The 2000 Miyakejima eruption: Crustal deformation and earthquakes observed by the NIED Miyakejima observation network

Motoo Ukawa[1], Eisuke Fujita[1], Eiji Yamamoto[1], Yoshimitsu Okada[1], and Masae Kikuchi[2]

[1]National Research Institute for Earth Science and Disaster Prevention, Tsukuba, Ibaraki 305-0006, Japan
[2]Association for the Development of Earthquake Prediction, Tokyo 101-0064, Japan

(Received September 7 , 2000; Revised September 11, 2000; Accepted September 11, 2000)

The Miyakejima observation network had been constructed by the National Research Institute for Earth Science and Disaster Prevention mainly until early 1999. This observation network has provided the crustal deformation data by tiltmeters and GPS and the seismic data by short-period and broadband seismometers in association with the 2000 Miyakejima eruption. The subsurface magma movement at the first stage of the present activity, during the period from June 26 to 27, was successfully detected mainly by the tilt measurements. The tilt change observed at five stations indicates the migration of magmas from the eastern part of Miyakejima to the western part. The most distinctive phenomenon appearing after the first stage is tilt steps, which started on July 8 with the first eruption from the summit crater. Each tilt step indicates an abrupt uplift of the summit area. These tilt steps continued until the eruption of August 18, which is the largest eruption up to early September, 2000. 45 tilt steps in total were observed in this period. The seismic data show a variety of seismograms including VT (volcano-tectonic) earthquakes, LF (low frequency) earthquakes and volcanic tremor. At the time of the tilt steps, very long period events with predominant periods of about 100 s were detected by the broadband seismometers. As the activity has still continued, this report summarizes the observation during June, July, and August, 2000.

1. Introduction

The volcanic activity of Miyakejima started at 18 h 30 m (JST) on June 26, 2000 with large crustal deformation and earthquake swarms. The Miyakejima volcano observation network constructed by the National Research Institute for Earth Science and Disaster Prevention (NIED) has been in operation. The data obtained from this network clearly show the first stage of magma intrusion underneath the island, providing useful information for the evacuation process of the local residents in Miyakejima. The volcanic activity has developed, since July 8, to eruptive activity from the summit crater. The summit eruption has then continued through September, 2000.

The recent three eruptions of Miyakejima occurred, with about 20 year intervals, in 1940, 1962, and 1983. The eruption style of the 1940 eruption is lateral and summit eruption, and those of the 1962 and 1983 eruption are lateral eruption. Their erupted volumes are in the range from 0.01 to 0.02 km^3 (Tsukui and Suzuki, 1998). The eruption style of the 2000 Miyakejima eruption is far different from these past eruptions. At the time of the first summit eruption of July 8, the volcanic activity entered into the stage of caldera formation process.

The NIED network has detected significant crustal deformation and seismicity changes corresponding to the change of the volcanic activity style. We describe here the outline of the observation by the NIED network, focusing mainly on tilt changes and typical seismograms during June, July, and August, 2000.

2. NIED Miyakejima Observation Network

Construction of the NIED Miyakejima observation network started in 1995 and the major part of the construction was finished by March, 1999. The network is composed of four stations (MKA, MKK, MKT, MKS). At each station, we installed a 2-component tiltmeter and a 3-component short-period seismometer system (ABS-33 type) in a 100 m deep borehole, in addition to a three component broadband seismometer (STS-2) and a GPS receiver (1 frequency type) at the surface. The Kanto-Tokai network for crustal activity research of NIED provides one station (MKE) with the same tiltmeter and short-period seismometer system in a 100 m deep borehole in Miyakejima. Five stations in total are currently available for the observation of volcanic activity on Miyakejima. Figure 1 shows a map of the location of the stations.

All the data except for GPS are continuously telemetered to the NIED headquarter at Tsukuba. The sampling rates for tilt, short-period seismic and broadband seismic observations are 1 Hz, 100 Hz, and 20 Hz, respectively. The dynamic range of the telemeter is 16 bits. The GPS data are stored at each station, and are collected through the telephone line typically once a week.

3. Tilt Changes

Corresponding to the change of the volcanic activity style, the observed tilt changes also show different styles of crustal

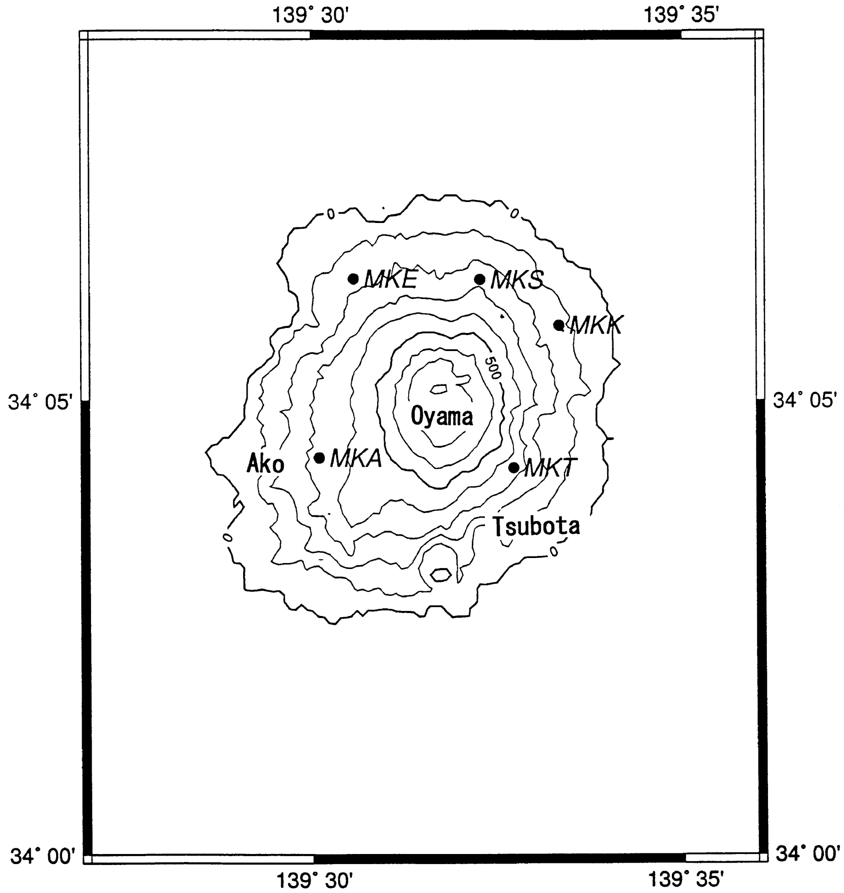


Fig. 1. Locations of the volcanic observation stations of the NIED Miyakejima network.

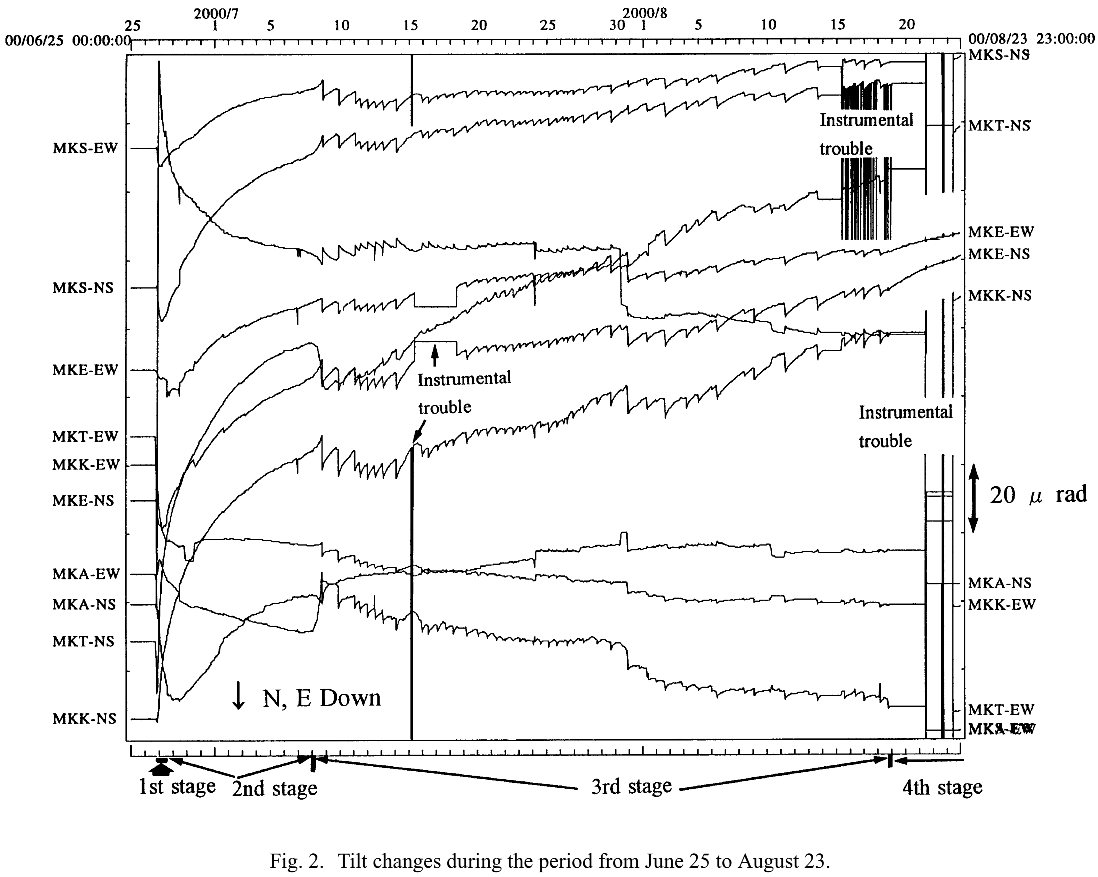


Fig. 2. Tilt changes during the period from June 25 to August 23.

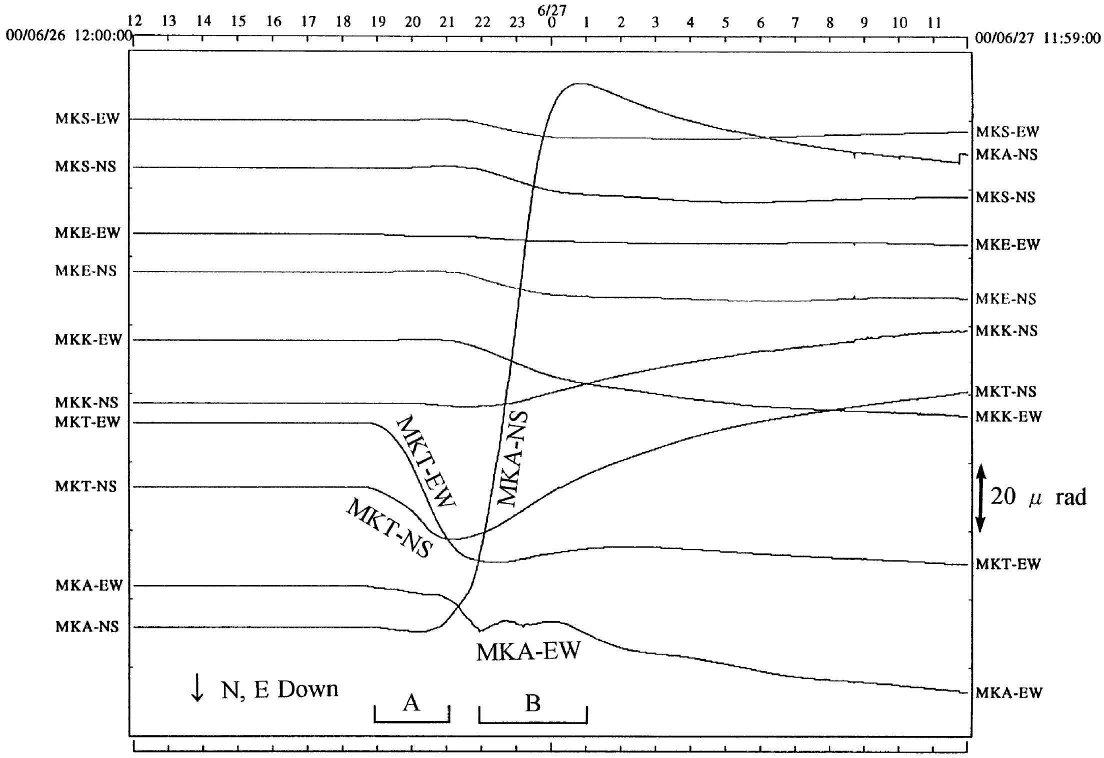


Fig. 3. Tilt changes from 12 h, June 26 to 12 h, June 27.

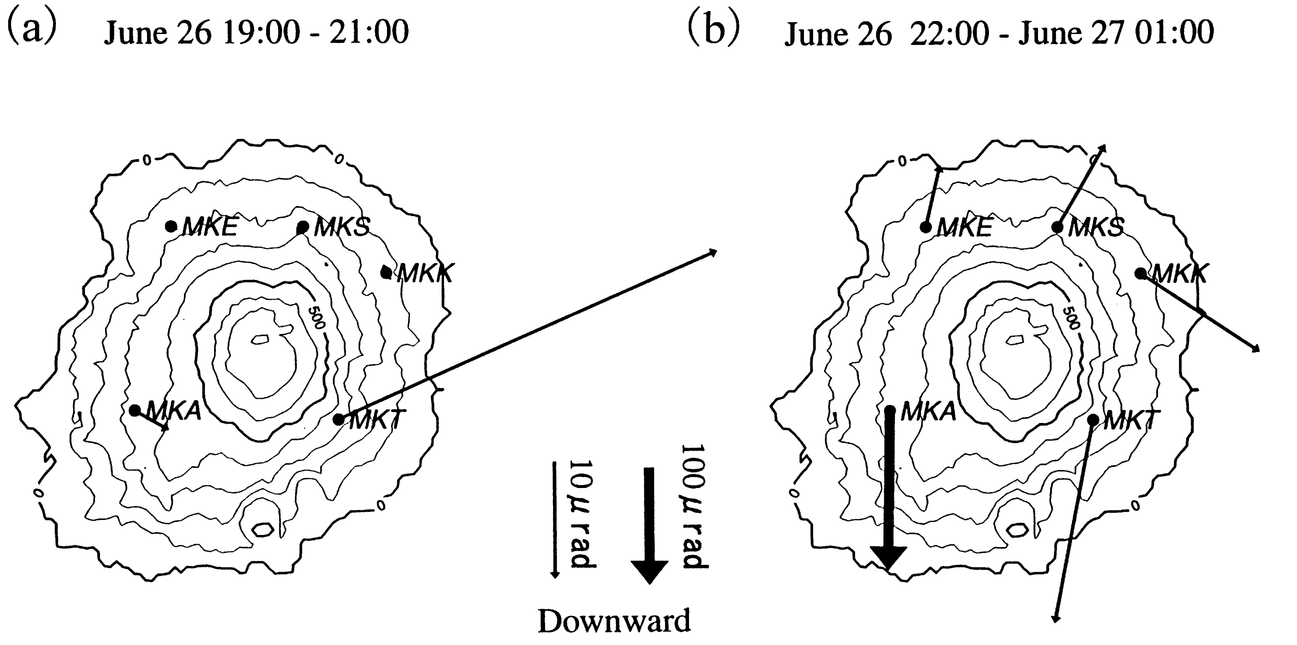


Fig. 4. (a) Tilt vectors for the time interval 19 h to 21 h on June 26 (indicated by A in Fig. 3). (b) Tilt vectors for the time interval 22 h, June 26 to 01 h, June 27 (indicated by B in Fig. 3).

deformation beneath Miyakejima. Figure 2 shows the tilt change observed during the period from June 25 to August 23. We divided this tilt change into 4 major stages; the fist stage covering the period from June 26 to 27, the second stage from June 27 to July 7, the third stage from July 8 to August 18, and the fourth stage from August 18 up to now (September 7). The characteristic tilt changes for each stage are summarized below.

3.1 The first stage (18 h 30 m, June 26 12 h, June 27)

The tilt change related to the first stage started at 18 h 30 m on June 26 and continued until early morning on June 27. Figure 3 shows the tilt changes at the five stations for one

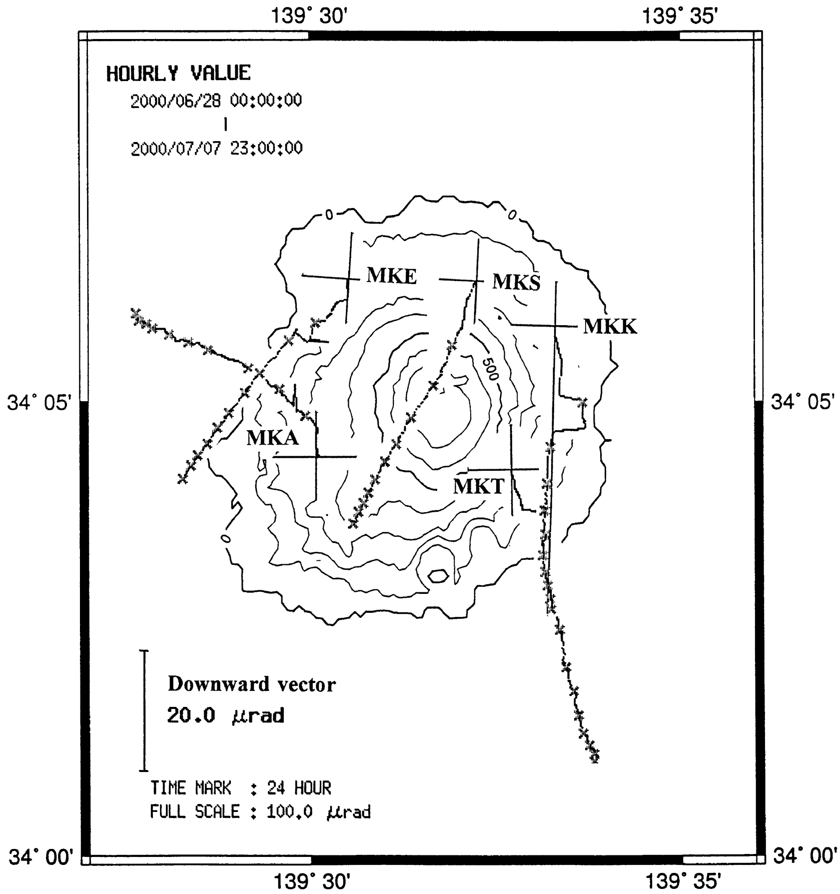


Fig. 5. Tilt vectors plotted for the period from June 28 to July 7.

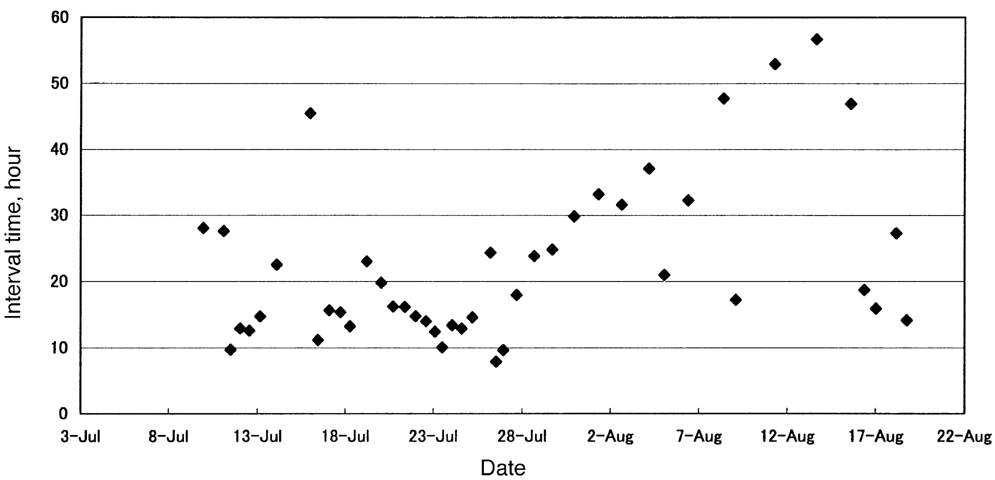
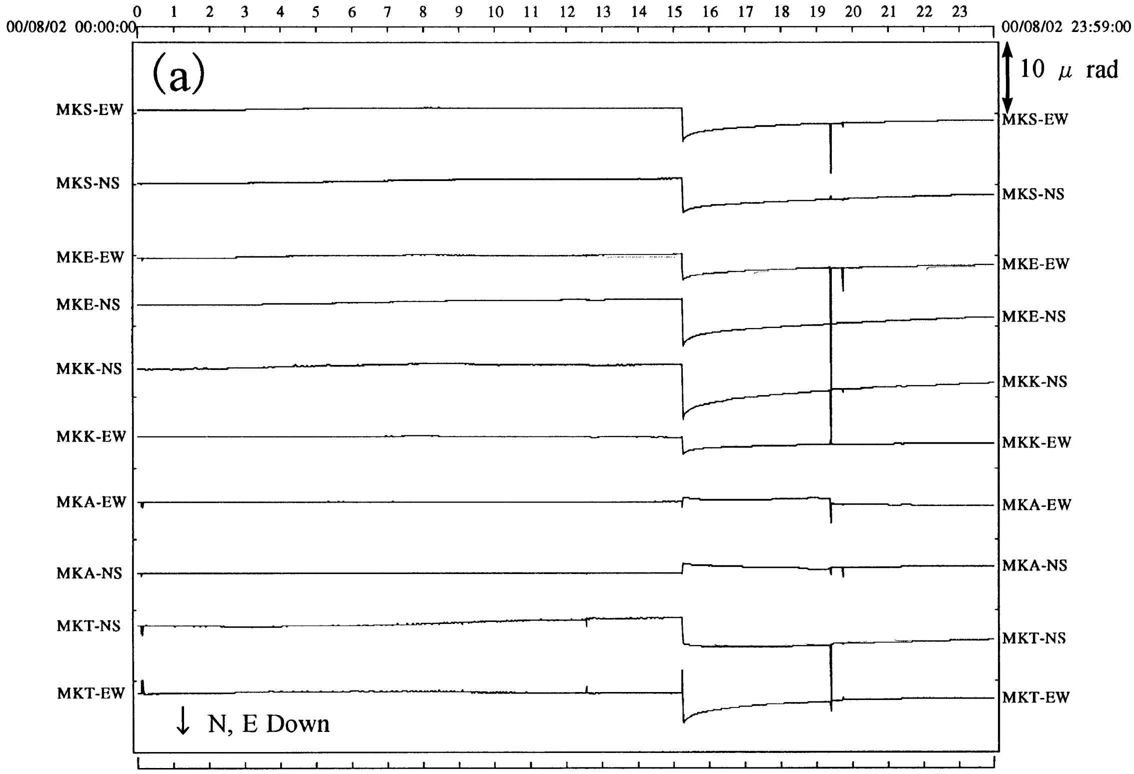


Fig. 6. Changes in the interval time for successive tilt steps.



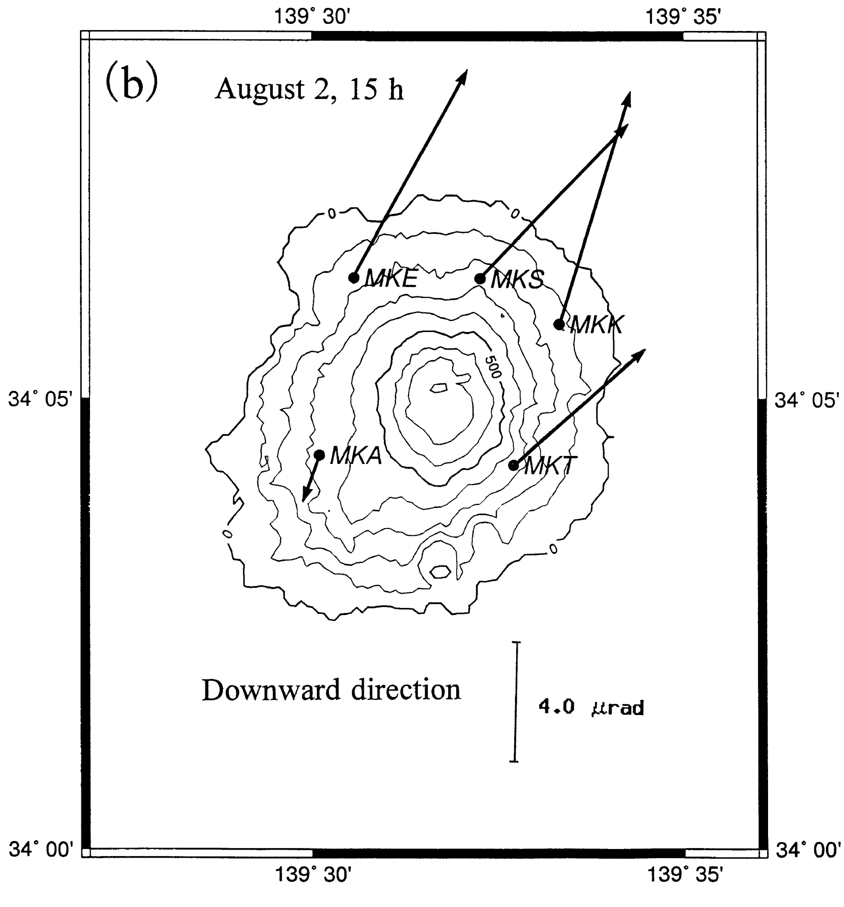


Fig. 7. (a) Typical tilt changes, including a tilt step, on August 2. (b) Typical tilt step vectors. The arrows indicate the tilt vectors in the downward direction.

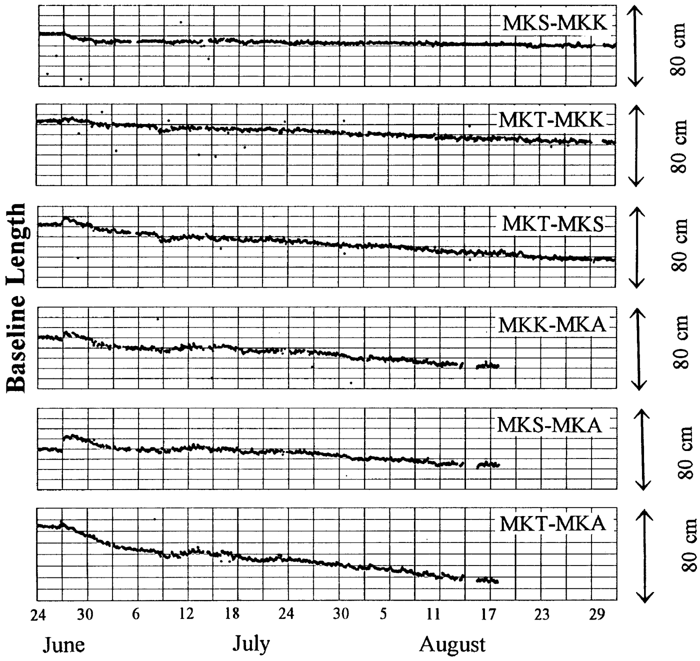


Fig. 8. Baseline-length changes detected by GPS measurements. The downward change means the contraction of baseline.

day from June 26 to 27. A clear tilt change first appeared at MKT from 18 h 30 m to 22 h on June 26, and then MKA showed a larger tilt change from 22 h on 26 to 00 h on 27.

The large tilt changes at MKT and MKA indicate magma intrusions at respective times. The first magmatic intrusion occurred near MKT (Tsubota area), and then another magma body intruded near MKA (Ako area). The tilt change at MKA amounted to about 0.16 mrad, which is comparable to the tilt change observed at the time of the 1986 Izu Oshima eruption (Yamamoto *et al.*, 1988).

The tilt vectors for the two representative time windows are plotted in Fig. 4. The difference in the directions of tilt vectors for the two time windows indicates a change in the location and direction of the magma intrusion during this period. The large tilt change with downward vectors pointing southward at MKA and MKT in Fig. 4(b) is a strong piece of evidence of dike intrusion with the E-W strike.

3.2 The second stage (June 28 to July 7)

During this period, gradual tilt changes, regarded as a recovery, are dominant at the all stations. The directions of tilt vectors at the five stations during this period are shown in Fig. 5. The tilt vectors indicate the subsidence at the west and south sides of the Miyakejima Island. This subsidence probably corresponds to magma migration from the deep magma chamber beneath Miyakejima to offshore the western coast of Miyakejima.

3.3 The third stage (July 8 to August 18)

This stage is characterized by successive occurrences of tilt steps, which are abrupt tilt changes indicating uplift of the summit area as a whole. Tilt changes during the intervals of successive tilt steps indicate gradual subsidence of the summit area. In Fig. 2, a sequence of tilt steps is recognized. Such a tilt step phenomenon started on July 8 after fairly large tilt changes (about 20 μrad at MKT), which suggest a subsidence of the summit area. The first tilt step is coincident with the time of the first eruption at 18 h 41 m, July 8 from the summit crater. Since then, tilt steps intermittently occurred usually once or twice a day. Tilt steps ceased after the eruption on August 18, which is the largest eruption up to now (September 7, 2000). The total number of tilt steps is 45. The interval times between the steps are plotted in Fig. 6. The interval time ranges from 7 hours to 56 hours, but no clear periodicity is recognized.

Figure 7(a) shows tilt changes, at the five stations, including a typical tilt step event on August 2. Figure 7(b) shows tilt vectors corresponding to the tilt step in Fig. 7(a). The maximum value of the tilt step is about 8 μrad observed at MKE, MKS and MKK. Although the steps indicate an upward motion of the summit area, which probably suggests a subsurface expansion under the central crater of the Miyakejima volcano, no eruption has synchronized with the steps except for the first (July 8) and the final (August 18) events.

3.4 The fourth stage

MKE is only the station available for the period from 23 h, August 18 to 10h, August 23, because of an instrumental trouble due to the eruption. Since the final step on August 18, no distinctive step has occurred up to now (September 7, 2000). As is seen in Fig. 2, the tilt changes little at MKE. Comparing the tilt changes at the second and the third stages at the four stations except for MKA, which could not be recovered after the trouble on August 18, the directions of tilt vectors stay almost the same. The tilt change rates at the fourth stage are approximately half of those at the second stage.

4. Deformation Detected by GPS

Figure 8 shows baseline-length changes for the four stations during the period from June 24 to August 31. Because of the instrumental trouble, we could not collect the data at MKA after August 18. The most distinctive change is the

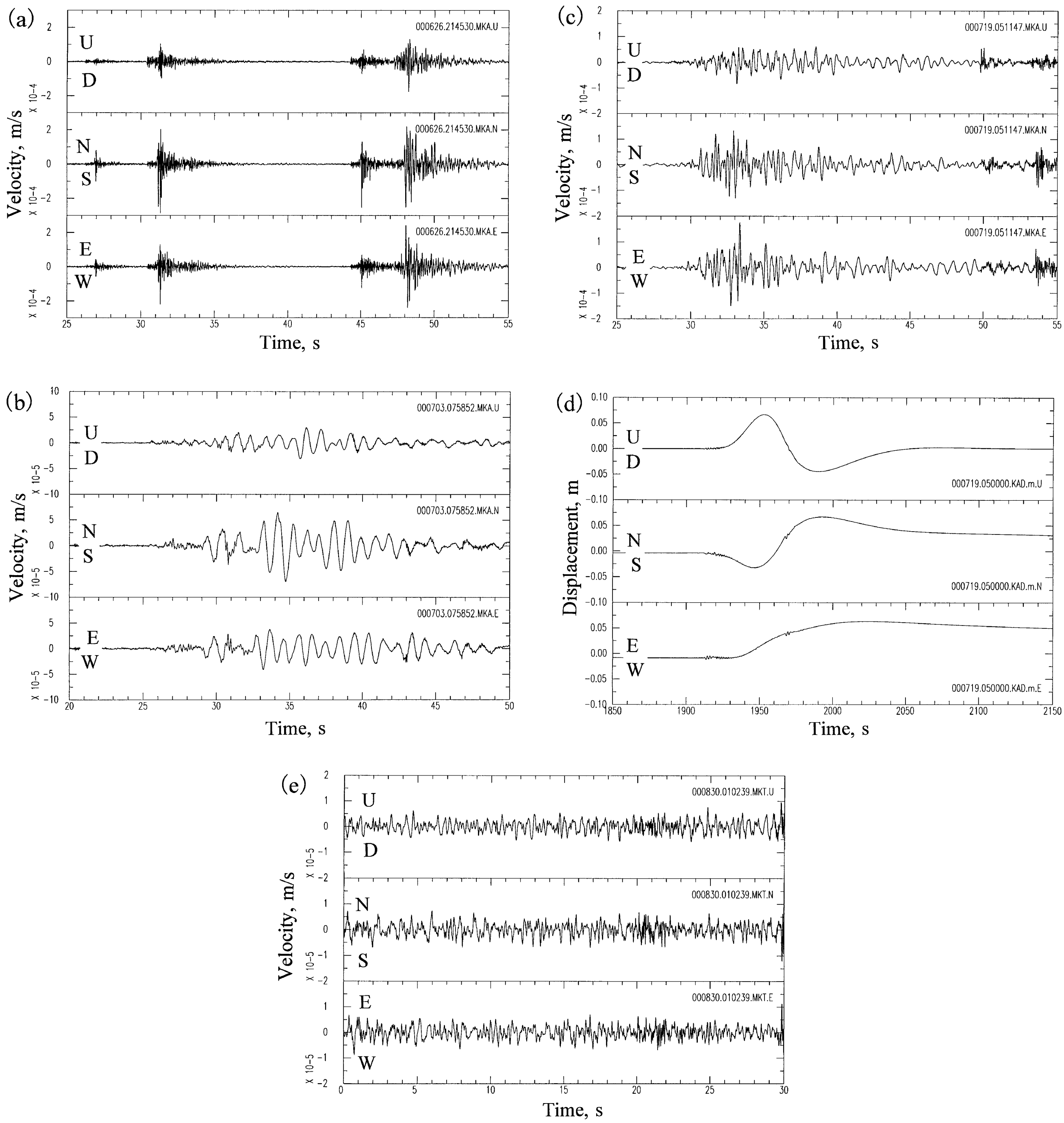


Fig. 9. Typical seismograms. The seismometer is of velocity type with a natural frequency of 1 Hz except for (d). (a) VT (volcano-tectonic) event observed at MKA at the first stage. (b) LF (low-frequency) event observed at MKA at the second stage. (c) LF event observed at MKA. This event occurred about 20 minutes before the occurrence of a tilt step. (d) Displacement seismograms for a long-period event occurring at the time of a tilt step. This seismogram was recorded at MKA by the STS-2 seismometer. (e) Continuous volcanic tremor observed at MKT at the fourth stage.

contraction of the island since June 27. The baseline lengths of all the combinations of the four stations show a change in contraction. The maximum contraction is seen for the combination of MKA and MKT, exceeding 40 cm during the period from June 28 to August 17. The large contraction rate observed at the southern part of Miyakejima suggests that the contraction source is located around the southern part of the island.

5. Typical Seismograms

Before the initiation of magma intrusion on June 26, no distinctive seismic activity had been detected in and around Miyakejima. One characteristic seismic activity was the occurrences of deep low-frequency (DLF) earthquakes at the depths of about 20 km. The outline of the activity is described in Fujita and Ukawa (2000). No clear increase of DLF earthquake activity had been observed before the present activity.

The observed seismograms in association of the present activity show a variety of the types of earthquakes, and also the type has changed as the volcanic activity style has changed. We show typical seismograms observed at the four stages below.

Most of the earthquakes at the first stage are of volcano-tectonic (VT) type. Figure 9(a) shows a typical seismogram for a VT event occurring beneath Miyakejima; the P and S phases are clearly seen.

At the second stage, the activity of VT events became quiet. Since June 29, small low-frequency (LF) earthquakes started to occur. Figure 9(b) shows one of the seismograms for the LF earthquakes. The magnitudes of this kind of LF events are usually smaller than M2.

At the third stage, several types of earthquakes occurred along with tilt steps. Several hours before the occurrence of tilt step, swarm-like activity of low-frequency earthquakes occurred. The magnitudes of larger events exceed M3. A typical seismogram is shown in Fig. 9(c).

At the time of tilt steps, long-period seismic waves were observed not only at the stations on the island but also over the whole Japan Islands. Figure 9(d) shows a typical displacement seismogram observed at MKT; we can recognize a predominant period of about 100 s.

At the fourth stage, volcanic tremor is the most active seismic event in the island. Figure 9(e) shows a part of the seismogram of the volcanic tremor. The predominant frequency is about 2 to 3 Hz.

6. Summary

By using the NIED Miyakejima volcano network, the 2000 Miyakejima eruption has been successfully monitored. The tiltmeters, the GPS receivers and the seismometers at the five stations have provided useful information about the ground deformation and seismicity changes associated with the volcanic activity. The activity observed by the NIED network during the period from June to August, 2000 can be divided into four stages; the first stage is characterized by abrupt tilt changes at MKT and MKA, the second stage by a gradual tilt change over the whole island, the third stage by tilt steps and low-frequency events, and the fourth stage by a gradual tilt change and occurrences of continuous volcanic tremor. These stages correspond to the change in the volcanic activity style. The first and second stages correspond to non-eruptive periods, the third stage to the period of intermittent summit eruptions and large subsidence of the summit area, and the fourth stage to the period of continuous eruptions at the summit crater.

The eruptive activity has continued up to now (September 7, 2000). Subsurface processes responsible for the volcanic activity should be modeled by using these tilt, GPS and seismic data, in particular for the purpose of volcanic eruption prediction.

Acknowledgments. Colleagues of NIED have helped us in performing the observations on Miyakejima. We thank Minoru Kasahara for his comments. We are also thankful to Yoshimori Honkura, Editor-in-Chief of EPS, for encouraging us to contribute to the research news section of EPS.

References

Fujita, E. and M. Ukawa, Deep low frequency earthquakes at Miyakejima volcano, *Kazan*, **45**, 2000 (in press).

Tsukui, M. and Y. Suzuki, Eruptive history of Miyakejima volcano during the last 7000 years, *Kazan*, **43**, 149–166, 1998.

Yamamoto, E., T. Kumagai, S. Shimada, and E. Fukuyama, Crustal tilt movements associated with the 1986–1987 volcanic activities of Izu-Oshima volcano—results of continuous crustal tilt observation at Gojinka and Habu, *Kazan*, **33**, 161–169, 1988.

M. Ukawa (e-mail: ukawa@geo.bosai.go.jp), E. Fujita, E. Yamamoto, Y. Okada, and M. Kikuchi