3. Activity of Iwate Volcano in 1998-2002

Iwate volcano is the active quaternary stratovolcano located in the northeastern Japan arc and consists of two subgroups (eastern Iwate volcano and western Iwate volcano) with several peaks. These subgroups, peaks and the caldera are aligned nearly east-west direction. This volcano has experienced two major eruptions in the historic times of 1686 and 1732. The former one accompanied lava flow, scoria emission and base surges from the summit crater. The second one did d a basaltic lava flow at the northeastern flank. Since the last eruption in 1732, the volcano has been quiescent conditions except several occurrences of small phreatic explosions at Oujigoku.

The volcano was in seismically calm until deep volcanic tremors with duration of 45 min were observed at depths of 8-10 km beneath the eastern flank in September, 1995. Since then, weak seismic activities and tremors have observed in the period from 1996 to 1997. The shallow and deep seismic activities and associated crustal deformations were started in middle February, 1998 and their activities increased with a lapse of times until September 5, 1998 when moderate tectonic earthquake with *M*6.1 occurred nearby Iwate volcano. After this earthquake, the number of shallow volcanic earthquakes started to gradually decrease with time. In consequence of decreases in number of the volcanic earthquakes, the volcanic unrest at this volcano is supposed to be over.

The long-term space-time plot of seismicity in and around Iwate volcano is shown in Fig. 1 for the period from 1976 to 2002, in which the long quiescence in seismicity around the eastern and western Iwate volcanoes (140.90E-141.02E) and stationary activity at a longitude around 140.88E can be recognized. The latter activity has been resulted by the exploration of deep geothermal energy at Kakkonda geothermal field.

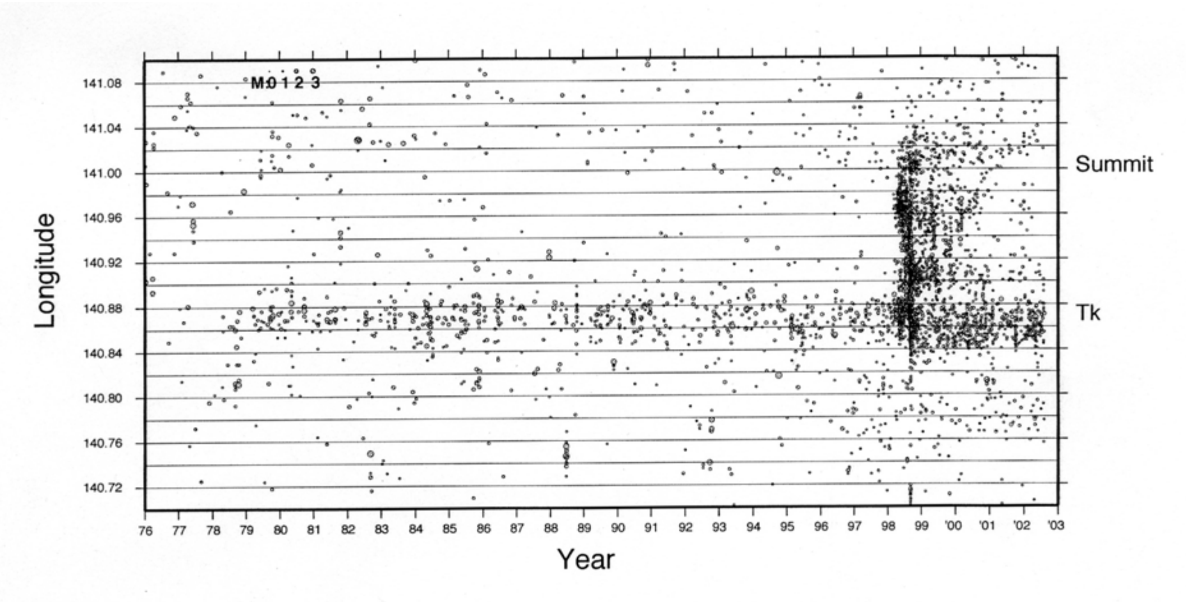

Fig. 1. The space-time diagram of seismicity in and around Iwate volcano in the period from 1976 to 2002. The epicenters are projected on the longitudinal direction between 140.72°E and 141.08°E. The positions for the summit of Iwate volcano and Kakkonda geothermal field (Tk) are indicated at the right margin.

The short-term space-time and magnitude-time plots in the period from 1998 to 20002 are shown in Fig. 2 (a) and (b), respectively. This figures reveal that (1) the number of volcano earthquakes increases with time until April 29, 1998, when large earthquake swarm occurred at nearby the western edge of caldera rim, (2) the seismic activity migrated intermittently westward from the eastern Iwate volcano, and (3) high seismic activity with relatively large events ($M > 3.5$) continued for about four months until the occurrence of the moderate tectonic earthquake of M6.1 on September 3. Hypocenters of high frequency (HF) volcanic earthquakes at depth above 6 km are distributed east-west direction from the eastern Iwate volcano to the western one (see Fig. 3). The spatial distribution of events can be divided into three groups. The eastern group is clustered beneath the summit crater and is characterized by relatively small events. The middle one beneath the caldera shows the highest activity and is distributed in the narrow belts. The western one is scattered onto north-south direction. Hypocenter of low frequency (LF) earthquakes is observed beneath the eastern flank of volcano at deeper depths of 6 - 12 km and at shallow depths of 0 - 4 km under the caldera (see Fig. 3). The deeper LF events have been active condition in the whole period of 1998-2002, whereas the shallow ones were mainly observed at the initial stage of seismic activity in the period from February to September, 1998.

Continuous ground deformations have been monitoring since 1994 by the Sacks-Evertson type strain meter and tilt meter that were deployed at the bottom of 300 m borehole at three stations around the volcano. In addition to the above monitoring, GPS has been operating at five stations in and around the volcano. These data were used to estimate the origin of the crustal deformations beneath the volcano. The detail of analysis and data sets were omitted in this report and only results are shown in Fig. 4 and discussed with reference to the associated seismic activity. Both the rectangular tensile crack source and the dilatational source (Mogi source) are required to interpret the data sets. Two sources are spatially separated by about 3 km. The tensile cracks that were located beneath the summit and caldera indicate that the magma intruded two times vertically and horizontally. The bottom of the HF and LF volcanic earthquake hypocenter limited the upper edge of tensile

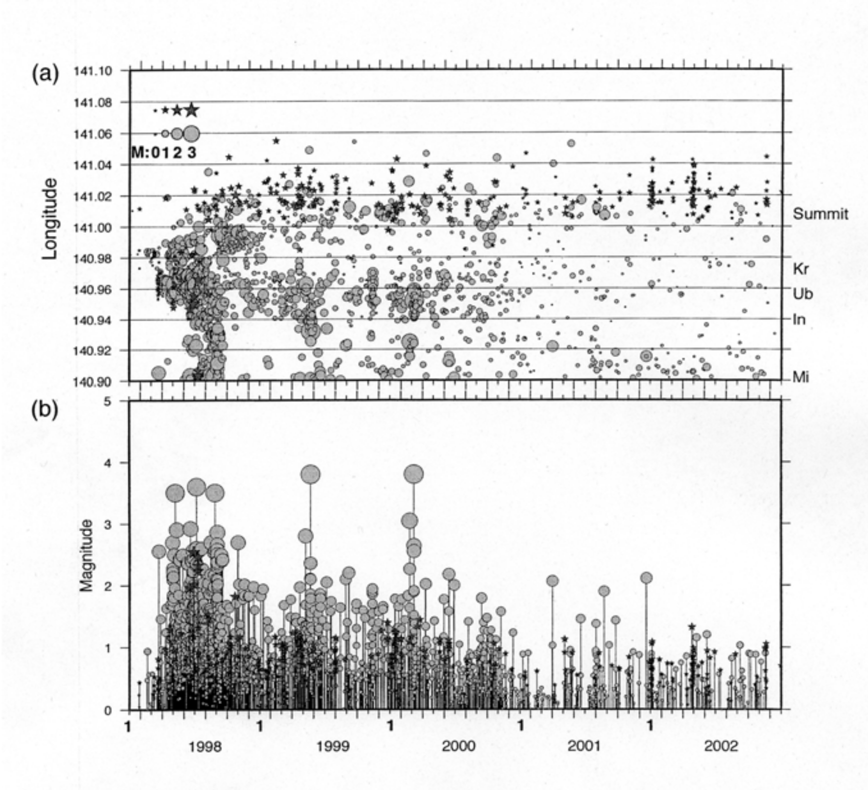

Fig. 2. (a) The space-time diagram of seismicity in Iwate volcano during the active period from 1998 to 2002. The circle and star indicate high- and low-frequency earthquakes, respectively. The codes in the right margin mean; summit, Kr, Ub, In and Mi are the peaks of Iwate volcano, Kurokura, Ubakura, Inukura and Mitsuishi , respectively. (b) The magnitude-time diagram corresponding (a).

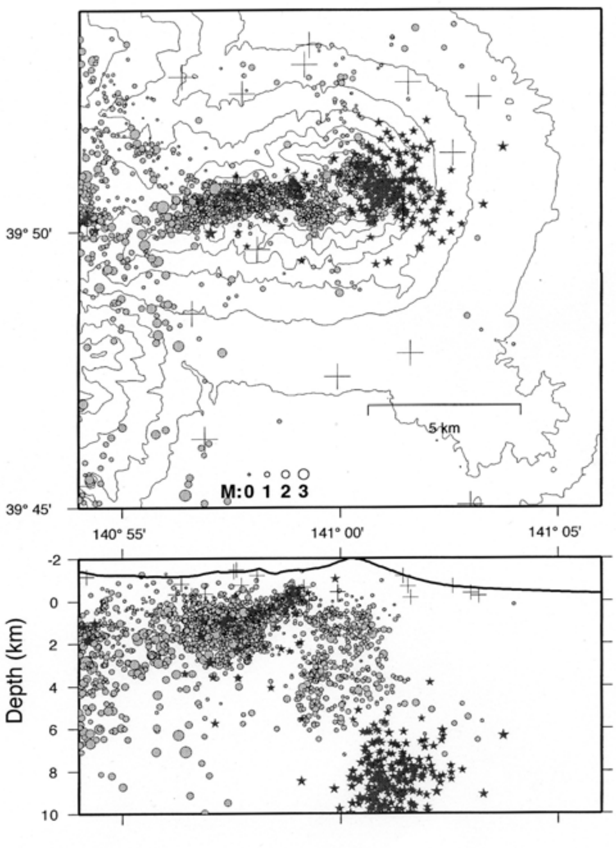

Fig. 3. The hypocenters in Iwate volcano during 1998-2002. Circle and star indicate high- and low-frequency earthquakes, respectively. Crosses are seismic stations.

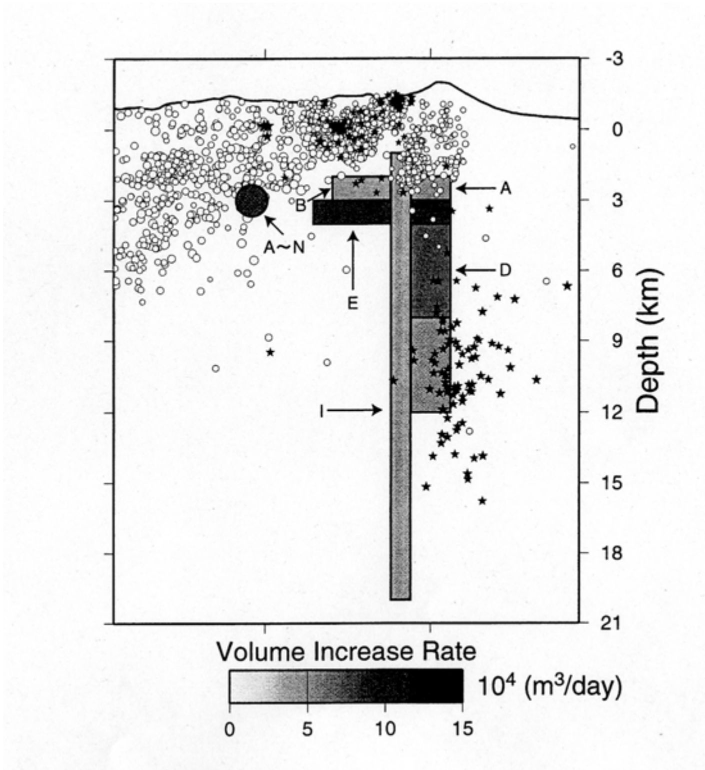

Fig. 4. The estimated origins of crustal deformations beneath the Iwate volcano together with the re-located hypocenters projected on to the E-W cross section. The circle is the dilatational source and the rectangles with marks (A to I) are a tensile crack corresponding different periods. Open circle and solid star indicate high- and low-frequency earthquakes, respectively. The volume increase rate is shown by a gray scale.

cracks. The eastern edge was close to the hypocenter of LF events, suggesting that intrusion processes of magma from a deeper part to a shallow one were closely relating the occurrence of volcanic earthquakes. On the other hand, the location of dilatational source was not changed during a lapse of time. The rate of dilatation increased exponentially at the initial stage of seismic activity and decreased gradually with time. These conditions suggest that the origin of dilatation at the fixed position was not magmatic but hydrothermal activity. This source was closely located at the northern edge of the faults associated with *M*6.1 earthquake on September 3, 1998. Based on the fracture function of the Coulomb failure criteria, it is concluded that the tectonic event of *M*6.1 was induced by the increases of shear stress of 0.7-0.8 MPa due to pressure increases of the dilatational source.

The present volcanic activity was marked by 350 deep low-frequency (DLF) events and 120 intermediate-depth low-frequency (ILF) events. The occurrence rate of the DLF events increased about 5 days before that of shallow events. The hypocenter of DLF events are located within three concentrated regions: the first is at a depth of 32 km about 10 km south of the summit, the second is at a depth of 33 km about 10 km northeast of the summit and the third is at a 37 km about 7 km northeast of the summit. ILF events are located within a vertical pipe-like region just beneath the summit, which sometimes shows a vertical migration of the focal depth. These results suggest that a complex magmas system may exist at a source regions of DLF and ILF events.

When the volcano-seismic activity was declined in 2000, the active seismic survey was conducted in and around the volcano in order to reveal the three-dimensional P velocity structure. Nine artificial explosions and 330 temporary seismic stations were operated in October, 2000 under the national project for the prediction of volcanic eruption. The most prominent feature of this survey is high P velocity column-like structure (V_P> 5.4 km/s) under the caldera, where the highest seismic activity was observed as pointed before.

In conclusion, Iwate volcano has experienced magma intrusion from the middle crust and the Moho region to a shallower part in 1998 and the volcano-seismic unrest was amplified in the period of 1998-2002. However, fortunately, there was no eruption.

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