Precise hypocenters in active hydrothermal systems determined by the double-difference technique: Implications for fluid flows at during an inflation event at Kusatsu-Shirane Volcano in 2014

*Tomoyoshi Kuwahara[1], Akihiko Terada[2], Yohei Yukutake[3], Wataru Kanda[2], Yasuo Ogawa[2]

1.Graduate School of Science and Engneering, Tokyo Insutitute of Technology, 2.Volcanic Fliud Research Center, Tokyo Insutitute of Technology, 3.Hot Springs Research Institute of Kanagawa Prefecture

Earthquake swarms occurred beneath the Shirane pyroclastic cone at Kusatsu-Shirane Volcano in 2014. The seismic activity was followed by an inflation at shallow depth beneath the cone and changes in geomagnetic field and chemical compositions of volcanic gas emitted around the cone. These unusual activities are likely caused by accumulation of hydrothermal fluid at shallow depth beneath the cone. MT surveys revealed that a low permeable layer probably composed of Smectite exist at shallow depth beneath the cone (Ogawa et al., personal communication). Such a subsurface structure may play an important roles in fluid storage and triggering of phereatic eruptions. To understand a relation between subsurface structure and fluid flow, precisely determined hypocenters give valuable clues (Yukutake et al., 2011). Applying the double-difference technique (Waldhauser and Ellsworth, 2000), we precisely relocated hypocenters which occurred in 2013-2014.
To obtain initial locations of hypocenters for applying the Double-Difference technique, reliable seismic velocity structure is necessary. However, it is not well known beneath the cone. Kuwahara et al. (2015) developed a simple 1-D model composed of two layer. Minimized average residuals of P-wave travel times suggest that optimal seismic velocities of upper and lower layer are 2.5 km/s and 4.8 km/s, respectively, which correspond to figures estimated by controlled source seismic experiments (Onizawa et al., 2005; Takeda et al., 2004). A height of bottom of upper layer is estimated to 1,500 m a.s.l. that corresponds to the height of the bottom of low permeable layer, suggesting the upper layer is mainly composed of volcanic rock altered by hydrothermal activities.
On the basis of the velocity model mentioned above, we obtained the initial hypocenters of 251 events. For the analysis, we selected events which the P- and S-wave arrival times obtained at six and at least three stations respectively, including three bore-hole type. The cross-correlation measurement consisted of 86,089 P-wave and 37,413 S-wave.
Relocated hypocenters concentrate on the height of 950-1,000 m a.s.l. beneath the center of Yugama crater lake. In March 2014, at the beginning of earthquake swarms periods, relocated hypocenters are same as events in 2013. One of notable feature is that earthquakes began to occur at shallower depth of 1,100-1,300 m a.s.l. from the end of April 2014. In May 2014, an increase in water temperature of Yugama crater lake were observed. Subsurface inflation monitored by tilt meters suggests a fluid storage rate was highest in May 2014. We believe that hydrothermal fluid supplied from depth began to accumulate under the low permeable layer in March 2014. The fluid began to fracture the low permeable layer, and penetrate into shallower part at the end of April. Finally, the fluid began to eject mildly from the lake bottom from May 2014.
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