Offshore double-planed shallow seismic zone in the NE Japan forearc region revealed by sP depth phase

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We detected the sP depth phase at small epicentral distances of ~150 km or more in seismograms of shallow earthquakes in the NE Japan forearc region. Earthquakes occurring in the period from 2000 to 2006 with distinct sP phase recorded at three or more stations were selected, and their focal depths were estimated from sP-P time. By calculating the average of focal depths estimated from sP-P times at individual stations, we determined the focal depth of each earthquake. Scatter in focal depths at individual station is ~5 km. Then, origin times and epicenters of those earthquakes are re-determined by assuming focal depths estimated from sP phase. About 90% of earthquakes have been relocated within 15 km distance from their original epicenters. The distribution of relocated hypocenters clearly shows the configuration of a double-planed shallow seismic zone (DSSZ) beneath the Pacific Ocean. The upper plane has a low dip angle near the Japan trench, increasing gradually to ~30 degree at approximately 100 km landward of the Japan trench. The lower plane is approximately parallel to the upper plane, and appears to be the near-trench counterpart of the lower plane of the double-planed deep seismic zone (DDSZ) beneath the land area. The distance between the upper and lower planes is 28-32 km, which is approximately the same as or slightly smaller than that of the DDSZ.

We found that seismograms show remarkable differences between earthquakes in the upper plane of the DSSZ and those in the lower plane. Seismograms for upper plane events display (1) indistinct P- and S- waves, (2) many later phases following P- and S-waves, and (3) a predominance of comparatively low frequency. In contrast, seismograms of lower plane events clearly show (1) distinct P- and S- waves, (2) virtually no later phases, and (3) a predominance of comparatively high frequency components. Out of the three notable contrasting waveform features, the presence of significant later phases is evaluated quantitatively in this study. We compare the maximum amplitudes of direct P- and S-waves with the average amplitude of coda waves. Waveforms of earthquakes that have no distinct sP phase can be roughly categorized into two groups on the basis of the amplitude ratio of direct waves to later phases, and there is no case in which a waveform cannot be categorized on this basis. This suggests that approximately 65% of all earthquakes, those with no distinct sP phase, can be categorized into two groups; those with a focal depth at a depth of ~10 km, and those occurring at a depth of ~40 km. This also seems to confirm the existence of a DSSZ.

Focal mechanisms of the relocated earthquakes are determined from P-wave initial motion data. We found that upper-plane events are characterized by normal faulting, whereas lower-plane events are characterized by thrust faulting. This focal mechanism distribution is the opposite to that of the DDSZ. The characteristics of these focal mechanisms for the DSSZ and DDSZ can be explained by a bending-unbending model of the subducting Pacific plate.

Some of relocated earthquakes took place in the source area of the 1933 Mw8.4 Sanriku earthquake at depths of 10 to 40 km. Available focal mechanisms for these events are characterized by normal faulting. Given that the 1933 event was a large normal fault event that occurred along a fault plane dipping landward, the earthquakes that occur just beneath or oceanward of the Japan trench are probably its aftershocks, which indicates that aftershock activity continues to the present day, 70 years after the main shock. Epicenter distribution from the unified hypocenter catalogue shows that there exist two distinct hypocenter alignments ~150 km long in the NS direction parallel to the trench axis in the source area of the 1933 earthquake, suggesting the alignments are formed by its aftershock activity.