Stress heterogeneity in northeastern Japan and its relationship with induced seismic activities by the 2011 Tohoku-Oki earthquake

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After the 2011 M9 Tohoku-Oki earthquake, a great number of earthquakes are induced even in the inland regions separated by more than several hundred kilometers from the large slip area. Because of the very large size of this earthquake, it is expected that we can investigate detailed characteristics of the induced seismicity, which will help improve our understanding of its generation mechanism. In this study, we investigated the seismicity, focal mechanisms and stress fields in northeastern Japan to understand the causes of the induced seismicity.
On the spatial distribution of the induced seismic activities, they tend to concentrate in several locations as clusters rather than distribute widely. Many of these clusters in northeastern Japan are located in regions where seismicity was inactive before the 2011 earthquake. Stress tensor inversion results before and after the earthquake are significantly different from each other. In addition, the stress orientations after the earthquake are quite similar to those of the static stress change [Yoshida et al., 2012]. This suggests the following two possibilities. a) Stress orientations rotated after the 2011 Tohoku EQ by its static stress change. b) Static stress triggered earthquakes in regions where stress orientations are different from the typical stress orientation in the surrounding areas but is consistent with the static stress change.
To distinguish these two possibilities, we reinvestigated the stress orientations before the Tohoku-Oki earthquake by using data of Tohoku University for the period of 1980-2002 and those by Yoshida et al. (2015a). In the arc and the backarc in northeastern Japan, it has been known that the compressive stress orientations are oriented WNW-ESE homogeneously in space. However, several regions were detected, where stress orientations are different from the regional orientation. Some of the regions have favorable stress orientations for the induced earthquake focal mechanisms there. This supports the possibility (b).
The regions having such anomalous stress orientations seem to be located near the focal regions of the past large earthquakes such as the 1896 Rikuu earthquake, the 1904 Shonai earthquake and the 1913 Akita-Senboku earthquake. Recently, spatially heterogeneous stress orientations were detected in the focal regions of the 2008 Iwate-Miyagi Nairiku earthquake and the 2011 Fukushima-Hamadori earthquake, which were probably caused by the mainshocks. This suggests that the spatially heterogeneous stress states have been formed by the past M~7 earthquakes. This is what is expected if the deviatoric stress magnitude is very small (differential stress < 20 MPa) in northeastern Japan as suggested from the correlation between observed stress regime and surface topography [Yoshida et al., 2015b]. Or, it might be partly caused by the effects of the heteronomous temperatures structure or the sliver motion in the Hokkaido corner.
In contrast, there exist some regions where the static stress change cannot explain increase in seismic activity. The earthquake cluster in the Yamagata-Fukushima border is positioned where the coulomb stress decreased [Terakawa et al., 2013]. It is considered that the reduction of frictional strength by upwelling fluids caused the induced seismicity in this region based on the following three reasons: 1) seismic activation delayed for eight days after the 2011 earthquake, 2) it is located just beneath the Ohtoge caldera, and 3) the seismicity migrates in space. Yoshida & Hasegawa [2015, SSJ] investigated the temporal evolution of the frictional strengths by using the diversity of focal mechanisms. As a result, the temporal increase in frictional strength was found. We can understand this induced seismic activity if this was caused by the pore pressure increased

after the Tohoku-Oki earthquake and diffused with earthquake generations.

Keywords: the 2011 Tohoku-Oki earthquake, induced seismicity, stress, frictional strength

