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Tomography of the Northeast Japan arc and mechanism of the 2011 Tohoku-oki earthquake sequence

ZHAO, Dapeng[1*]

[1]Department of Geophysics, Tohoku University

We have investigated the detailed 3-D seismic structure of the crust and upper mantle under the NE Japan arc and its implications for the mechanism of the 2011 Tohoku-oki earthquake (Mw 9.0) sequence. Significant structural heterogeneities are revealed in the interplate megathrust zone under the NE Japan 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 major 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 (or a cluster of asperities) in the megathrust zone that ruptured during the Tohoku-oki mainshock.

High-resolution tomographic images of the crust and upper mantle in and around the area of the 2011 Iwaki earthquake (M 7.0) and the Fukushima nuclear power plant are determined by inverting a large number of high-quality arrival times with both the finite-frequency and ray tomography methods. The Iwaki earthquake and its aftershocks mainly occurred in a boundary zone with strong variations in seismic velocity and Poisson's ratio. Prominent low-velocity and high Poisson's ratio anomalies are revealed under the Iwaki source area and the Futaba fault zone, which may reflect fluids released from the dehydration of the subducting Pacific slab under NE Japan. The 2011 Tohoku-oki earthquake (Mw 9.0) caused static stress transfer in the overriding Okhotsk plate, resulting in the seismicity in the Iwaki source area that significantly increased immediately following the Tohoku-oki mainshock. This result suggests that the Iwaki earthquake was triggered by the ascending fluids from the Pacific slab dehydration and the stress variation induced by the Tohoku-oki mainshock. The similar structures under the Iwaki source area and the Futaba fault zone that is close to the Fukushima nuclear power plant suggest that the security of the nuclear power plant site should be strengthened to withstand potential large earthquakes in the future.

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.

Keywords: Great earthquakes, slab, fluids, active faults, seismic tomography