Continuous Caldera Changes in Miyakejima Volcano after 2001

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Abstract

This study investigated the evolvement of the caldera at Miyakejima volcano after February 2001. DEMs acquired with Light Detection and Ranging (LIDAR) surveys were used for analysis. Topographic changes for each surface category were examined and the change in shape was analysed. Results showed that the caldera floor had risen more than 10 m because of secondary sediment caused by collapse of the caldera wall. However, topographic changes on slope surfaces were limited to gullies. The caldera wall height was 450 m at its maximum; its slope was steep. Analysis of the shape change revealed that the volume of the caldera increased by 10.0 million m^3 from February 2001 to September 2003. Lost substance in the new crater and around it reached 8.6 million m^3, whereas volume expansion of other areas was only 1.7 million m^3. These facts indicate that the main cause of caldera expansion was the formation of a new crater. Because of measurement errors, we could not determine whether or not the caldera floor has been subsiding. As a whole, the caldera volume has continued to increase. Additionally, the caldera wall slope is steeper than the angle of repose. These facts imply that enlargement of the caldera area will continue for the time being.

Keywords: Miyakejima volcano, Caldera evolvement, LIDAR survey

1. Introduction

This study investigated the evolvement of a newly developed caldera at Miyakejima volcano. Current activities at Miyakejima began in June 2000. Observing topographical changes of an active volcano is a fundamental and important task for monitoring volcanic activity. The caldera formation process has already been investigated using time series analysis of aerial photos (Hasegawa et al., 2001). Nevertheless, no quantitative analysis has been considered regarding topographical changes after the degassing stage that began in late August 2000. This study is intended to elucidate topographical changes in the caldera after the degassing stage, using LIDAR-derived DEMs. LIDAR is an instrument for collecting high-resolution topographic data. It offers high accuracy (10–15 cm in the vertical direction and 50–100 cm in the horizontal direction), high density (50 cm – 2 m maximum), and canopy penetration.

This report first outlines Miyakejima volcano and its 2000 eruption. It then describes the DEMs used in the study. Finally, the report describes topographical changes and volume changes of the caldera of Miyakejima volcano subsequent to its 2000 eruption.

Miyakejima (Fig. 1 Hill shade image of Miyakejima volcano. Original DEM was acquired on September 2003.) is a circular, 9-km-wide volcanic island located 180 km south of Tokyo. It had two nested calderas around its summit before its recent eruption. The 1.7-km-wide newer and inner caldera, Hatchodaira, was formed 2,500 years ago. Its rim closely follows the 700-m contour line (Tsukui and Suzuki, 1998). The central cone was Oyama, which formed and grew in the Hatchodaira caldera, rising 120 m from the caldera floor. The volcano has erupted 14 times during recorded history (Tsukui and Suzuki, 1998). Recent eruptions have occurred about every 20 years: in 1940, 1962, 1983, and 2000.

The Miyakejima 2000 eruption began with a submarine eruption on 27 June. The first phreatic eruption at the summit began on 8 July with a sudden collapse of the summit. Eruptions at the summit continued until mid-August, and were accompanied by progressive subsidence of the summit and revelation of the newest caldera (Nakada et al., 2001). Volcanic gas emissions became vigorous from late August (the degassing stage), reaching tens of thousands of tons per day during the period of maximum emission. Gas

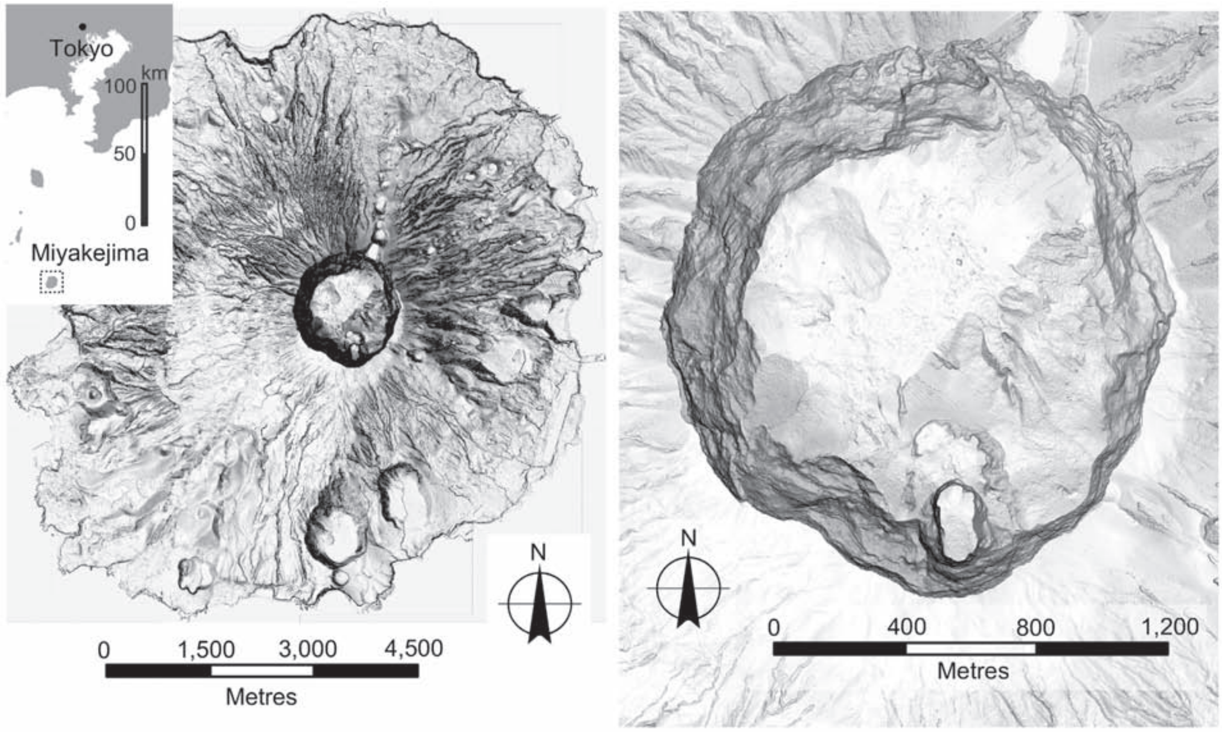

Fig. 1 Hill shade image of Miyakejima volcano. Original DEM was acquired on September 2003.

emissions dropped to 3,000 tons per day, but the emissions have continued to the present day. Crustal deformation of the island has continued from the beginning of the volcanic activity. Contraction stopped once in August 2002, but has proceeded since restarting in June 2003 (Geographical Survey Institute, 2004).

2. LIDAR data

Table 1 shows the DEMs used in this study. Although the coordinate systems of all DEMs are a Japanese plane rectangular coordinate system, their reference spheroids are different. September 2003 DEM uses only the JGD2000 reference spheroid, whereas others use a Bessel spheroid (Tokyo Datum). For that reason, older DEMs were registered as September 2003 DEM because the DEMs are inferred to be the most accurately positioned of all. Six GCPs were used for the 1983 DEM. Horizontal accuracy was less than 2.5 m. The mean height difference was 2.8 m and its standard deviation was 3.3 m. Nine GCPs were used for the February 2001 DEM. Horizontal accuracy was 2.5 m. The mean height difference was 0.4 m and its standard deviation was 0.6 m.

3. Results

The caldera surface was categorized and height differences of respective categories were analysed. Fig. 2 shows a hill shade. Fig. 3 shows height differences between February 2001 and September 2003. Remarkable height declines were found in the north, southeast, and southwest parts of the caldera. These areas were classified as the caldera wall and the main crater. The caldera rim did not reach the Hatchodaira caldera rim at the southeast and south, but the caldera exceeded the Hatchodaira caldera at other parts.

Table 1

Acquisition date	Data source	Resolution
1983	Paper map	10 m
9–12 Feb. 2001	LIDAR	1 m
22 Aug. – 30 Sept. 2003	LIDAR	1 m

DEMs used in the study. Some DEMs contain defective areas because of volcanic clouds.

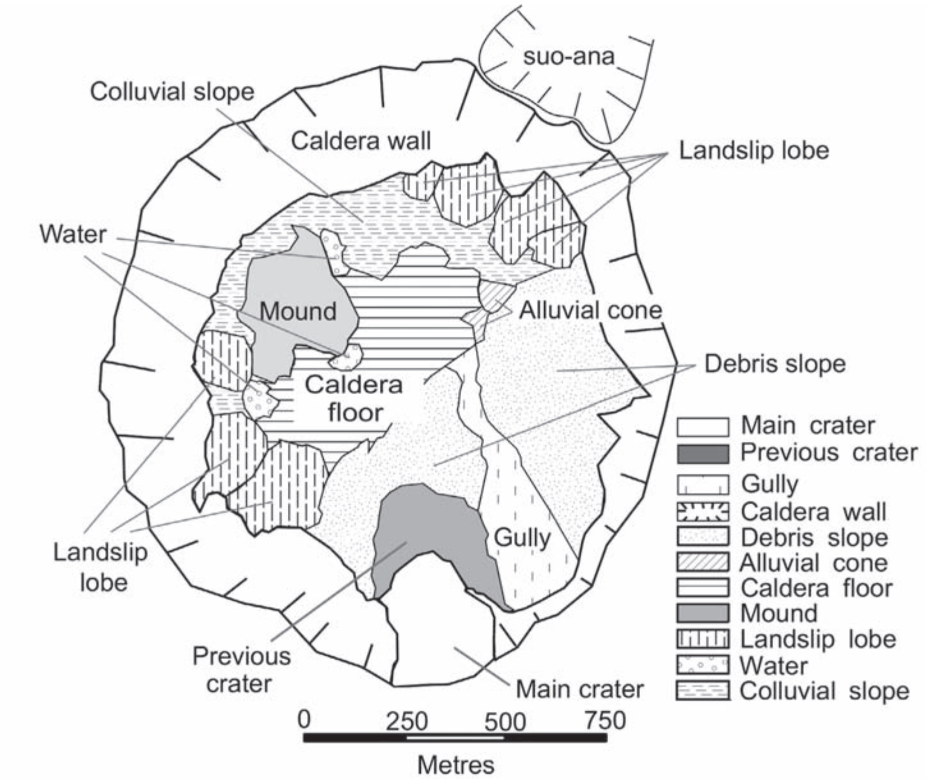

Fig. 2 Hill shade image of the caldera. The caldera is divided by the slope transformation line. The new crater is visible at the south end.

The caldera bottom was virtually flat until February 2001. However, in September 2003, the foot of the caldera wall was covered with landslide lobe deposits, the thickness of which reached 50 m at maximum.

The caldera is divided by a slope transformation line. The northwest half is the caldera floor. The caldera floor rose 2–10 m at its southeast part and 5–30 m at its northern part. This rise is attributable to accumulation of secondary sediment from the instances of wall collapse. The height change is negligible on a mound, which lay westward of the caldera floor.

The current main vent was at the southernmost part of the caldera in September 2003. That position did not agree with the drawn Oyama central cone before the 2000 eruption. The southern half of the main crater was the caldera wall in February 2001. The caldera wall collapsed up to 65 m deep and 380 m across. The deterioration at that location reached 309 m, which is the largest value in the caldera. The previous crater bottom subsided by up to 40 m, whereas the previous crater rim did not subside. On the other hand, the main crater rim rose 10–25 m, suggesting that pyroclastic material is piled up around the main crater.

The debris slope is divided by a huge gully, the floor of which rises 10 m. Interpretation of ortho images suggests that the floor was filled with caldera wall collapse sediment or secondary sediment. No marked height change is evident on the northern half of the debris slope and little caldera wall collapse is found above the slope.

Table 2

Date	Diameter (m)	Perimeter (m)	Area (ha)	Volume (10^6 m^3)
Feb. 2001	1,662	5,230	190.1	601
Sept. 2003	1,722	5,338	195.6	611

Calculated caldera shape. The diameter was measured manually on ArcGIS. The volume was different from that of the 1983 DEM.

Table 2 shows the caldera diameter, perimeter, area, and volume. The perimeter and area were calculated using ArcGIS built-in functions. Regarding diameter, an operator manually measured distances with ArcGIS. Caldera volume was defined as the difference between the volume of each DEM and the volume of DEM derived from the basic map of Miyakejima volcano in 1983. A mask was created from the caldera outline in September 2003 to avoid errors caused by topographical changes outside the caldera. The caldera diameter, perimeter, and area expanded continuously throughout the period. Assuming that area enlargement and volume expansion were constant, its speeds were 2.1 hectares per year and 4.0 million m^3 per year, respectively.

4. Discussion

Results indicate that the main sources of topographical changes in the caldera might be caldera wall collapse and new crater formation. To validate the contribution of each factor, we evaluated the volume change in the new (active in September 2003) crater and volume change except the new and old (active in February 2001) crater area. The result shows that the new crater area is 83,600 m^2 and lost volume was 8.6 million m^3. These facts indicate that the greater part of caldera volume expansion is attributable to volcanic activity.

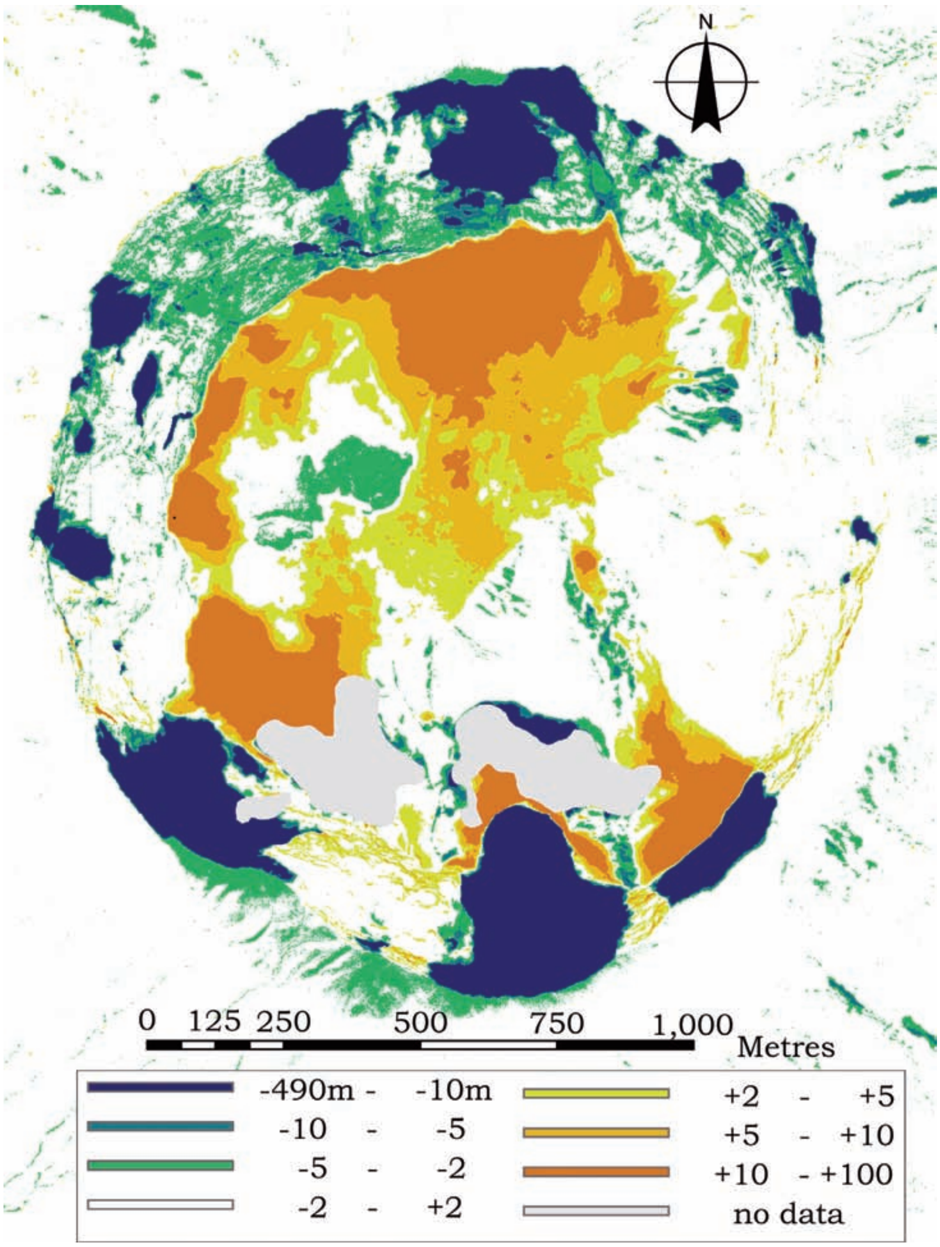

Fig. 3 Height change between February 2001 and September 2003. Outer and inner solid lines indicate the caldera rim and caldera wall bottom, respectively.

On the other hand, caldera volume aside from the new and old crater area has increased 1.7 million m^3. This fact indicates that the caldera wall has continually fallen down into the caldera. These facts also indicate that the caldera bottom might have subsided during the period because the caldera wall collapse never engenders volume expansion of the caldera. A GPS ground receiving station that was used in the February 2001 survey was situated on Kozushima Island (35 km from Miyakejima), and caused a greater offset in the February 2001 DEM. Presuming that the offset of the February 2001 DEM is the same as registering the offset to the September 2003 DEM, the obtained result is the same as the measurement errors and we cannot conclude whether or not the caldera bottom has subsided.

5. Conclusions

Topographical changes in the Miyakejima caldera after February 2001 were shown using LIDAR DEMs. In February 2001, the foot of the caldera wall was clear and debris slopes existed at the caldera floor. The caldera floor had risen as the result of secondary sediment. At that time, negligible height variation was observed on the mound and the debris slope. These results indicate that the caldera wall collapse is the main cause of caldera area enlargement.

Caldera volume increased about 10.0 million m^3, most of which occurred in the new crater area. Volume expansion in other areas was 1.7 million m^3. The caldera wall collapse did not contribute to volume expansion. Therefore, probable causes of the expansion might include discharge material outside the caldera with eruption and caldera floor subsidence. More measurement results are needed to reach a meaningful conclusion because the value of subsidence is comparable to that of measurement errors.

Volume change caused by new crater formation was 8.6 million m^3. A new pyroclastic slope was built at the north of the crater although the volume of the slope deposit did not compensate the missed volume. The lost material was emitted outside the caldera or drawn into the vent.

Overall, the caldera volume is increasing. Moreover, the caldera wall slope is steeper than the angle of repose. Considering these facts, the caldera will continue to become larger for the time being.

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