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Lowermost mantle shear velocity anisotropy beneath Siberia^{*}

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Introduction

D'' layer plays an important role in geodynamic process. And seismological research indicates that D'' layer has large scale seismic anisotropy, however, most research concentrated on areas such as Northern Pacific, Central Pacific, Caribbean, Central America, Alaska *etc.* (Wookey *et al.*, 2005; Garnero and Lay, 2003; Matzel *et al.*, 1996; Pulliam and Sen, 1998), because of the limited distribution of sources and stations. And there is no research record concerning the anisotropy of the lowest mantle beneath Siberia.

Shear wave splitting is usually used in the seismological studies on the anisotropy of D'' layer, such as S, ScS and Sdiff (Fouch *et al.*, 2001; Garnero and Lay, 1997; Karato, 1998), but it is difficult to consider the influence of the shallow anisotropy near the sources or stations in the analysis. In general, the source side's anisotropy is negligible for deep events (Thomas *et al.*, 2002), while the SKS splitting are usually employed to correct the effects of the upper mantle on receiver side. However, the influence of anisotropy in crust and the upper mantle can be reduced by travel time difference as much as possible, because ray paths of ScS and S are close. In this paper, we use the events in Japan and the records of Germany Regional Seismic Array Network (GRSN, Germany), and employ the travel time differences between ScS and S to analyze the lowermost mantle shear velocity anisotropy beneath Siberia.

1 Data and processing

We chose five events in Japan as shown in Table 1, with 31 records on GRSN satisfying the requirements. Figure 1a shows the events, stations and the ray paths, and the bounce points cover 60°N to 71°N, 75°E to 86°E.

Table 1 Earthquake catalog

Date (UTC) a-mo-d	Origin time h:min:s	$\varphi_N/^\circ$	$\lambda_E/^\circ$	Depth/km	Magnitude
2007-03-09	03:22:42.76	43.22	133.53	441	6.1 (m_b)
2006-06-11	20:01:26.31	33.13	131.14	139	6.3 (M_W)
2003-08-31	23:08:00.26	43.39	132.27	481	6.2 (M_W)
2002-06-28	17:19:30.27	43.75	130.67	566	7.3 (M_W)
2000-08-19	17:26:27.94	43.82	147.17	62	6.0 (m_b)

In the study, simple waveforms with stable radiation pattern of SH, high signal noise ratios and clear peaks of SH and SV were selected from masses of records. The station-event pairs were limited between 70° and 83°, in this

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region the travel time difference is sensitive to the anisotropy of D'' layer for the ray paths of ScS and S are close in mantle except the D'' layer. And for the events whose epicentral distances less than 70° , the bounce points of S are much above the core mantle boundary (CMB), and the ray paths of S and ScS have significant discrepancy, also the ScS and S will be interfered by SKS for the distances larger than 83° .

Before measuring the travel time differences, the data are processed by the following steps: ① The instrument responses were removed; ② the components of radial and tangential were separated by rotating the horizontal components to great circle path; ③ the velocity records were integrated to displacements; ④ the waveforms were filtered to improve the SNR (Figure 2), with a band pass between 5 s and 100 s.

Figure 1 Distribution of Japan earthquakes (open circles), seismic stations (triangles), and the great circle paths geometry (lines) (a) and ray paths geometry of S and ScS (b)

Figure 2 Two waveforms after being processed

HLG and FUR are two recording stations; Δ stands for epicentral distance. The upper waveform is tangential components, and the lower waveform is radial ones

2 Method and results

Travel time differences analysis and the cross correlation are mainly employed in the research of shear wave splitting. DAI *et al* (2007) compared these two methods, and proposed a formula to calculate the splitting time in D'' Layer.

$$\delta t = \Delta T_{\text{ScSV-SV}} - \Delta T_{\text{ScSH-SH}} - 0.2 \quad (1)$$

2.1 Splitting time

We calculated splitting times of the 31 records with the formula above. We found the values range from -1.67 s to 0.35 s, and only two positive values. The average value is -0.62 s, which means that most of the tangential components travel slower than the radial ones.

2.2 Anisotropy strength

Both the splitting time and the strength of anisotropy are important parameters of the anisotropy in lower-mantle. Ignoring other segments' contributions, we calculated the strength as $\alpha = \delta t / T$. The δt is the splitting time measured, while T is the total travel time in D'' layer. We adopted the Preliminary Reference Earth Model (PREM) (Dziewonski and Anderson, 1981) model of D'' layer with the depth of D'' layer ranging from 2 641 km to 2 891 km. The travel time was calculated according to PREM model and the anisotropy was assumed homogenous in D'' layer. As Figure 4 shows, the results range from -0.92% to 0.20% , most of which are between -0.6% and 0.0% , and the mean value is -0.33% .

Figure 3 Observations (a) and the histogram (b) of ScS wave splitting time of Japan earthquake
The center of mark is the bounce points at CMB, the mark size is proportional to splitting time's magnitude.
Triangles indicate the negative splitting time while the circles indicate the positive ones.

Figure 4 Strength of anisotropy (a) and its histogram (b) of ScS wave splitting time of Japan earthquake
Triangle indicates the anisotropy strength corresponding to the negative splitting time while the circles indicate that to the positive one. The mark size is proportional to magnitude of anisotropy's strength.

3 Mechanism of lowermost mantle anisotropy in Siberia

Seismologists have investigated anisotropy in D'' layer's in many regions. Most results showed that the SH travels faster than SV (Fouch *et al*, 2001; Wookey *et al*, 2005; Thomas *et al*, 2002; DAI *et al*, 2007), which agrees with the vertical transverse isotropy (VTI) geometry properties. On the contrary, our results demonstrated that the SV is faster than SH, which is caused by the horizontal transverse isotropy (HTI) (Pulliam and Sen, 1998). In our observations, seismic wave propagated along E-W direction, which illustrates that the geometry structure beneath Siberia has a symmetry axis paralleled to N-S direction.

There are two possible mechanisms of HTI. One is the lattice-preferred orientation (LPO) of anisotropic materials. The other is the shape-preferred orientation (SPO) of material with large velocity anomaly (Pulliam and Sen, 1998).

The observations can be well explained with HTI caused by SPO. Strong vertical shear upwelling in boundary region can result in vertical alignment of the chemically distinct or nonuniform-melted material, which will display as HTI structure. These materials might be the potential products of a core-mantle reaction or the partial melted materials above the CMB (Pulliam and Sen, 1998).

Another alternative explanation is the LPO. The material which has LPO property is the main potential mineral, such as [Mg, Fe]O, [Mg, Fe]O is cubic crystal, and its anisotropy varies with azimuth, which may cause $v_{SV} > v_{SH}$ in lower mantle (Maupin *et al*, 2005). The [Mg, Fe]SiO₃ post-perovskite is another candidate, which

shows strong shear wave anisotropy in tri-axial stress field. v_{SV} is larger than v_{SH} when [010] paralleled to horizontal, taking agreement with our observation(ZHANG *et al.*, 2007; Karato, 1998).

4 Conclusions

The differential travel times of qualified records were used to study the shear wave anisotropy of the D'' layer beneath Siberia. Most of the observations acted as $v_{SV} > v_{SH}$. The splitting time ranged from -1.67 s to 0.35 s, and the mean value was -0.62 s. The most strength of anisotropy was -0.92% , while the mean value was -0.33% . Their distributions had similar trends.

Our observation indicated that the HTI is the dominant structure beneath Siberia. And there are two possible mechanisms of HTI. One is the lattice-preferred orientation (LPO) of anisotropic materials. The other is the shape-preferred orientation (SPO) of material caused by strong upwelling from CMB.

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