Analysis of foreshock sequence of the 2014 M_w6.2 Northern Nagano earthquake: Implications for slow-slip transient and unusual source property

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The M_w 6.2 Northern Nagano earthquake occurred on November 22, 2014, central Japan, which broke a northern part of the Itoigawa-Shizuoka Tectonic Line active fault system. The earthquake has a foreshock sequence from four days before the mainshock, which was captured by a dense permanent seismic observation. We first determined hypocenters of foreshocks, mainshock, and aftershocks by assuming two different one-dimensional velocity models to account for heterogeneous structure in the area. We then applied the double-difference (DD) method to improve the precision of event relative locations. The DD location reveals that the foreshocks were located at a depth of 3-4 km and distributed on a NNW dipping 1 km x 1 km plane with an angle of about 60 degree (plane A), which is distinct from the aftershock distribution. The geometry of the plane A is consistent with the foreshock focal mechanisms determined by P-wave polarities as well as body-wave amplitudes. We also found that the foreshock sequence is located at the eastern extension of two Neogene faults described in the geological sheet map at 1:50,000 (Geological Survey of Japan, 2002), where the strike of one of the faults agrees well with that of the plane A. These Neogene faults cut active folds as well as Otari-Nakayama fault, making the region become a local structural heterogeneity. We infer that the foreshock sequence appears associated with fault zone complexity, as suggested for other foreshock sequences (e.g., Chen and Shearer, 2013).

In order to investigate the foreshock sequence in more detail, we analyzed seismograms recorded at Hakuba Hi-net station, which is a 632-m deep borehole station located about 5 km west of the foreshock region. By a visual identification of running spectra at the Hakuba station and S-P time, we newly detected 384 foreshocks, which are nearly seven times more than those in the JMA catalogue. We determined their locations and magnitudes on the basis of waveform cross-correlations and amplitude ratios, respectively, between newly detected foreshocks and DD relocated events. Our new catalogue delineated another plane with a N-S striking vertical plane (plane B), which is consistent with one of nodal planes of the P-wave first-motion mechanism of the mainshock. The spatial and temporal distribution of our new catalogue indicates that the foreshock sequence started at the deeper part of the plane A, migrating to the shallower part, and then jumped to the plane B, migrating to the mainshock hypocenter. The migrating speed is less than a few km/day, implying a possible slow-slip transient. A hypothesis is that the foreshock sequence is driven by aseismic slip, which causes stress loading at the mainshock hypocenter and triggers the mainshock.

We further determined source parameters of the foreshocks to investigate their fault properties. We applied Multi-Window-Spectral-Ratio method (Imanishi and Ellsworth, 2006) to the foreshocks and aftershocks using the deep borehole data. The estimated corner frequencies of aftershocks decrease with magnitude and indicate constant stress drop. In contrast, the estimated corner frequencies of foreshocks are almost constant over nearly two orders of magnitude. The constant corner frequency suggests that fault dimension is the same regardless of magnitude or stress drop increases with magnitude under an assumption of scale-invariant rupture velocity. It is noted that the same observation was reported for the foreshock sequence of the 1999 M_w7.6 Izmit earthquake, Turkey (Bouchon et al., 2011), which may indicate that the constant corner frequency or the size-dependent stress drop is a common specific property of foreshocks.

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