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Megathrust-zone heterogeneity and megathrust earthquakes

Dapeng Zhao[1*]

[1]Tohoku University

We investigated the detailed 3-D seismic structure of the crust and upper mantle under the NE Japan and SW Japan arcs and its implications for the generation of large megathrust earthquakes. We used P and S wave arrival times from earthquakes under the forearc region under the Pacific Ocean and back-arc region under the Japan Sea which are relocated precisely using sP depth phases. P and S wave arrival-time data from many relocated aftershocks of the 2011 Tohoku-oki earthquake (Mw 9.0) are added to determine the updated 3-D Vp and Vs models of the Tohoku forearc region.

Significant structural heterogeneities are revealed in the interplate megathrust zone under the Tohoku forearc. Three low-velocity (low-V) anomalies exist off Sanriku, off Fukushima and off Ibaraki. There is a correlation between the velocity variation and the distribution of large thrust-type earthquakes ($M > 6.0$) that occurred from 1900 to 2011, including the foreshock, mainshock and aftershocks of the 2011 Tohoku-oki earthquake. The low-V patches in the megathrust zone may contain subducted sediments and fluids associated with slab dehydration, thus the subducting Pacific plate and the overriding continental plate may become weakly coupled or even decoupled in the low-V areas. In contrast, the high-velocity (high-V) patches in the megathrust zone may result from subducted oceanic ridges, seamounts and other topographic highs on the Pacific seafloor that become asperities where the subducting Pacific plate and the overriding continental plate are strongly coupled. Thus tectonic stress tends to accumulate in these high-V areas for a relatively long time during subduction, leading to the nucleation of large and great earthquakes in those areas. The off-Miyagi high-V zone, where the Tohoku-oki mainshock and its largest foreshock occurred, corresponds to the area with large coseismic slip (> 25 m) during the Tohoku-oki mainshock. This indicates that the off-Miyagi high-V zone is a large asperity in the megathrust zone that ruptured during the Tohoku-oki mainshock. These results indicate that the rupture nucleations of the large events in the 2011 Tohoku-oki earthquake sequence, including the mainshock and major foreshocks and aftershocks, were controlled by the structural heterogeneities in the interplate megathrust zone and the over-riding continental plate.

Detailed 3-D Vp and Vs models of the entire Southwest Japan arc from the Nankai trough to the Japan Sea are determined for the first time using a large number of high-quality arrival-time data from local earthquakes. Our results show that strong lateral heterogeneities exist in the interplate megathrust zone under the Nankai forearc. Large interplate earthquakes mainly occurred in or around high-V patches in the megathrust zone. These high-V patches may represent asperities formed by the subducted oceanic ridges and seamounts. Low-V zones in the megathrust zone may contain sediments and fluids associated with slab dehydration and so become weakly coupled areas. Our results also show that the coseismic slip distributions of some megathrust earthquakes are not limited in the high-V patches (asperities) where the ruptures initiated. Because of the weak interplate coupling in the low-V areas, the rupture of an interplate earthquake could unimpededly pass through the low-V anomalies and so result in a great megathrust earthquake.

References

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