Journal of Volcanology and Geothermal Research 308 (2015) 1–9

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

journal homepage: www.elsevier.com/locate/jvolgeores

Lava flow hazards—An impending threat at Miyakejima volcano, Japan

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A R T I C L E I N F O

Article history:
Received 7 July 2015
Accepted 7 October 2015
Available online 21 October 2015

Keywords:
MAGFLOW model
Vent opening probability
Eruptive history

A B S T R A C T

The majority of the historic eruptions recorded at Miyakejima volcano were fissure eruptions that occurred on the flanks of the volcano. During the last 1100 years, 17 fissure eruptions have been reported with a mean interval of about 76–78 years. In the last century, the mean interval between fissure eruptions decreased to 21–22 years, increasing significantly the threat of lava flow inundations to people and property. Here we quantify the lava flow hazards posed by effusive eruptions in Miyakejima by combining field data, numerical simulations and probability analysis. Our analysis is the first to assess both the spatiotemporal probability of vent opening, which highlights the areas most likely to host a new eruption, and the lava flow hazard, which shows the probabilities of lava-flow inundation in the next 50 years. Future eruptive vents are expected in the vicinity of the Hatchodaira caldera, radiating from the summit of the volcano toward the costs. Areas more likely to be threatened by lava flows are Ako and Kamitsuki villages, as well as Miike port and Miyakejima airport. Thus, our results can be useful for risk evaluation, investment decisions, and emergency response preparation.

1. Introduction

Miyakejima is a basaltic stratovolcanic island in the northernmost Izu-Bonin volcanic arc (Japan) characterized by repeated, persistent summit activity with episodic eruptions from fissure situated on the flanks of the volcano (Tsukui and Suzuki, 1998). These flank eruptions are usually responsible for effusive activity, which may feed lava flows capable of flowing over the volcano's slopes and invading vulnerable areas. In the last century, fissure eruptions have repeatedly occurred, increasing significantly the threat posed by lava flow inundations to the residents of island (Tsukui et al., 2001). Importantly, several recent fissure eruptions (i.e., flank eruptions), commonly characterized by multiple aligned vents that radiate from the summit of the volcano, caused fatalities and significant economic damage and disruption since they occurred as low as a few hundred meters altitude, close to or even well within inhabited areas (Tsukui et al., 2001).

In addition, the latest eruption at Miyakejima in 2000 was far different from what had been experienced during the last century. It produced a collapse caldera associated with huge sulfur emission that has even forced the total evacuation and resettlement of 3845 island inhabitants (Fujita et al., 2003; Furuya et al., 2003). The evacuation order was removed more than 4 years later. Approximately 70% of the residents who had left the island came back to Miyakejima, and recovery work, such as cultivation of agricultural lands, began.

Given the high number of people exposed to volcanic activity and the potential economic impact of eruptive events, it is understandably crucial to conduct volcanic hazard studies in Miyakejima that can help residents decide where to live, build, and work. Mitigation of risk to life, property, and infrastructure can be undertaken by avoiding threatened areas and by taking protective measures to reduce the effects when and where vulnerable areas cannot be avoided. Currently, Miyakejima volcano is continuously monitored using seismology, deformation, gravity, magnetism, and gas emission studies by Tokyo Metropolitan Government (1990) and Japan Meteorological Agency (2000). Detection of volcanic precursors can generally identify the locality of impending volcanic activity, even though it often does not determine exactly the typology or timing of an eruption or even its certainty. Hazard maps can then be used for risk-based decision making in land-use planning and emergency management. Thus, effective monitoring of Miyakejima volcano, combined with the preparation of emergency plans to face future eruptions, can help reduce the risk to lives and property in an island, where about 3000 people live.

The effective use of hazard maps of Miyakejima may help in minimizing the risk from volcanic eruptions through correct land use in urbanized areas. In particular, a detailed map showing areas that are likely to be inundated by future lava flows is extremely useful, allowing people living nearby to judge for themselves the relation between potentially dangerous areas and their daily lives.

Here we provide the first quantitative assessment of lava flow hazard posed by flank volcanic activity in Miyakejima, which can be useful in the case of future volcanic unrest, as well as for making more informed decisions regarding long-term land-use planning. We first calculate the future probability of vent opening using the spatiotemporal distribution of the volcano-tectonic structures of the island. Then we characterize the historical eruptions and simulate a great number of

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http://dx.doi.org/10.1016/j.jvolgeores.2015.10.005
0377-0273/

possible lava flow paths using the MAGFLOW model (Del Negro et al., 2008). Next we produce a detailed map showing the probability of lava flow inundation in the next 50 years over the whole island. Finally we quantify the amount of buildings, roads and critical facilities that could suffer damage in case of flank effusive eruptions in Miyakejima.

2. Regional setting

The Miyakejima volcano is on the Izu Islands chain south of Tokyo (Fig. 1a). It has a conical edifice with a horizontal diameter of ~13 km and a height of ~1200 m including its submarine part. Subaerial part of the volcanic edifice forms Miyakejima Island, which is a circular island with 8 km in diameter (Fig. 1b). The summit area is characterized by double calderas, outer Kuwanokitaira Caldera (3.5 km in diameter) and inner Hatchodaira Caldera (1.5 km across), in which a scoria cone Mt. Oyama (814 m above sea level) is grown (Fig. 1b). Near the coastal line, there are many craters formed by phreatomagmatic eruptions.

The oldest part of Miyakejima volcano was probably formed before 10 ka and Kuwakidaira Caldera, widely buried by recent products, has probably formed during this stage of activity (Fig. 1b). The Hacchodaira Caldera is believed to have formed as the result of a large-scale eruption which occurred approximately 2500 years ago (Tsukui et al., 2005). Since then more 25 eruptions have been identified, with a 315-year-long period of inactivity between 1154 and 1469 A.D. (Aramaki et al., 1986). The latest large eruption at Miyakejima occurred in 2000, which resulted in the formation of a collapse caldera 1.6 km in diameter and 450 m deep at the summit (Geshi et al., 2002).

Flank eruptions from radial fissures have been dominant (Tsukui et al., 2005). The distribution of the recent eruptive fissures concentrates in the north–north eastern and south–south western sectors of the island, though the flank eruptive fissures are distributed almost all around the volcano (Fig. 1b).

An almost complete account of historical eruptions is available for the last 1100 years (Table 1), during which 17 fissure eruptions have been recorded with a mean interval of about 76–78 years. In the last century the volcano has erupted at shorter intervals of approximately 21–22 years. All the historical eruptions since the 15th century include flank fissure eruptions, and produced typically the dense-rock equivalent of 10^{-2} km^3 of magma in each eruption (Tsukui et al., 2005). The magmas erupted from the volcano are mainly tholeiitic basalts to andesites, with whole rock SiO_2 content ranging from 49 to 63 wt.% (Niihori et al., 2003). The erupted magma during the Shinmyo stage concentrates between 51 and 57 wt.% of SiO_2.

The orientations of fissure eruptions are controlled by both the regional and local stress fields. The seismic activities in the northernmost part of the Izu-Bonin arc, including Miyakejima area, show that the maximum regional compressive stress aligns in NW–SE direction, which is perpendicular to the orientation of Suruga trough parallel to the motion of the Philippine Sea plate (Shimozuru et al., 1972). The radial distribution of eruptive fissures in Miyakejima Island shows the development of a radial compressive stress probably controlled by a compressive pressure source beneath the center of the volcano (Ueda et al., 2005).

2.1. Recent historic eruptions

The chronicles of the more recent historic eruptions provide information on the fundamental parameters that characterize the flank fissure eruptions of Miyakejima volcano. Since the middle of 19th century four flank fissure eruptions occurred (1874, 1940, 1962, and 1983; Fig. 1b), leading to an increasing trend in the frequency of occurrence of events. All these eruptions produced lava flow from the flank eruptive fissure and the lava flows inundated the inhabitant areas. A minor submarine fissure eruption also occurred during the initial stage of the last eruption in 2000.

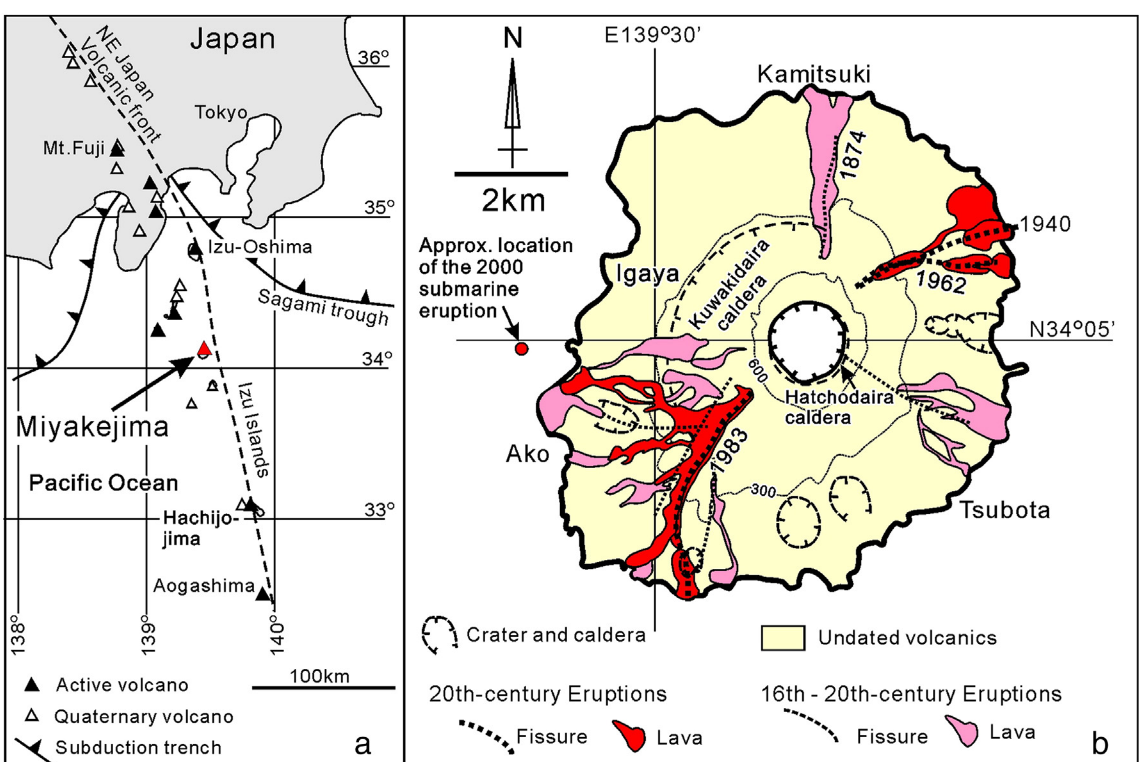

Fig. 1. Miyakejima volcano. (a) Tectonic framework and (b) simplified geological map. Modified after Geshi et al. (2002). Distributions of lava flows are from Tsukui and Suzuki (1998).