Po phases recorded on an array of ocean-bottom seismometers on 150-160 Ma seafloor south of Shatsky Rise. We separate Po into the upgoing and downgoing components by combining vertical and pressure records. Then stacking the auto- and cross-correlations of upgoing and downgoing records from many earthquake sources reveals the local reverberatory response. We model the stacked correlograms to infer local sediment/crustal structure using a reflectivity method. Reflections at the base of the sediments are just as important as reflections at the seafloor, but coherent multiple reflections are almost undetectable. Despite the relatively flat seafloor, changes in the stacked correlograms with back azimuth from individual stations indicate that variations in local sediment structure play a key role in randomizing the local response and minimizing coherent reverberations.

Keywords: Pn coda, Oceanic lithosphere

Microstructural & geochemical evolution of the deep arc lithosphere: implications for seismic discontinuities beneath continents

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Lower crustal and upper mantle xenoliths provide the only direct samples of deep lithosphere, and therefore play an essential role in understanding lithospheric structure. We examine the microstructural and geochemical evolution of peridotite xenoliths from the Sierra Nevada, a Mesozoic continental arc. These xenoliths represent an arc mantle column grading from depleted spinel peridotite characterized by strong orthorhombic olivine LPO to fertile garnet peridotite with weak axial-[010] LPO. In contrast to observed nominally dry axial-[010] LPO, intragranular olivine microstructures indicate deformation under hydrous conditions (in which the (001)[100] system is dominant). However, water contents in olivine are too low to account for E-type fabric. These seemingly contradictory results can be reconciled in the context of the Sierran peridotites' P-T-t path, which was found to consist of initial lithosphere formation via melt depletion at shallow (<2 GPa) depths followed by thickening, modal metasomatism (involving a hydrous melt), and final equilibration and rapid cooling (~5 My) at deep (>3 GPa) and cold (750 –800 C) conditions. We propose that melt infiltration and associated precipitation of fine-grained pyroxene and garnet facilitated grain-size sensitive creep, localizing deformation in fine-grained regions and resulting in weak, axial-[010] LPOs in the most metasomatized peridotites. So, even though (001)[100] slip may have been the dominant active slip system, E-type fabrics were not produced because the overall LPO was dominated by grain-size sensitive creep promoted by presence of melt. Subsequent cooling resulted in water loss from olivine owing to the drastic lowering of solubility with decreasing temperature. However, final temperatures were too low (750 C) to enable significant deformation –effectively preserving the relict intragranular (001)[100] microstructures. Our study has implications for seismic structure of subduction zones globally. We show that overriding plate lithosphere –an often overlooked aspect of the subduction system –is stratified in terms of composition and fabric. The transition from orthorhombic E-type to weak axial-[010] fabrics results in a significant decrease in Vp anisotropy. Seismic anisotropy in subduction zones is complex, and thus the interplay between compositional gradients and cooling histories of mantle lithosphere need to be considered when interpreting subduction zone structure.

Keywords: subduction, peridotite, xenolith, LPO

Layered anisotropic structure of the Huatung Basin oceanic lithosphere offshore eastern Taiwan

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We analyze ambient noise of continuous seismic waveform data recorded by ocean-bottom seismometers (OBS) deployed in the Huatung Basin and adjacent regions off the east coast of Taiwan. Taiwan is a young and active orogenic belt resulting from the oblique subduction and collision between the Eurasian Plate and the Philippine Sea Plate. Sitting on the westernmost edge of the Philippine Sea Plate, the Huatung Basin is directly involved in the subduction-collision processes. The structural characteristics of the lithosphere provide important constraints not only on its own history but the tectonic evolution in this complex region. We integrate data from OBS with those from land stations along the east coast of Taiwan to derive Rayleigh wave Green’s functions from cross-correlation between all available station pairs, covering the majority of the Huatung Basin. We measure phase velocity dispersion at periods from 4 to 20 sec, and invert for 2-D anisotropic phase velocity maps based on a wavelet-based multi-scale inversion scheme. Our results reveal a distinct period-dependent variation in anisotropy. At periods of 4-8 s, the anisotropy is generally weak and the fast direction is aligned in N-S direction. In contrast, at periods of 12-20 s, stronger anisotropy is observed with fast direction in NW-SE. The N-S anisotropic pattern reflects characteristics at crustal depths, and is consistent with magnetic lineation suggesting past basin spreading direction. Therefore, what we observe is likely the fossil anisotropic fabric created during the development of the ocean basin. On the other hand, the mantle lithosphere is dominated by NW-SE anisotropy, a direction sub-parallel to that of the convergence between the Philippine Sea Pate and the Eurasian Plate. The coincidence implies that the Huatung Basin’s mantle lithosphere is under the influence of asthenospheric flow induced by the plate motion of the Philippine Sea Plate.

Keywords: seismic anisotropy, ambient noise, ocean-bottom seismometer, Huatung Basin, Philippine Sea Plate, Multi-scale wavelet inversion

Imaging the Lithosphere-Asthenosphere boundary beneath circum-Pacific areas with the precursors of sP

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Lithosphere-asthenosphere boundary (LAB) is the negative upper mantle discontinuity. The lithospheric slabs with different subducting angles and velocities and stagnant slabs induce the different temperature and material anomalies into the deep Earth's interior, and the related dehydration and other volatiles are different in the processes, then affect the topography and characteristics of the LAB. Detecting the LAB in the Pacific subducting zone with seismic data will be helpful for understanding the interaction between the lithosphere and asthenosphere and the geodynamics of subducting slabs, and provides important geophysical parameters for recognizing the Earth's evolution.
The seismic waveform data recorded by the Chinese Digital Seismic Network, USArray, etc, are processed with the N-th root slant stack method to retrieve the seismic triplications or precursors of strong phases related to the LAB. The LAB is imaged and can be used to study the effects of the subducting slabs and related stagnant materials on the LAB. In the work, we found that: (1) The depth of LAB in the northern Lau Ridge is about 63 km with a range of 63 to 64 km, in the northwest is about 77 km with a range of 76 to 78 km and in the south is about 72 km; (2) The depth of LAB beneath Izu-Bonin is around between 58 and 65 km, and the average depth is 62 km; (3) In the western part of the south America, the LAB depths range between 60 and 63 km, with the average depth of 61 km and the topography of 3 km, while in the eastern part, the ones range between 78 and 82 km, with the average depth of 80 km and the topography of 9 km. We infer that the continental lithosphere may be subjected to the stronger erosions in the area near the trench, for the higher degree of partial melting and the more fertile melts in the asthenosphere; the one may be subjected to the weaker erosions in the area far from the trench, for the lower degree of partial melting and the less fertile melts in the asthenosphere.

Keywords: Lithosphere-Asthenosphere Boundary, N-th Root Slant Stack, Chinese Digital Seismic Network

Mid-lithosphere discontinuities beneath the western and central North China Craton

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We image the mid-lithosphere discontinuity (MLD) beneath western and central North China Craton (NCC) by a new approach —seismic daylight imaging (SDI), which analyzes P reflectivity extracted from stacked autocorrelograms for teleseismic events recorded by a dense array. The array across the NCC extended west-to-east for about 1000 km with average station interval of about 15 km, and was deployed by Institute of Geology and Geophysics, Chinese Academy of Sciences under North China Interior Structure Project (NCISP).

With higher and broader frequency band (0.5-4Hz) than used with receiver functions, the SDI approach reveals finer scale components of multi-scale lithospheric heterogeneity. The depth of the MLD beneath the western and central parts of the NCC ranges from 80-120 km, with a good match to the transition to negative S velocity gradient with depth from Rayleigh wave tomography. The MLD inferred from SDI also has good correspondence with the transition from conductive to convective regimes estimated from heat-flow data indicating likely thermal control within the seismological lithosphere.

Keywords: Mid-lithosphere discontinuity, Seismic daylight imaging, Autocorrelogram

Measurements of Rayleigh wave particle motions beneath the Japanese islands: Implications for the crust and uppermost mantle structures

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The amplitude ratio of horizontal and vertical components of Rayleigh waves can be used to investigate the relatively shallow Earth structure, such as the crust and uppermost mantle. Most of the earlier studies using surface wave are primarily based on the measurements of phase and/or group speed dispersion, and the Rayleigh wave ellipticity (or H/V ratio), which is more sensitive to shallow subsurface structure, has rarely been applied to the construction of the large-scale velocity structure. It has been well-known that such H/V ratios can be used to infer the internal structure of the Earth, but the spatial distribution of the H/V ratios of long-period Rayleigh waves with dense seismic arrays has yet to be investigated.
In this study, we analyzed the H/V ratios of intermediate to long period (30 −200 s) Rayleigh waves for all stations of the Japanese broadband seismic network (F-net), and discuss their relation with the crust and upper mantle structure beneath the Japanese islands.
The frequency-dependent variations of observed H/V ratios for each station are relatively mild. This reflect that the H/V ratios of Rayleigh waves are far more sensitive to the near surface structure irrespective of frequency even in the long period. Still, some slight changes in H/V ratios as a function of frequency can be observed, which is likely to reflect the large-scale structure in the uppermost mantle, since the sensitivity kernels of H/V ratios have a secondary peak below the Moho. Our results show that the observed H/V ratios in the shorter period than 60 s become larger than the regional average, particularly in the south of Hokkaido, the south of Kyushu and Kanto areas, while those in the south-western Japan show relatively smaller values. In general, high H/V ratios can be found in a region with strong vertical velocity gradients; for example, sedimentary areas above relatively fast velocity bedrock. Our results reflect such features well in shorter period range, and also coincide well with the velocity anomalies in the upper crust based on ambient noise analysis (Nishida et al., 2008); i.e., high H/V ratios in slow velocity regions, and low H/V ratios in fast velocity regions. In the longer period at around 100 s, the H/V ratios become large in Tohoku and Kyushu areas, just above the subducting plates. This may reflect the effects of secondary peak of the sensitivity profile of Rayleigh wave ellipticity. These results indicate that the Rayleigh wave ellipticity has a good potential to constrain the crustal and uppermost mantle structure, if we use them in conjunction with the conventional phase speed data.

Structural Variations of Inner Lithospheric Discontinuities beneath the North China Craton: Implications of the craton stability and destruction

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The North China Craton (NCC), namely the Sino-Korean Craton, is one of the ancient Archean cratons with the crust rocks as old as ~3.8 Ga. Similar to other Archean cratons worldwide, the western part of NCC has retained its cratonic nature and stability over long periods of geological time, and presently is characterized by a thick and cold root with a negative mid-lithosphere discontinuity (MLD) marking the vertical heterogeneity of the mantle lithosphere. However, the detailed structural features of the MLD and the related low-velocity layer (LVL) below remain unclear. On the other hand, the eastern NCC has experienced server destruction since Mesozoic, as manifested by the transformation from a thick, cold and refractory lithosphere in the Paleozoic to a thin, hot and fertile one in the Cenozoic. Thus the NCC is an ideal laboratory to investigate the influences of the MLD on the evolution, particularly destruction of cratons.
The implementation of numerous portable seismic array observations in the past two decades within the NCC makes it possible to obtain more high-resolution images of the deep structure of the region than ever. In this study, we used the seismic data from 8 linear portable arrays of densely-deployed stations and the network of ~300 permanent stations within the NCC and surrounding areas to image the elaborate lithospheric structure with various seismological methods. Our results show that a negative MLD and an underlying LVL widely exists within the mantle lithosphere of the Ordos Block, namely the cratonic nuclei of the western NCC. The depth of the MLD varies mainly in the depth range of 80-120 km, uncorrelated with the depth variations of the Moho and LAB. An obvious deepening of the MLD and the LVL was observed beneath the orogenic belts surrounding the Ordos Block, which may reflect the modification of the lithospheric mantle structure by the associated orogenic processes. The depth of the MLD beneath the Ordos Block is comparable to that of the LAB in the eastern NCC where the lithosphere has been thinned and destroyed. Based on this observation, we propose that the MLD and the LVL may have acted as a mechanical weak layer in the lithospheric mantle, facilitating the destruction of the eastern NCC. Finally, we also observed a LVL in the mid-crust of the Ordos Block. It may be another clue to decipher the evolution of the craton.
This study is supported by National Scientific Foundation of China (grant: 41274002, 41225016, 41125015).

Keywords: North China Craton, Mid-Lithosphere discontinuity

Lithospheric structures beneath Chinese Mainland: Insights from S receiver functions

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A rigid lithosphere floating over the viscous asthenosphere is the basic model of continental drift. The displacement of lithosphere-asthenosphere boundary (LAB) provides important clues of lithospheric deformation. However, because the LAB is not a sharp discontinuity but marked in many places by a smooth velocity gradient, it is difficult to determine the precise depth of LAB with body waves. It can be also complicated by another relatively sharp discontinuity, named as mid-lithosphere discontinuity (MLD), which may result from deformation at mineral grain boundaries (Karato et al., 2015).
The Chinese Mainland is tectonically shaped in the Cenozoic by the collision with the Indian plate on its southwestern side and the subduction of the Pacific and Philippines oceanic plates on the eastern side. Investigation of the LAB under mainland China can help us understand its geodynamic evolution and the mechanism controlling intraplate seismicity and volcanism in China.
We have integrated the dataset from ~1000 permanent seismic stations of the Chinese seismic network and dataset from ~700 stations of IRIS in west China to obtain more than 300 thousands S receiver functions. We use these results to investigate the lithospheric structures beneath the Chinese mainland. The preliminary results indicate a low velocity layer between 60~150 km, which represents the LAB or MLD. The results show clear differences of the crustal and lithospheric structures between east and west China, the deformation of LAB between different blocks, the subduction of India Plate, the depth variations of LAB and the relationship between LAB and the seismicity of strong earthquakes. We will discuss the implications of these results on the Cenozoic tectonic evolution in mainland China. This work is supported by National Natural Science Foundation of China (Grant 41274093 and 41574077) and the Basic Research Project of Institute of Earthquake Science of CEA (Grant 2014IESLZ03).

Keywords: lithosphere-asthenosphere boundary, S receiver functions, Chinese mainland, mid-lithosphere discontinuity

Lithospheric thinning in the Cathaysia block (South China) from joint inversion of receiver function, surface wave dispersion, and P-wave velocity

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Cratons are stable geological blocks, whose thickness is typically more than 200 km. However, the lithosphere in the North China Craton is believed to have been modified since Mesozoic. More recent geochemical studies show that the lithosphere in eastern China has been destructed. Nevertheless, the study of the lithospheric structure in the Cathaysia block (South China) is rare. In this study, we use a new joint inversion method to focus on the lithospheric structure below a dense seismic array in the Cathaysia block, where the P-wave receiver functions, surface wave dispersions, and P-wave velocity are available. The layered S velocity and Vp/Vs ratio are obtained simultaneously. The thin lithospheric thickness (60-70 km) is comparable with the thickness in eastern North China Craton, which provides clear evidence of lithospheric thinning in the Cathaysia block. The low S velocity and high Vp/Vs in the middle crust indicate possible partial crustal melting. The lithospheric thinning and the consequent crustal melting could be possible reason for the widely distributed granitoids in South China.

Keywords: Lithospheric thinning, Joint inversion, South China, Partial melt

Velocity structure of the mantle transition zone beneath the southeastern Tibetan Plateau

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P-wave triplications related to the 410 km discontinuity (the 410) were clearly observed from the seismograms of three intermediate-depth earthquakes that occurred in the Indo-Burma Subduction Zone (IBSZ) and were recorded by the Chinese Digital Seismic Network (CDSN). By comparing the observed triplications with synthetic waveforms, we obtained the best-fit models for four azimuthal profiles to constrain the P-wave velocity structure near the 410 beneath the southeastern Tibetan Plateau (TP). We find that there is a ubiquitous low-velocity layer (LVL) atop the mantle transition zone (MTZ). The LVL is characterized by a thickness of 35-45 km, and the P-wave velocity decreased by up to 4.1-4.7%. We attribute the LVL to the partial melting induced by water or other volatiles released from the subducted Indian Plate and the stagnant Pacific Plate. A high-velocity anomaly of up to 1% is detected at a depth of 500 km, providing additional evidence for the remains of the subducted Pacific plate within the MTZ. There is a clear transition in the velocity decrement and the depth of the 410. We therefore infer that the mantle structure beneath the southeastern TP is primarily controlled by the southeast extrusion of the Plateau to the north, combined with the eastward subduction of the Indian Plate to the south.

Keywords: seismic triplication, low-velocity layer, mantle transition zone, southeastern Tibetan Plateau