Deep low-frequency earthquakes beneath Hakone volcano, central Japan, and their relation to the volcanic activity

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It has been recognized that the occurrence of deep low-frequency earthquakes (DLFs) beneath a volcano is controlled by a behavior of magmatic fluid. Nakamich et al. (2003) estimated moment tensor solutions of DLFs occurred beneath Iwate volcano by using spectral ratios of body waves, and found that they contained a volumetric change component as well as a double-couple component. On the other hand, the relation between DLF activity and other observations such as volcano-tectonic (VT) earthquakes, crustal deformations and surface phenomena has not been well understood. Harada et al. (2010) argued that the occurrence of DLFs beneath Hakone volcano was not correlated with the crustal deformation, on the basis of the earthquake catalog compiled by Japan Meteorological Agency (JMA). However, since the DLF signals represent usually ambiguous onset and are contaminated by noises, it is likely that many DLFs were missed by using the conventional detection method. In the present study, we detected DLFs occurred beneath Hakone volcano by using the matched-filter method (e.g. Peng and Zhao, 2009) and discussed its relation to the volcanic activity.

We used continuous seismic waveforms in the period from August, 2001 to January, 2017, recorded at 11 permanent stations around the epicentral area of DLFs beneath Hakone volcano. The template waveforms of 94 DLFs were prepared on the basis of the JMA catalog. We applied a band-pass filer between 1-5 Hz to both continuous and template waveforms, and decimated them to the sampling frequency of 20 Hz. The cross-correlation analysis was conducted between the template and the continuous waveform records, and the correlation coefficient for each template event was stacked at the time subtracting its theoretical arrival time from the onset time. We assumed that DLFs occurred at the time when we detected 9 times larger correlation coefficient than its median absolute deviation, and showed them in a new catalog. We also estimated the temporal sequence of b-value by using our DLF catalog.

As a result, we could detect approximately 15,000 events of DLFs that correspond to 37 times larger than the number of events in the JMA catalog. We identified remarkable increase of DLF activity in 2006, 2013 and 2015. At the same time, the expansion of volcanic edifice was detected by GNSS stations around the volcano and the remarkable VT swarm activity occurred at shallower depth. The onset of each increase of DLF activity seems to precede the beginning of the crustal expansion and the VT swarm activity. We found that b-value of DLFs increased when the DLF activity increased. High b-values were often estimated during a water-induced seismicity (e.g. Maxwell et al., 2009) and a earthquake swarm activity (e.g. Yoshida et al. 2017), suggesting the increase of pore fluid pressure at the source areas. Above the source region of DLFs, the pressure source for the expansion of volcanic edifice is estimated around a depth of 10 km. The low velocity region was also detected at this area by a seismic tomography method (Yukutake et al. 2015), suggesting the existence of magma reservoir. Given these results, it is reasonable to consider that the DLFs with high b-value were triggered by the increment of fluid pressure around a depth of 20 km, following the inflation of pressure source at a depth of 10 km and the VT swarm activity at shallower depth. On the other hand, we also identified the increases of DLFs and b-value without accompanying of crustal expansion and increase of VT events, during 2001-2004, 2005, 2010 and 2011. The increase of fluid pressures during these periods might not propagate to the shallow magma reservoir due to some factors.

Acknowledgment
We used the waveform record obtained by the permanent stations of National Research Institute for Earth Science and Disaster Resilience and GNSS data of Geospatial Information Authority of Japan. We used zmap program code (Wiemer, 2001) to estimate b-value.

Keywords: Deep low-frequency earthquake, Volcanic activity, Hakone volcano

