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Precursory Seismic Activity Surrounding the High-Slip Patches of the 2011 Mw9.0 Tohoku-Oki Earthquake

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The 2011 Tohoku-Oki earthquake (Mw9.0) was preceded by foreshock activity that occurred north of the main-shock epicenter two days earlier. The epicentral area of the foreshock activity is almost the same as that of the prominent seismic activity in 1981 [Ando and Imanishi, 2011; Shao et al., 2011a]. The question arises, why did the 1981 event not trigger an event like the 2011 Tohoku-Oki earthquake? The time difference of 30 years is negligible in comparison with the long time required for the slip deficit of more than 40 m. In order to address this problem, we investigated the long-term seismicity pattern with reference to the slip distribution of the Tohoku-Oki earthquake. We used the earthquake catalogue compiled by the Japan Meteorological Agency (JMA) for the past 90 years since 1923. We assume that the variation of frictional strength on the megathrust, as suggested by the slip distribution of the Tohoku-Oki earthquake, would manifest itself in the spatio-temporal distribution of seismic activity.

The slip distribution of the Tohoku-Oki earthquake we obtained from the coseismic displacements of the GEONET and sea-bottom stations is characterized by a low-slip zone sandwiched between the two patches of high slip (20m) along the Japan Trench. The epicenters of the foreshock activity are distributed over the boundary between the low-slip zone and the two high-slip patches (LHSB seismic zone), where other prominent activity had been accommodated during the past 90 years. The main-shock initiated near the junction of the northern edge of the southern high-slip patch and the mid-asperity seismic zone that divides the southern high-slip patch into two parts. The main-shock was able to rupture the western half of the southern high-slip patch, which is located down-dip of the main-shock epicenter, because the stress increased by the foreshock activity surpassed its strength. However, we infer that it is not only because the foreshock activity was the largest to have ever occurred in the LHSB seismic zone, but also because the western half of the southern high-slip patch had been sufficiently weakened by surrounding events since 2003. A substantial reduction of its strength might have been caused by the 2003 M6.8 event in the mid-asperity seismic zone and the 2005 events in the area of characteristic events such as the 1936 and 1978 Off-Miyagi earthquakes. The afterslip of the 2008 and 2010 events off the coast of Fukushima prefecture might also have contributed to weakening the western half of the southern high-slip patch. The last significant stress change was caused by the foreshocks that occurred along the northern edge of the southern high-slip patch one day before the main-shock.

The following rupture of the eastern half of the southern high-slip patch, which is located up-dip of the main-shock epicenter and includes an area of slip greater than 60 m, was probably made possible because that portion had also been sufficiently weakened by the surrounding events since 2003. The contribution of the 2003 activity extending along the southern edge of the center of the southern high-slip patch may be important because no prominent activity had occurred there before. A couple of moderate-sized events on the eastern edge of the southern high-slip patch might also have made important contributions. We infer that the foreshocks occurring along the northern edge of the southern high-slip patch also played an important role for weakening of the center of the southern high-slip patch. Lastly, the main-shock was able to expand to its large size by rupturing the center of the southern high-slip patch. The magnitude of the slip caused the subsequent ruptures of adjacent areas including the northern high-slip patch. The doughnut-shaped seismicity pattern that formed around the center of the southern high-slip patch is considered to be due to the presence of an extremely strong area on the megathrust.

Keywords: Off the Pacific coast of Tohoku Earthquake, Tohoku-Oki earthquake, Pacific plate, subduction zone, precursory seismic activity, foreshock activity