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Fluid-induced swarm activity as revealed by precisely determined hypocenters and focal mechanisms of earthquakes

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A swarm earthquake sequence is often assumed to be triggered by fluid flow within a brittle fault damage zone, which is supposed to be highly permeable. However, there is little seismological evidence of the relationship between the fluid flow within fault damage zone and the occurrence of swarm earthquakes. Here, we proposed that the 2009 swarm activity at Hakone volcano provide a good example of such fluid-induced activity.

We relocated 1,156 events that occurred in Hakone caldera during the period from August 4 through August 13, 2009 with the double-difference (DD) method (Waldhauser and Ellsworth, 2000). For the relocation of the hypocenters, we used the differential arrival time obtained by both manual picking and wave form cross-correlation analysis. We determined focal mechanisms from the absolute P- and SH-wave amplitudes by adding the P-wave polarities.

We demonstrate that the swarm earthquakes are concentrated on four thin plane-like zones whose thickness is approximately 100 m. One of the nodal planes of the focal mechanisms agrees with the planar hypocenter distribution. The thickness of the plane-like zones is considered to be statically significant, considering the location error of the hypocenters. The value of thickness is consistent with that of fault damage zone for a fault with 1 km length [e.g., Vemilye and Scholz, 1998].

The swarm earthquakes in the initial stage of the activity exhibited a feature of hypocenter migration that can be represented by a diffusion equation. Based on the spatio-temporal distribution of the earthquakes, the hydraulic diffusivity (D) is estimated to be approximately 0.5 to 1.0 m2/s. The values of D are comparable to those estimated in other studies based on the reservoir-induced seismicity, the water injection-induced seismicity, and the spatio-temporal distribution of swarm activities. The observations imply that swarm earthquakes were triggered by diffusion of highly pressured fluid within the fault damage zone.

Keywords: swarm earthquake, fluid, fault damage zone, hypocenter distribution, focal mechanism