Details of hypocenter migration in the Yamagata-Fukushima swarm probably caused by fluid pressure change after the 2011 Tohoku-Oki earthquake

*Keisuke Yoshida[1], Akira Hasegawa[1]

1. Tohoku University

It is known that earthquakes can be triggered by fluid injection [e.g., Shapiro, 2008]. They are caused by reduction of frictional strength due to increase in pore pressure associated with the fluid injection. Even in the case of the natural tectonic earthquakes, crustal fluids probably play an important role. Several studies suggested that a remarkable earthquake swarm that occurred near the border between Yamagata and Fukushima Prefectures is one example of such fluid-driven seismicity [Yoshida et al., 2012; Terakawa et al., 2013; Okada et al., 2015; Yoshida et al., 2016].
Seven days after the 2011 M9.0 Tohoku-Oki earthquake, a great number of earthquakes started to occur in this earthquake swarm despite the reduction of the coulomb stress. Hypocenters in this swarm activity exhibit a distinct migration behavior. Stress drops, b-values [Yoshida et al., 2016, SSJ], and frictional strengths [Yoshida et al., 2016, JGR] remarkably change with time, which might be explained by temporal change in pore pressure. In this study, we investigated in detail spatio-temporal distribution of hypocenters in order to obtain a comprehensive view of the mechanism causing this earthquake swarm.
Firstly, we attempted to detect earthquakes that might occur before the first event of the activity in the JMA unified catalogue. We applied STA/LTA method [Ross & Ben-Zion, 2014] to continuous waveform data at a nearby Hi-net station, and detected 20 events for which we could pick P- and S-wave arrival times at least at four stations.
Secondly, we computed cross correlations of P- and S-waves of event pairs with their epicenter separations less than 1 km, and obtained normalized cross correlation coefficients and differential times. By adding differential time data thus obtained to manually picked arrival time data, we relocated hypocenters of 28,010 events by the Double-Difference method [Waldhauser & Ellswoth 2002]. The residuals of differential time reduced from ~160 ms to ~20 ms after 30 times iteration.
Hypocenter distribution drastically changed after the relocation. Although original hypocenters show a cloud-like scatter, relocated hypocenters distribute on several sharp planes. Similar earthquakes classified by their waveforms concentrate on common fault planes, and one of nodal planes of focal mechanisms coincides with them. Hypocenters migrate along these fault planes, most of which from deep to shallow. The hypocenter migration can be roughly explained by fluid diffusion [e.g., Shapiro, 2008]. However, the migration velocity increased drastically when M>2~3 earthquakes occurred.
Hypocenters of newly detected events in the initial part of the activity were located along the northwestern rim of the Ohtoge caldera, where almost no earthquakes are listed in the original JMA catalogue. Then, hypocenters moved both to the west and east of the caldera rim. After that, a great number of earthquakes started to occur in a subhorizontal layer in the eastern cluster for ~50 days. This period corresponds to the period when the seismicity rate and b-values were exceptionally high. Pore pressure might have approached lithostatic level in this period. In fact, estimated values of stress drop and frictional strength in this period were very small. Looking at hypocenter distribution on each plane in detail, not a few earthquakes seem to occur repeatedly at the same locations, which might suggest the occurrence of aseismic slip along the plane.

Keywords: frictional strength, pore pressure, hypocenter migration, swarm, 2011 Tohoku-Oki earthquake