

Swarm activity beneath Sendai-Okura Dam, NE Japan, induced by the 2011 Tohoku-Oki earthquake - Precise hypocenter distribution and fine fault structure

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An earthquake occurs when shear stress acting on a weak plane reaches its frictional strength. Therefore, we can roughly divide the cause of earthquake occurrence into two: increase in shear stress and reduction in frictional strength.

There occurred several earthquake swarms in NE Japan induced by the 2011 Tohoku-Oki earthquake, regardless of the reduction in ΔCFF . Since they commonly show the migration behavior of hypocenters as well as the delay of their initiation of a few days to a few weeks after the Tohoku-Oki earthquake, several studies suggested that these swarms were caused by the reduction in frictional strength due to the increase in pore pressure by fluids rising from below [Yoshida et al., 2012; Terakawa et al., 2013; Okada et al., 2015; Yoshida et al., 2016].

In order to know detailed behavior of crustal fluids, we investigated spatio-temporal distribution of hypocenters in an earthquake swarm beneath Sendai-Okura Dam that was induced by the Tohoku-Oki earthquake. Approximately 10 km southeast of this swarm, an M5.0 earthquake took place in 1998. Subsequent studies showed that there exist a remarkable S-wave reflector in the middle crust [Umino et al., 2002] and a prominent low-velocity zone in the lower crust right beneath the source area [Nakajima et al., 2006].

Spatial distribution of earthquake hypocenters listed in JMA catalogue shows a slightly east-dipping cloud-like distribution with ~ 4 km width, probably due to the errors in hypocenter locations, which makes it difficult to understand the detail of hypocenter migration. We relocated hypocenters by using the cross-correlation of waveforms to obtain a clearer image of hypocenter migration.

First, we classified earthquakes based on waveform similarity. When there is an event pair with correlation coefficient >0.92 at least at three stations within 20 km from the swarm region, we regarded them as similar earthquakes. We then searched for other similar events. Repeating the same procedure, we produced groups of similar events. As a result, we obtained 7 similar earthquake groups involving >30 events.

Second, we computed cross correlations of P- and S-waves of the event pairs with their epicenter separations less than 2 km, and obtained normalized cross correlation coefficients and differential times. By using differential times with normalized cross correlation coefficient higher than 0.9, scatter of S-P times reduced from 0.2s to less than 0.05s. By adding the differential time data thus obtained to the manually picked arrival time data, we relocated hypocenters by the Double-Difference method [Waldhauser & Ellsworth 2002]. The residuals of differential time reduced from ~ 120 ms to ~ 10 ms after 30 times iteration.

Hypocenter distribution drastically changed from the original east-dipping cloud-like scatter to the distribution on several sharp planes. Similar earthquakes in one group concentrate on a common fault plane. Most of the hypocenter alignments are dipping to the west. However, there exist some subhorizontal alignments. Their focal mechanisms are consistent with this alignments, which are unfavorably-oriented from the regional stress field. This suggests that the strength of fault planes decreased as suggested from the hypocenter migration. The relocated distribution of hypocenters shows that the hypocenters migrated along the fault planes mainly from deeper to shallower parts.

Keywords: crustal fluid, frictional strength, 2011 Tohoku-Oki earthquake, swarm

