火山 第 58 巻（2013）
第 2 号，CD-BOOK

2013 IAVCEI Field Trip Guide

B04: Basaltic and Rhyolitic Island Volcanoes in Izu Islands

Masashi TSUKUI*, Yoshihisa KAWANABE**, Jun'ichi ITOH**,
Koichiro SAITO***, and Hidefumi WATANABE****

*: *Graduate School of Science, Chiba University, Chiba, Japan*
**: *Geological Survey of Japan, The National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan*
***: *Cabinet Office, Government of Japan; Tokyo, Japan*
****: *Tokyo Metropolitan Government; Tokyo, Japan*

1. Introduction

The Izu-Mariana volcanic arc is located north to south on the Philippine Sea Plate **(Fig. 1)**. In this region, the Philippine Sea Plate moves in the NNW direction. The Philippine Sea Plate is bounded by the Suruga and Sagami troughs to the north, and is subducting beneath Honshu, which is part of the Eurasian (Amurian) Plate. The Izu peninsula, located at the northern tip of the Philippine Sea Plate, cannot subduct and has been colliding against central Honshu since the Quaternary.

Toward the west, the Suruga trough continues to the Nankai trough and farther to the Ryukyu Trench, along which the Philippine Sea Plate goes down under southwest Honshu. Large-scale earthquakes have occurred periodically along the Suruga, Sagami, and Nankai troughs, such as the 1923 Kanto earthquake.

Magmas formed in the Izu-Mariana arc, where the crust to the west is also part of the oceanic Philippine Sea Plate, show bimodal features. Volcanoes sit on the volcanic front, including Izu-Oshima, Miyakejima, and Hachijojima islands, which consist mostly of basalt to basaltic andesite (Aramaki and Ui, 1982). while those away from and arranged obliquely to the volcanic front, such as Niijima and Kozushima, are made of contrasting rhyolites (Isshiki, 1982, 1987). On the other hand, andesite predominates in other volcanic arcs in Japan.

On this four-day field trip, we will visit Izu-Oshima and Niijima, the closest island volcanoes to the Tokyo metropolitan area, to view various types of active volcanoes in the northern end of Izu-Mariana arc. These two island volcanoes show several contrasting features; Izu-Oshima is a polygenetic stratovolcano of basaltic to basaltic andesite in composition, while Niijima comprises more than fifteen monogenetic rhyolite dome volcanoes with a small trace of basalt. Large eruptions (in the order of 0.1-1km^3) have occurred 12 times during the last 1,700 years in Izu-Oshima, while the frequency of large eruptions is estimated to be once every thousand to several thousand years for Niijima. More than 230 years have passed since the latest large eruption of Izu-Oshima, and 1,100 years in the case of Niijima. A monitoring network system has been constructed to detect any unrest for the purpose of hazard mitigation.

Following geological descriptions and stop guides on Izu-Oshima and Niijima will help you to understand histories of these volcanoes and take you on tours of attractive volcanic features.

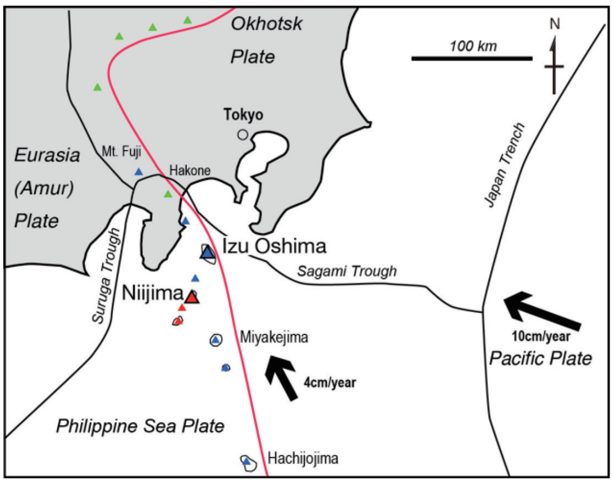


Figure 1　Location and tectonic setting around Izu Oshima volcano. Blue triangle: basaltic volcano, Red triangle: rhyolitic volcano, Green triangle: andesitic volcano, Red line: volcanic front, arrow: direction of plate motion.

2. Izu-Oshima Volcano

2.1 Overview

Izu-Oshima is a basaltic stratovolcano located about 120 km SSW of Tokyo **(Fig. 1).** The parallelogram-shaped island is approximately 15km north and south and 9km east and west. Its eastern coast is a maximum of 300m high sea cliff and old dissected volcanoes; late Pliocene to early Pleistocene basaltic stratovolcanoes called Okata, Gyoja-no-iwaya, and Fudeshima are exposed (Nakamura, 1964; Isshiki, 1984).

Izu-Oshima volcano has a collapsed summit caldera with a diameter of approximately 4km, **(Fig. 2)** forming a multiple caldera complex consisting of an older eastern caldera and a younger western caldera (Kawanabe *et. al.*, 2010). The present caldera is estimated to have been formed about 1,700 years ago after violent steam explosions at the summit area (Yamamoto, 2006). Inside the caldera is an active central cone, Miharayama, standing about 100 m from the floor.

Flank volcanoes, queuing up from NW to SE, are considered to be arranged parallel to the

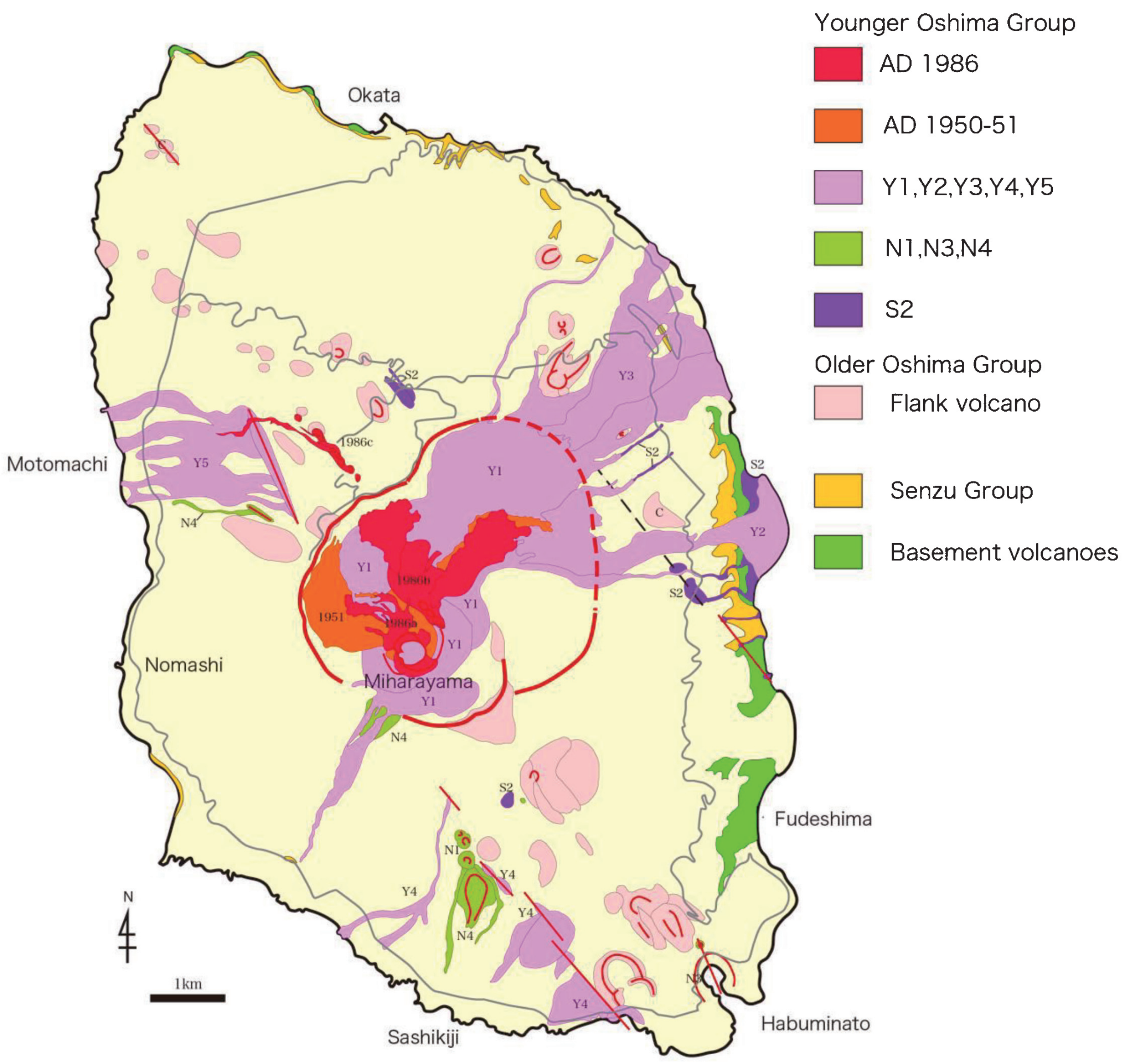


Figure 2. Geological map of Izu-Oshima volcano (modified after Kawanabe, 1998)

Table 1. Members of the Younger Oshima Group and the mode of eruption. ○ ; certain, large scale. △ ; certain, medium to small scale. ? ; uncertain but probable. - ; not happened. 14C age : *1; Kawanabe (2012), *2 ; Isshiki (1984), *3 ; Yamamoto (2006).

Units	age		summit eruption			flank eruption			scale
	Historical Records	14C age (yBP)	sub-plinian eruption	Lava flow	Explosive eruption, ash fall	northwest	southeast	east	
	1986-		○	○	△	○	-	-	middle ($>0.01 km^3$)
	1950-			○	△	-	-	-	
	1912-			○	△	-	-	-	
	1876-			○	△	-	-	-	
Y1	1777-1778		○	○	△	-	-	-	Large ($>0.1 km^3$)
Y2	1684	240±40	○	○	△	-	-	-	
Y3	1552?		○	○	△	-	-	-	
Y4	1421?	480±40 430±40	○	○	△	-	○	-	
Y5	1338??	720±40	○	?	△	○	-	-	
Y6		900±40	○	?	△	-	-	-	
N1	1112??	810±40 960±40	○	?	△	-	○	-	
N2			○	?	△	-	-	-	
N3	856??	1130±80	○	?	△	-	○	-	
N4		1500±40 1720±40	○	?	△	○	○	-	
S1			○	?	○	-	-	-	
S2		1780±50 1730±60	○	?	○	○	○	○	

maximum horizontal stress axis (Nakamura, 1977). Submarine volcanoes of similar basalt as Izu-Oshima are distributed along the extension to the southeast and the northwest, as far as 15 to 20 km from the summit (Ishizuka et al., 2009).

2.2 Eruption history of Izu-Oshima Volcano

Izu-Oshima volcano began its activity covering the older volcanoes about 50,000 years ago (Isshiki, 1984). The lower unit of the edifice of Izu-Oshima volcano is called the Senzu group (Nakamura, 1964). It is composed largely of explosion breccia, mudflow deposits, and a small amount of lava flows. The Senzu group probably represents the products of an explosive eruption that occurred in shallow water (Isshiki, 1984).

The upper unit of the Izu-Oshima volcano consists of subaerial products, alternations of basaltic lava flows and pyroclastic fall deposits, scoria, and ash, along with explosion breccia. The upper unit is subdivided by the latest caldera formation period. The pre-caldera deposits are called the Older Oshima group, while the syn- and post-caldera deposits are called the Younger Oshima group (Nakamura, 1964). The Younger Oshima group is subdivided into 12 tephra members by development of soil or weathered ash layers (Nakamura, 1964). These tephra eruptions occurred, mainly at the summit and sometimes with flank eruptions. The products of the eruptions are basaltic scoria fall deposits, lava flows, and ashfall deposits with small amounts of andesite and dacite. Phreatic explosions also occurred where the flank fissure reached the seashore. In the recent 130 years, medium-scale eruptions (in order of 0.01 km^3) occurred four times with intervals of 36 to 38 years.

2.3 Major historical eruptions and disasters

The latest large-scale eruption (Y_1) of Izu-Oshima, the 1777-1778 eruption, began with a fire fountain at Miharayama. Scoria and ash that had fallen on the outer slopes of the caldera and lava flows from the foot of Miharayama flowed down the caldera floor and reached to the sea. Then, ash emission activity began and lasted until 1792 (Tsukui et al., 2009). Similar sequence of eruption is also seen in many large- and medium-scale eruptions.

During large-scale eruptions, the fall deposits sometimes reached about 1 m thick in the middle slope of the island, causing the destruction of houses, farmlands, and vegetation. The lava flows from the summit usually poured down only on the caldera and uninhabited area, but when a flank fissure is opened on the outside of the

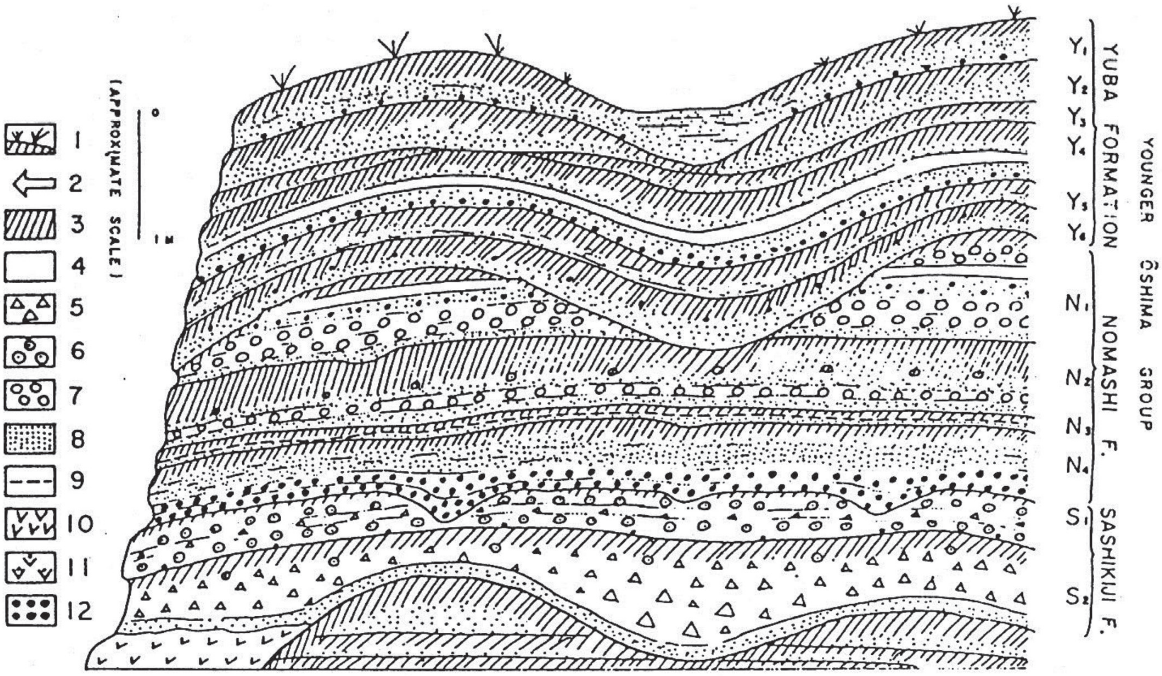


Figure 3. An idealized exposure of the Younger Oshima group (Nakamura, 1964). 1: Present surface; 2: horizon of pottery remains; 3: weathered ash or soil; 4: fine volcanic ash; 5: tuff breccia; 6: accretionary lapilli tuff; 7: rounded lithic lapilli; 8: coarse volcanic ash; 9: rhyolite ash in N_3; 10: lava flow; 11: agglutinated debris; 12: scoria fall

caldera, such as in the 1986 eruption, lava flows and phreatic explosions in the coastal area may induce large disasters.

2.4. The 1986-1987 eruption

Precursors to the 1986 eruption

The medium-term precursors to the 1986 eruption are divided into magma accumulation and ascent stages (Watanabe, 1998). Magma accumulation continued for more than 10 years until around 1980, causing increasing seismic activity, inflation of the volcano, the source of which was estimated at a depth of 8 km, and an anomalous decrease in the geomagnetic total intensity. During the ascent stage since 1981, however, a small deflation and low seismicity had been observed at the caldera region until the beginning of the eruption, while remarkable short-term precursors had been detected after August 1986 around the summit crater, including shallow tremors (Watanabe, 1987), an anomalous decrease in the geomagnetic field, and electrical resistivity beneath the crater (Yukutake et al., 1990a, 1990b).

A two-stage (magma accumulation and ascent) model can consistently explain the apparently contradicting medium-term precursors

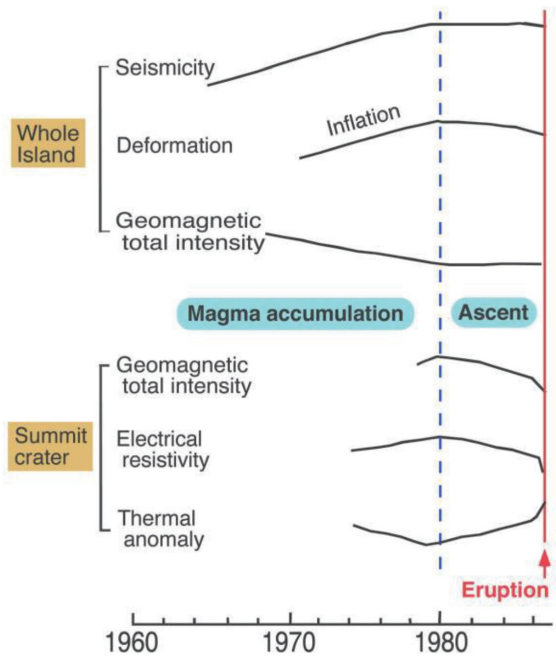


Figure 4. A schematic summary of the precursors to the 1986 summit eruption of Izu-Oshima volcano (Watanabe, 1998).

(**Fig. 4**: Watanabe, 1998). We may suppose that basalt magma began its gradual ascent through the well-developed conduit in around 1980, producing no remarkable seismic activity and deformation around the summit crater.

Summit eruption

During the period from April to the beginning of the summit eruption on November 15, 1986, the seismic activity was high at the northern and western parts of the island but very low at the caldera region.

Miharayama started to erupt at 17:25 on November 15, 1986. A fire fountain broke out on the southern wall of the pit crater (1986 "A crater").

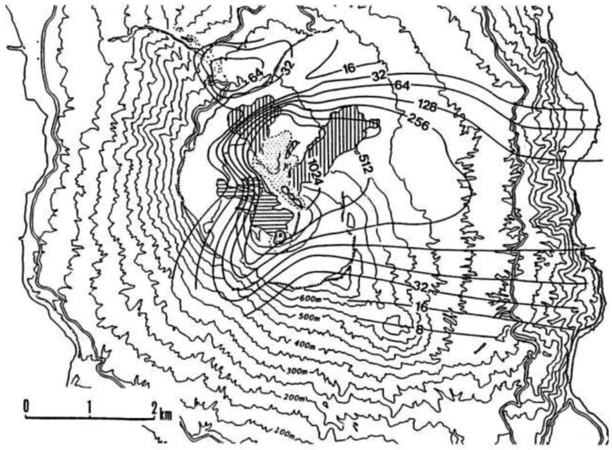


Figure 5. Isopach map of the 1986 eruption fall deposit (thickness in mm) (Endo et al., 1988) .

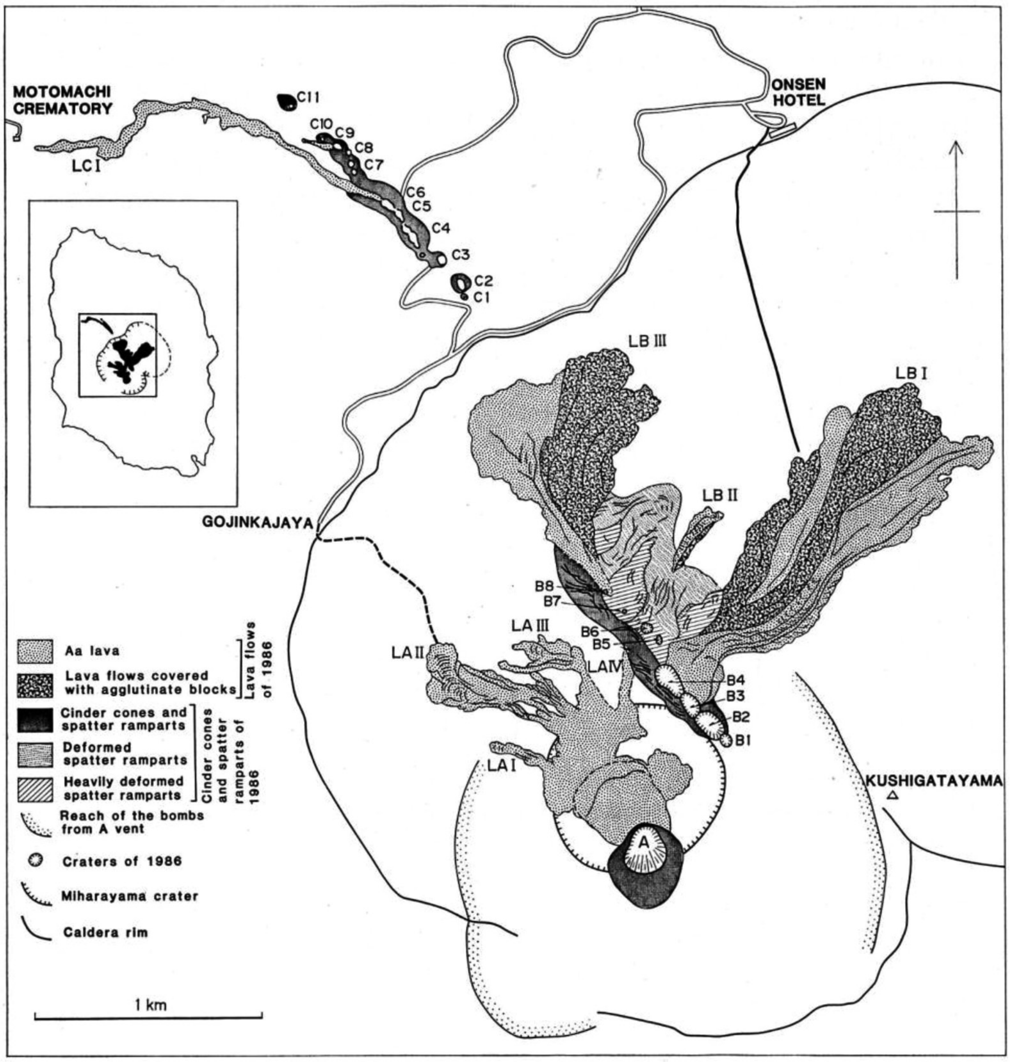


Figure 6. Map showing craters, fissure vents, and pyroclastic cones in 1986 (after Soya et al., 1987)

After the beginning of the summit eruption, an intense earthquake swarm began at the northern and western parts of the island. The swarm activity reached its maximum on November 18 and then declined on November 20 in parallel with the rate of eruption production. Lava flows began rushing down the slopes of Miharayama and spread on the caldera floor on November 19. On November 20, the effusion of lava almost stopped, and the eruption became more explosive. Intermittent bursts of violent explosions with visible shockwaves were observed.

In contrast to the summit eruption, the fissure eruptions were accompanied by an intense earthquake swarm activity and remarkable ground deformation. The swarm activity began two hours before the outburst at the northern part of the caldera. At 16:15 on November 21, a new fissure (1986 "B fissure") opened on the NW caldera floor. A sub-plinian eruption column reached about 16 km altitude, and a fall deposit of scoria and ash extended eastward from the vents **(Fig. 5)**. Lava flows spread out from the foot of the fountains and formed two lobes (LB-I and LB-III) **(Fig. 6)**. At 17:45, another new fissure (1986 "C fissure") opened outside the caldera on the northwestern slope of the volcano.

The chain of fissures B and C opened above the western part of the swarm area. Lava began to flow down from "C fissure" toward the largest town, Motomachi. After the beginning of the fissure eruption, the earthquake swarm propagated toward both the NW and SE directions to form a NW-SE seismic zone across the island. The authorities then decided to evacuate all of the 9,000 residents of the island (This operation was completed by 05:00 of the next morning. The evacuees returned home after one month.).

The intensity of the eruption from "B and C fissures" declined by 21:00, but new ground cracks were found on the SE part of the island. The focal depths of the earthquakes at the northwestern part and at the southern offshore portion of the island were deeper than 5 km, while most of the earthquakes at the southeastern part were located at shallower depths. The focal mechanisms of the former group were strike-slip type, with pressure axes in the NW-SE direction, consistent with the common tectonic stress field around the island; those of the latter were normal-fault type, with tensional axes in the NE-SW direction (Yamaoka et al., 1988). Many cracks and remarkable subsidence amounting to several tens of centimeters were observed around the fissures and at the southeastern part of the island. Fissure eruptions outside the caldera occurred for the first time during the recent 500

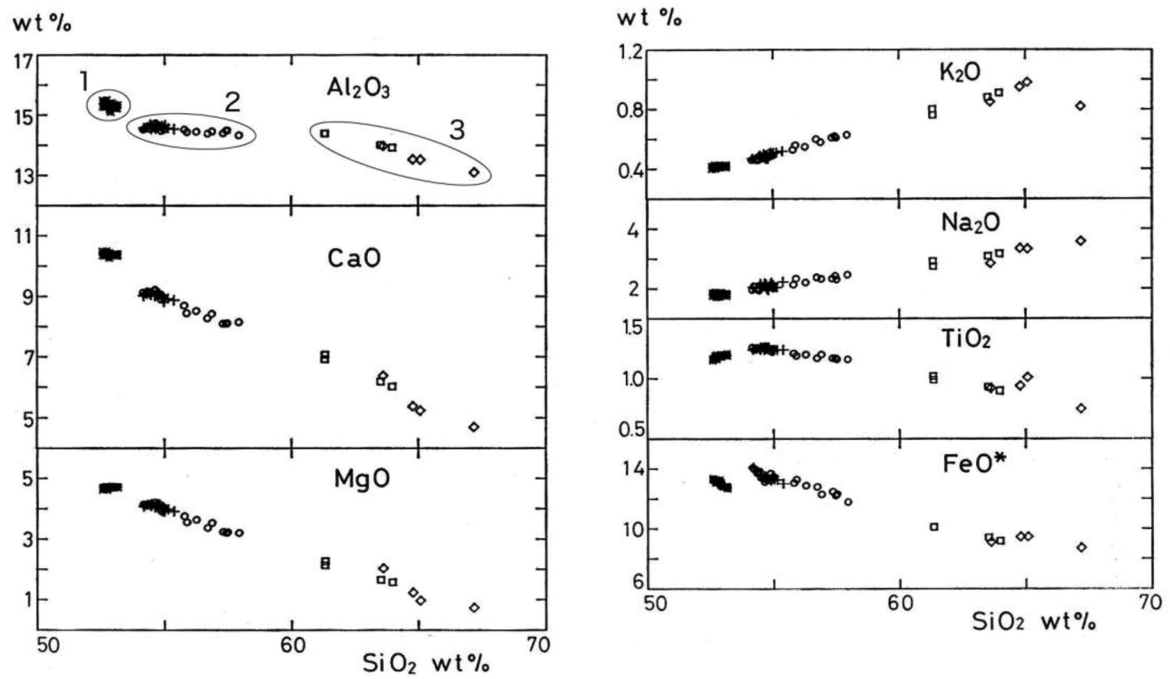


Figure 7. Harker diagram of major elements of the 1986 eruption products (Fujii et al., 1988). 1: Basalts of 1986 "A crater"; 2: basic products of B and C fissures.

years. The eruption itself had ceased by the next morning. On November 23, LB-II lava flow broke out from the middle part of "B fissure" but soon stopped **(Fig. 5)**. The rocks from "B and C fissures" have wider compositional variations, basalt to dacite, and are definitely different from "A crater" products; thus, it is suggested that the magma conduit system of "A crater" is different from those of "B and/or C fissures" (Aramaki and Fujii, 1988; Fujii et al., 1988) **(Fig. 7)**.

Post-eruption

After the fissure eruption, the seismic activity and ground deformation decreased gradually, except for a shallow earthquake swarm just beneath the pit crater of Miharayama that developed after the 1986 eruption. On the morning of November 16, 1987, almost one year after the 1986 eruption, Miharayama erupted again. Accompanied by a low-frequency earthquake and large detonations, the lava lake collapsed and its crusts blew up. Another eruption took place on November 18, during which the lava that filled the summit crater was drained, a small amount of ash was ejected from the summit crater, and a shallow earthquake swarm occurred but soon declined. Repeated microgravity measurements detected the whole drain-back process of the magma in the summit conduit (Watanabe, et al., 1998). A new pit crater of almost the same diameter and at the same location as that before the 1986 eruption was formed. After the 1987 activity, intermittent small eruptions in the pit crater continued until 1991.

2.5 Petrology of Izu-Oshima Volcano

The essential materials of Izu-Oshima volcano are low-alkali, arc-type tholeiitic basalt and a subordinate amount of pyroxene andesite. All of the rocks contain plagioclase phenocrysts. The amount of plagioclase phenocrysts in basalt is usually very small (<2%) in lava flows of the large-scale eruption but relatively rich (>5%) in to have formed from the accumulation of plagioclase phenocrysts in aphyric magma (Soya, 1976; Nakano et al., 1988) **(Fig. 8)**.

The basalts of the Senzu group are the most primitive basalts in Izu-Oshima; differentiated basalts appear in younger products in general. However, the rocks of the Younger Oshima group have undifferentiated compositions compared to the uppermost rocks of the Older Oshima group, and the ratios of trace elements in the rocks differ between the Younger and the Older Oshima group. In the Younger Oshima group, the differentiation has progressed gradually over time (Kawanabe, 1991; Fujii et al., 1988) **(Fig. 9)**.

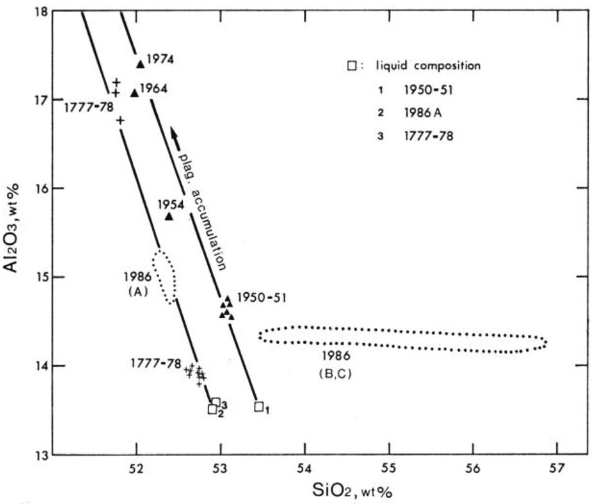


Figure 8. Al_2O_3 vs. SiO_2 diagram of lavas and ejecta for 1777-78, 1950-74 and 1986 eruptions (Nakano et al., 1988) .

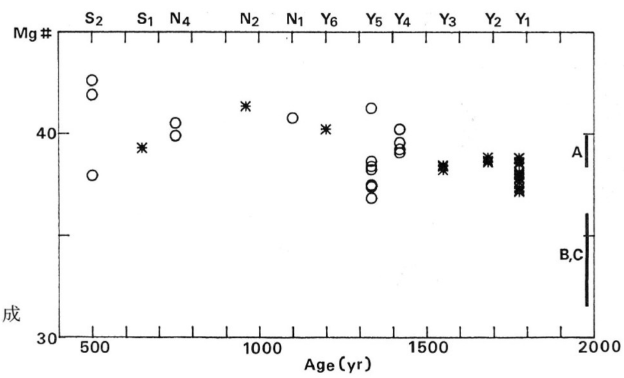


Figure 9. Chronological variation of Mg# in the products of the Younger Oshima group. ○: eruption with flank eruption; *: eruption without flank eruption (Fujii et al., 1988).

The products of the flank eruption are divided into three groups according to their compositional characteristics. Group 1 consists of aphyric basalt with a homogeneous composition, accompanied by large-scale eruptions, such as in Y_4 (A.D. 1421?). Group 2 comprises aphyric differentiated rocks with a heterogeneous composition, accompanied by medium-scale eruptions, such as that in 1986; this group erupted only around the summit area. The differentiated Group 2 magma was supplied by a shallow sub-magma reservoir around the central area of Izu-Oshima volcano, while Group 1 magma might have been supplied by a dike from the main reservoir or conduit. Group 3 comprises plagioclase phyric alumina-rich rocks **(Figs. 10, 11)**.

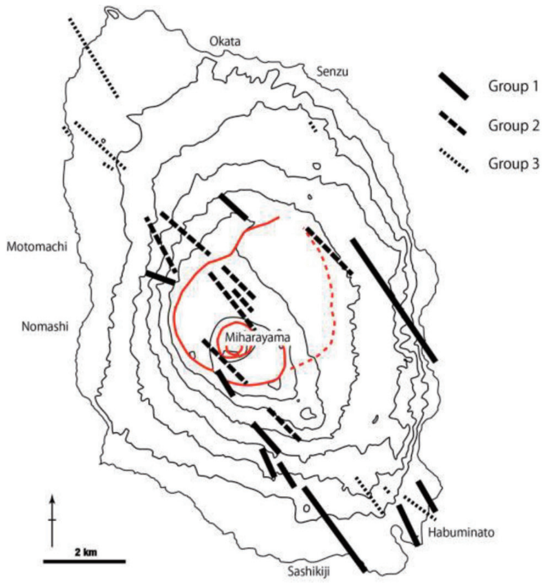


Figure 10. Distribution map of the flank eruption types (after Hayashi and Tsukui, 2005).

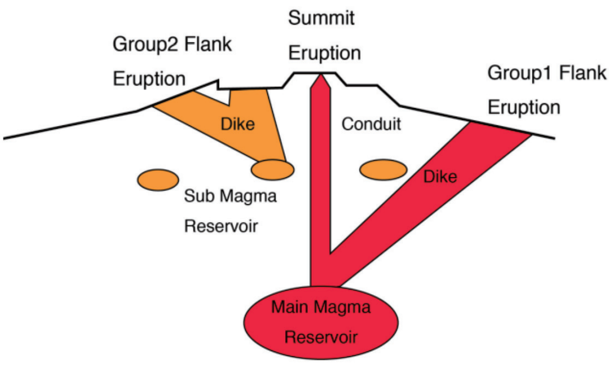


Figure 11. Model of the magma plumbing system of the summit and flank eruptions of Izu-Oshima volcano (after Hayashi and Tsukui, 2005).

3. Niijima volcano

3.1 Overview

Niijima is a volcanic island extending 11.5km long and 3km wide **(Figs. 12 and 13)**. The major volcanic edifices of Niijima are thick lava flows and lava domes, some of which are surrounded by eroded remnants of pyroclastic cones, arranged from south to north. The degree of dissection increases toward the southern mountain except for Mt. Mukaiyama. The topography of each lava flow typically shows a table-like shape with a rugged surface and steep sides. The surface of Mts. Niijimayama, Minejiyama, and Akazakinomine is slightly tilted toward the west, while Miyatsukayama and Atchiyama have a flat and nearly horizontal surface.

In the northern part of Niijima island, four small pyroclastic cones are recognized on the lowland between Mts. Niijimayama and Miyatsukayama.

Mukaiyama lava sits in the Omine pyroclastic cone and extends toward west; thus, only the eastern side of the cone is preserved (Fig. 14).

Judging from the small-scale morphological patterns, the Mukaiyama lava flow has several lobes, which might have been effused from a different eruptive center. Mt. Tangoyama, the highest part of Mukaiyama, might be the spine of one of these lobes.

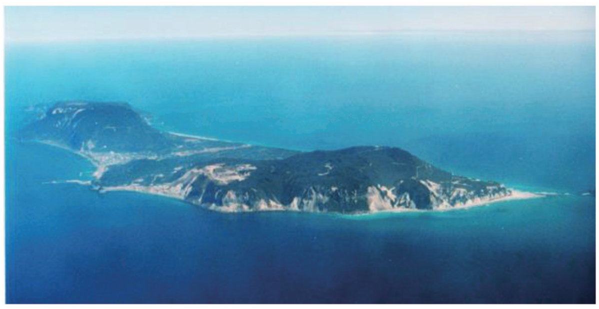


Figure 12. Aerial photograph of Niijima island viewed from the southwest.

3.2 Eruption history of Niijima volcano

The activity of Niijima started in the late Pleistocene (ca. 100ka). At least 19 monogenetic edifices have been identified on this volcano **(Fig. 14)**. Niijima does not have a stable central conduit system through which magma ascends repeatedly, but each volcanic edifice was fed by a new conduit system. Generally, an eruption starts with an explosive ejection of rhyolitic pyroclastics, followed by the effusion of thick lava flows or lava domes (Isshiki, 1987).

The pyroclastic layers on the lava domes reveal the stratigraphic relationship of each edifice **(Fig. 15)**. Based on tephro-chronological studies, the average recurrence period is estimated to be a couple of thousand years, with some exceptions, such as two eruptions that occurred within 50 years in the 9th century (Tsukui et al., 2006). Yoshida (1992) reported two widespread tephras, K-Ah (ca. 7.3ka from Kikai caldera) and AT (ca. 27ka from Aira caldera), as chronological indicators of the stratigraphic sequence of Niijima volcano. The eruption ages were determined as follows: Mukaiyama eruption, 1.1ka (A.D. 886); Atchiyama eruption, 1.1ka (9^{th} century); basaltic Wakago eruption, 3ka; Niijimayama eruption, 5.5ka; Hanshima eruption, 7ka; Shikinejima eruption, 10ka; Miyatsukayma eruption, 14ka; Akazakinomine eruption, 17ka; and so on **(Fig. 15)**. The average production rate of Niijima volcano is estimated to be 0.08×10^{12}kg/kyr **(Fig. 16)**.

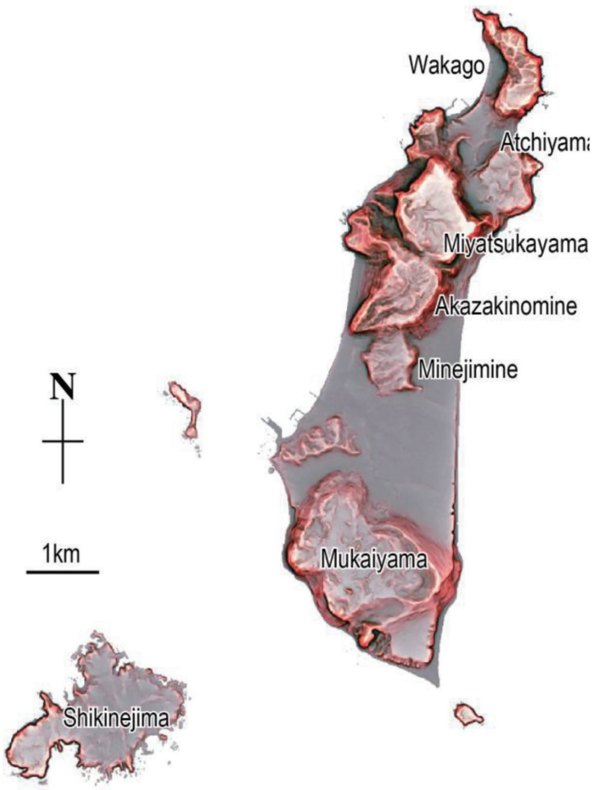


Figure 13. Topography of Niijima and an adjacent island (Red Relief Image Map; Asia Air Survey Co. Ltd. Japanese Patent No. 3670274).

Two eruptions in the 9^{th} century

Kudamaki-Atchiyama eruption: The Kudamaki- Atchiyama eruption occurred sometime between A.D. 838 and A.D. 886 (Yoshida, 1996; Tsukui et al., 2006). The pyroclastic products and lava dome of this series of eruptions are intercalated with exotic Tenjosan tephra (A.D. 838) from Kozushima volcano and Mukaiyama tephra (A.D. 886) from Niijima volcano **(Fig. 18)**. Although we have no detailed record of the Kudamaki-Atchiyama eruption, Tsukui et al. (2006) suggested the possibility that the eruption was responsible for the ashfall event in Boso peninsula and the thunderous sounds heard at Kyoto in A.D. 856-857, which appears in old documents.

The Kudamaki-Atchiyama eruption occurred in the northern part of Niijima island and is divided into an earlier basaltic "(a) Kudamaki eruption" and a rhyolitic "(b) Atchiyama eruption". These eruptions occurred within a geologically short period because the two tephras are in almost direct contact.

(a) Kudamaki eruption: Explosion breccia and fine ash (KdB) were ejected by a phreato-magmatic eruption, and the Kudamaki craters were formed **(Fig. 18a)**. The explosion breccia was distributed near the craters and characteristically consisted of a basaltic cauliflower-shaped bomb and basaltic fragments, with a small amount of porous rhyolite and rhyolitic fragments. A fine ash layer, mainly composed of poorly porous basaltic scoria, becomes thinner southward on the Miyatsukayama and Akazakinomine lava domes with increasing distance from the Kudamaki craters. The estimated volume of this eruption is $0.003km^3$.

(b) Atchiyama eruption: A phreato-magmatic to magmatic eruption formed a pyroclastic cone and an ash layer (AtP). Subsequently, viscous lava (AtL) flowed into low topographies **(Fig. 18b)**. An ash layer consisting of rhyolitic pumice and free crystals becomes thinner toward the south on the Miyatsukayama and Akazakinomine lava domes, similarly to the KdB. AtL, which characteristically includes a large amount of mafic enclave, flowed into one of the Kudamaki craters. The volumes of AtP and AtL are approximately $0.01km^3$ and $0.12km^3$.

Mukaiyama eruption: Mukaiyama is the youngest volcanic body in Niijima. The activity of this eruption started beneath the shallow

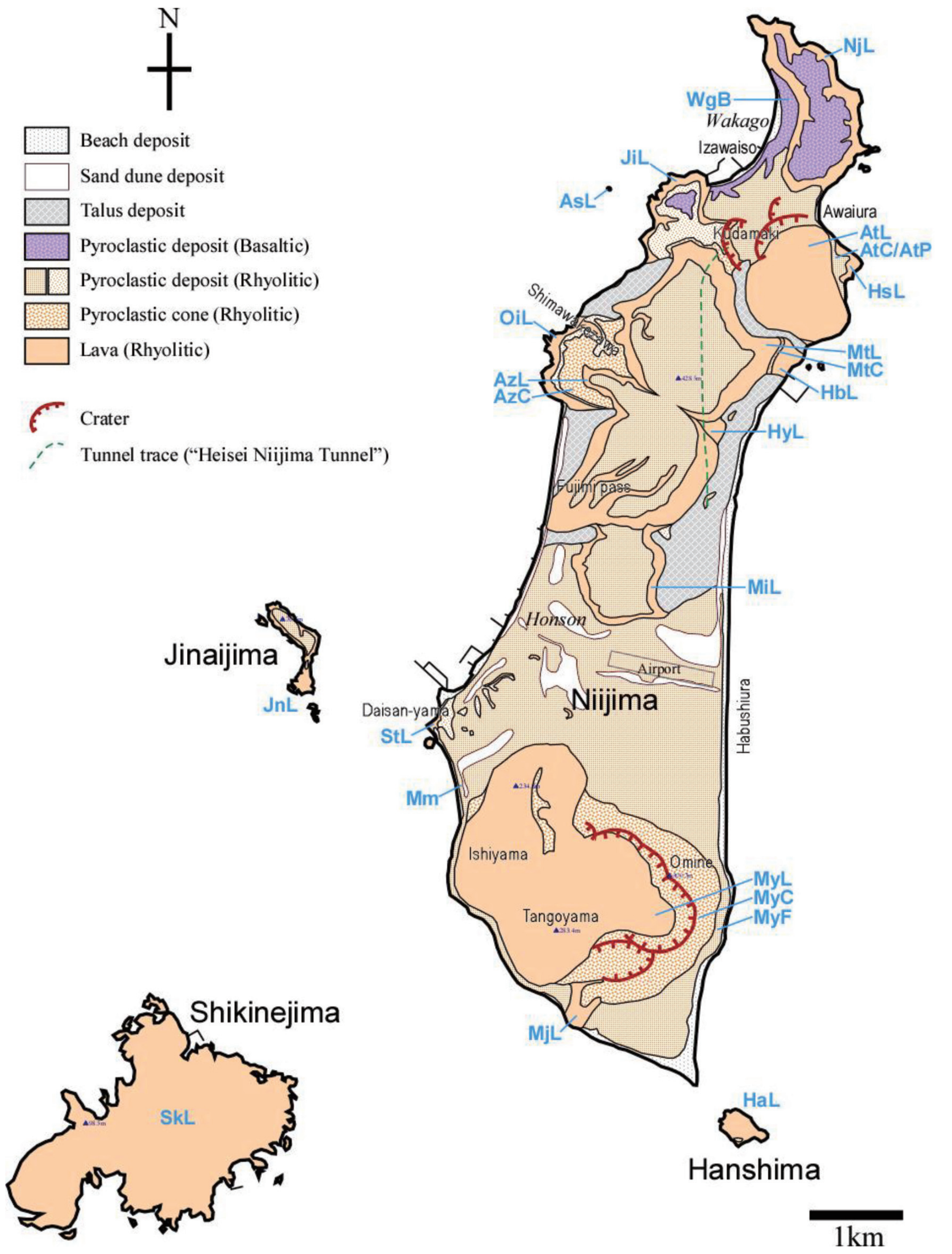


Figure 14. Geological map of Niijima Volcano (after Isshiki, 1987; Isobe, 1996; Isobe & Itoh, 2003).
As, Asane; At, Atchiyama; Az, Akazakinomine; Ha, Hanshima; Hb, Habushiiso; Hs, Hatashirobana; Hy, Hinokiyama; Ji, Jinakayama; Jn, Jinaijima; Mi, Minejiyama; Mj, Marujimamine; Mm, Mamashitaura; Mt, Miyatsukayama; Mu, Mamashitaura; My, Mukaiyama; Nj, Niijimayama; Oi, Oiso; Sk, Shikinejima; St, Setoyama; Wg, Wakago.
L, lava; C: pyroclastic cone deposit; P, pyroclastic deposit; F, pyroclastic flow deposit; B, basaltic breccia.

seawater environment on June 29, 886 A.D. and some witness is recorded briefly in old documents.

Several tens of pyroclastic flow layers and ash cloud surge layers were formed by phreato-magmatic activity. The most explosive

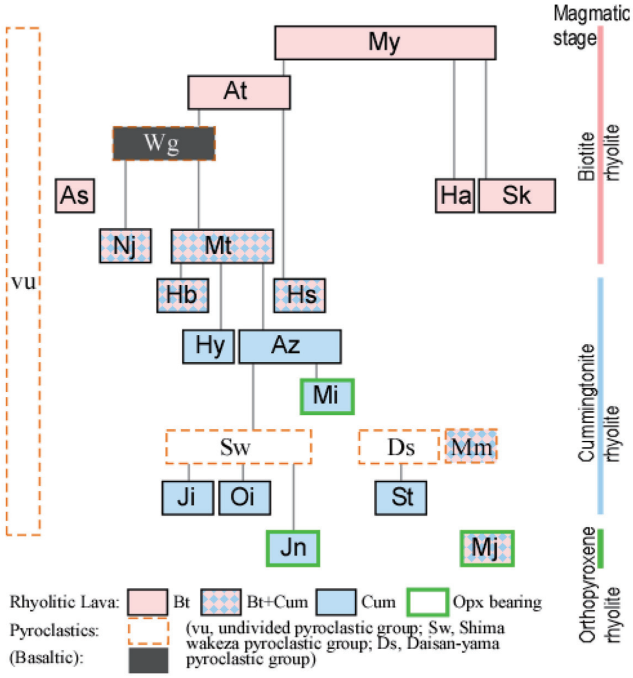


Figure 15. Stratigraphic relation of each volcanic edifice and magmatic stage of Niijima Volcano. Symbol for each edifice is shown in Fig. 14.

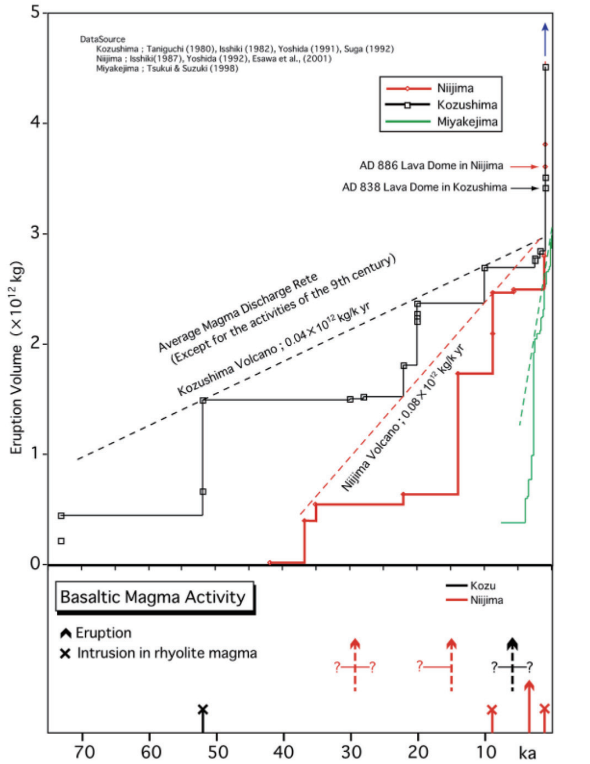


Figure 16. Cumulative volume for estimated erupted volume for Niijima, Kozushima and Miyakejima volcanoes.

eruption occurred at about daybreak on July 1, 886 A.D. Dispersed fallout tephra covered Boso peninsula, about 100km north of the crater. Then, a vent was opened through the pyroclastic deposit, and the eruption shifted to a base surge. This series of violent explosions continued for at least three days in the earliest stage of the activity. Then, magmatic explosions became dominant, and at least five pyroclastic cones were formed.

Finally, viscous lavas extruded from several vents to form the Mukaiyama lava dome **(Fig. 19)**, the second largest eruptive unit in Mukaiyama volcano. A government officer witnessed the pyroclastic cones and the eruption of juvenile fragments in 887 A.D.; this explosion occurred at another part of the cones. The explosive activities happened during the period of

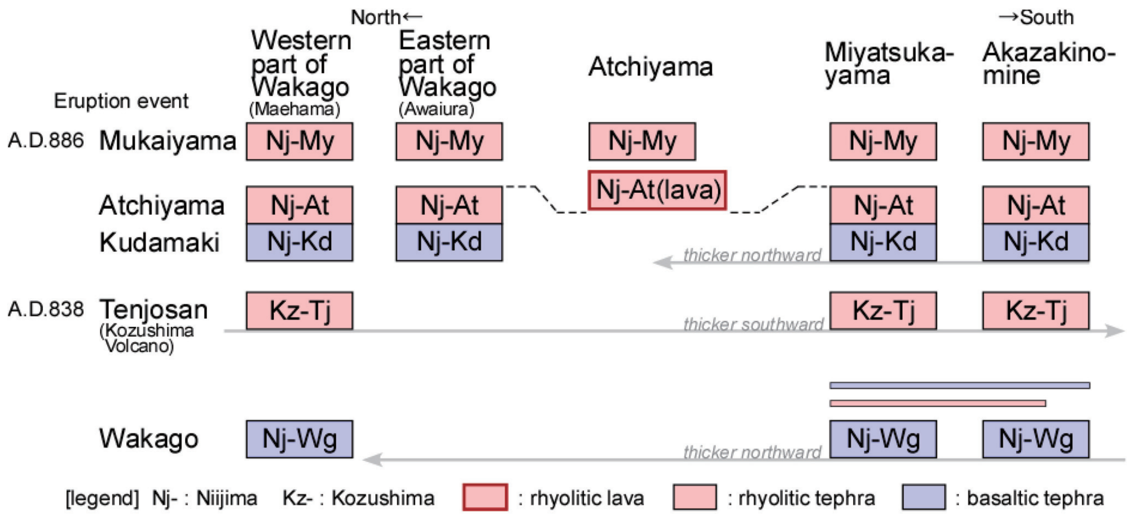


Figure 17. Tephrostratigraphy from Wakago eruption to Mukaiyama eruption

lava flow effusion. Small-scale explosions opened two craters on a surface of lava flow, forming small-scale pyroclastic flow deposit and fallout tephra layers.

These explosions were the concluding phase of the activity. The total volume of erupted material was estimated at 1.4km^3. The total eruptive period was at least one year, but half of the erupted material was ejected during the first three days.

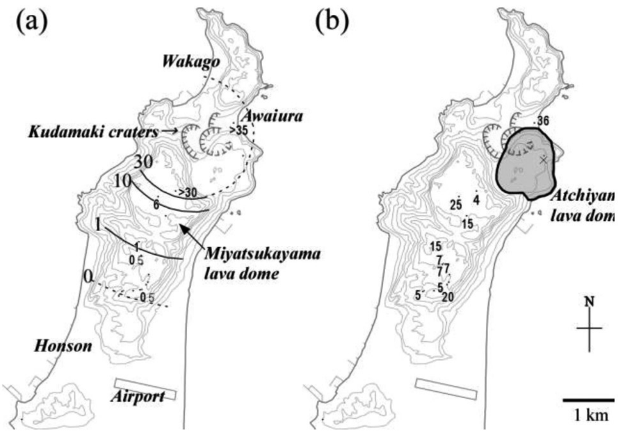


Figure 18. Map showing the thickness of (a) the Kudamaki tephra and (b) the Atchiyama tephra (in cm) (after Tsukui et al., 2006).

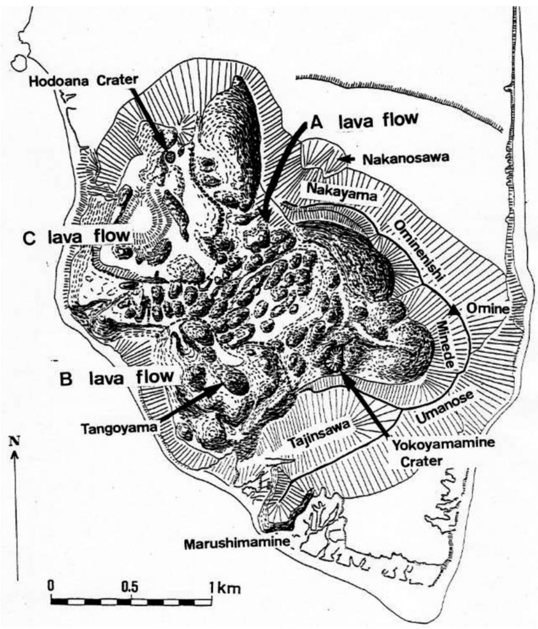


Figure 19. Landform classification map of Mukaiyama volcano (Itoh, 1993)

3.3 Volcanic products on Niijima Island

Niijima island consists of fifteen monogenetic volcanoes **(Fig. 14)**. Figure 15 presents a summary of its volcanic stratigraphy. The rocks of each volcano are petrographically distinct from each other. Based on the hydrous mafic phenocryst assemblage and bulk chemical compositions, the felsic volcanic rocks of Niijima island are divided into three groups (Isshiki, 1987). These groups are, from oldest to youngest: hypersthene-cummingtonite hornblende rhyolite, cummingtonite rhyolite, and biotite rhyolite. These types cannot be derived from each other through fractional crystallization (Yoshiki et al., 2006; Matsui et al., 2009).

Despite its small amount in the rocks, basaltic (and andesitic) magma played an important role alongside rhyolitic magma. Olivine-pyroxene basalt magma was erupted during the youngest stage of the biotite rhyolite group. Miner andesite is formed by magma-mixing of rhyolite and basalt (Koyaguchi, 1986).

(1) Hypersthene-cummingtonite hornblende rhyolite group

Jinaijima, Marujimamine, and Minejiyama volcanoes belong to this group. Pyroclastic ejecta erupted from these volcanoes are not found, while ash and soil layers cover the Minejiyama lava flow. A buried charcoal was dated at 11,970+-30 yBP (Isshiki, 1987), 20,690+-320 yBP (Itoh, 1993), and 35,810+-630 BP (Itoh and Isobe, 2007).

(2) Cummingtonite rhyolite group

Oiso, Jinakayama, Setoyama, Akazakinomine, Habushiiso, Hatashirobana, and Mamashitaura volcanoes, and Daisan-yama and Simawakezawa pyroclastic deposits belong to this group. The Daisan-yama and Simawakezawa pyroclastic deposits consist of fallout tephra and base surge deposits. The eruptive center of these two deposits could not be determined. Seven other volcanoes are lava domes.

(3) Biotite rhyolite group

This volcanic group is characterized by bimodal volcanic activities. Miyatsukayama, Niijimayama, Atchiyama, and Mukaiyama volcanoes were constructed by felsic volcanism Miyatsukayama and Atchiyama lavas has basaltic inclusions, while Miyatsukayama and Mukaiyama lavas have andesitic to dacitic inclusions. Wakago volcano was constructed by basaltic volcanism during the stage of the biotite rhyolite group.

(4) Basic rock group

The only basaltic eruption occurred in Wakago, the northern part of the island, two thousand years ago (Sugihara et al., 1967; Kawasaki, 1984; Kaneko, 1984). Wakago volcano consists of olivine-pyroxene basalt. Because of its low-viscosity magma, a lava dome was not formed; instead, base surge deposits piled up on the northern part of the island. The location of the eruptive vent is assumed to be at the central part of Izawa Bay, on the western side of Mt. Niijimayama.

Another occurrence of basaltic (to dacitic) magma is evidenced by dark inclusions in rhyolitic magma. In this case, the irregular boundary between the two deposits suggests that magma-mixing had taken place.

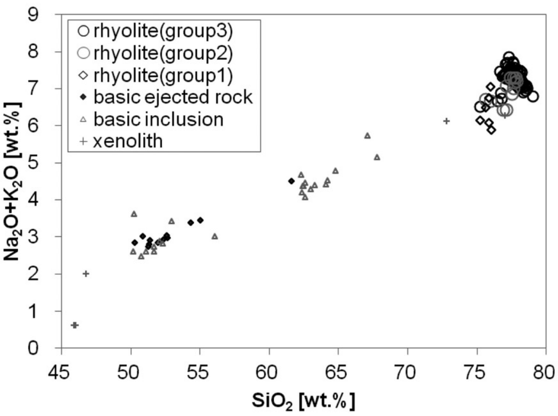


Figure 20 . Harker diagram of products in Niijima volcano (after Kuno, 1960; Koyaguchi, 1986; Isshiki, 1987; Itoh & Aramaki, 1992; Saito, umpub.). Rhyolite groups(1-3).

4. Monitoring Systems and Recent Activity of Izu-Oshima and Niijima Volcanoes

4.1. Monitoring systems and measures for disaster mitigation

The Oshima Weather Station of the Japan Meteorological Agency (JMA) started continuous monitoring of the volcanic activity of Izu-Oshima volcano in 1938. At present, the JMA, the Earthquake Research Institute (ERI) of the University of Tokyo, the National Research Institute for Earth Science and Disaster Prevention (NIED), the Geospatial Information Authority of Japan (GSI), and the Japan Coast Guard (JCG) are also continuously monitoring the volcanic activity by using various equipment throughout the island, as shown in **Fig. 21a** and b.

The JMA, the GSI, the NIED, the Nagoya University, and the Tokyo Metropolitan Government conduct continuous monitoring of the activity of Niijima volcano, as shown in **Fig. 22**. The data are telemetered to each institute and partly to the headquarters of the JMA. The JMA conducts monitoring around the clock and has a Mobile Observation Team that periodically collects basic observational data on the volcanoes (e.g., through GPS, geothermal, SO_2 surveys, and others). When abnormal phenomena are observed, the JMA issues Warnings/Forecasts to the disaster prevention authorities and to the public so that relevant disaster mitigation measures can be initiated and undertaken. Moreover, JMA issues Volcanic Alert Levels, which are classified into five levels in terms of the target area and action to be taken in Volcanic Warnings/Forecasts. For Izu-Oshima volcano, JMA started application of the Volcanic Alert Levels in December 2007. As of March 2013, the Volcanic Alert Levels for Izu-Oshima is 1 ("Normal"). The local governments of Oshima town, and Niijima village have the responsibility to take measures for mitigation of volcanic disaster. Oshima town published a volcano hazard map in 1994 and revised the regional disaster prevention plan for a volcano crisis in 2008. On November 21, 2006, the 20th year anniversary of the 1986 evacuation, Oshima town and the Tokyo Metropolitan Government conducted a disaster mitigation training, in which 4,000 people from the island and the disaster prevention authorities took part.

4.2. Recent activity of Izu-Oshima and Niijima volcanoes

Since 1989, Izu-Oshima volcano has continued its reinflation, indicating a quasi-continuous magma supply to the reservoir at a depth of 5-9 km from the depths, and has repeatedly undergone deflation-inflation cycles, resulting in net inflation of the volcano. Tomographic studies on the subterranean structure have delineated a low-velocity zone and a melt batch in the same location beneath the caldera as that of the inflation source (Mikada et al., 1997). The rate of secular inflation decreased exponentially until 2006, while the amplitude of the deflation-inflation cycles increased.

1:50,000 Scale Topographic Map (Oshima) published by the Geospatial Information Authority of Japan

Legend

(JMA)
seismometer(SP)
GPS
tiltmeter
strainmeter
EDM
infrasonic microphone
seismometer(SP)
(For earthquakes and tsunamis)

(GSI)
GPS

(JHOD)
GPS

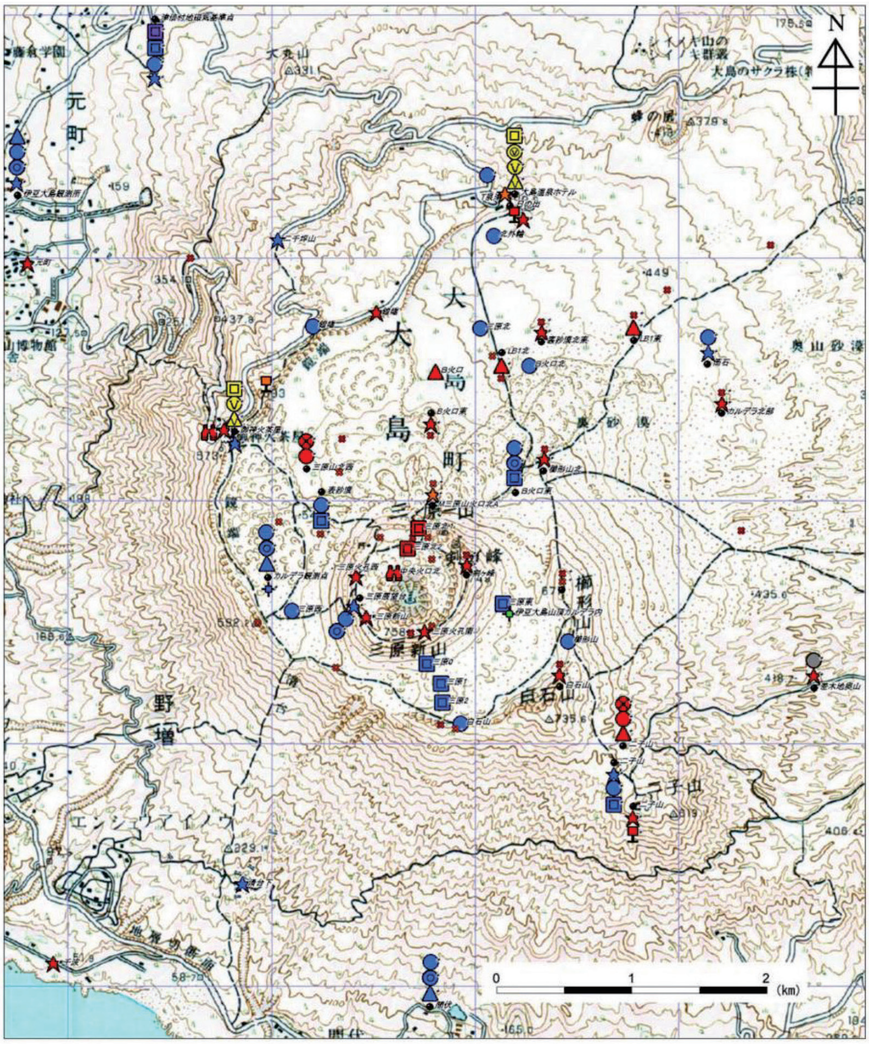
(NIED)
V-net(SP)
V-net(broadband)
V-net(tiltmeter)
Hi-net
Hi-net(tiltmeter)
K-NET
vector magnetometer

(ERI)
seismometer(SP)
seismometer (broadband)
GPS
tiltmeter
scalar magnetometer
vector magnetometer

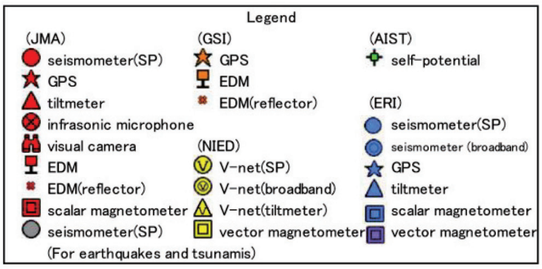
Figure 21a. Network for continuous monitoring in Izu-Oshima as of June 2012 (Japan Meteorological Agency, 2013)

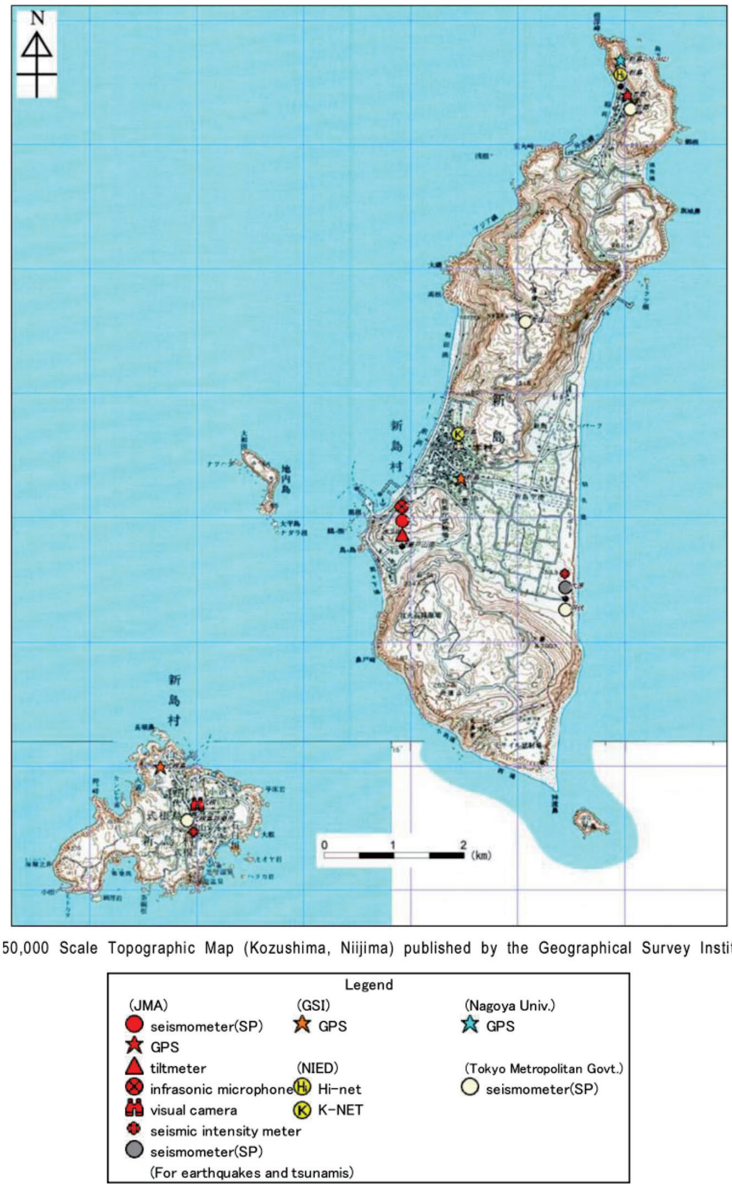
The rate of secular inflation since 2007 has remained constant and has also increased the activity of deep, low-frequency (LF) earthquakes occurring at a depth of 30-40 km beneath the volcano. Each episodic, deep LF earthquake activity was preceded by volcanic deflation and accompanied by inflation. Based on this evidence, we may suppose that the supply of magma from a source region 30-40 km beneath the volcano causes the volcanic inflation and that episodic outgassing from the shallow magma reservoir triggers each deflation-inflation cycle (Watanabe, 2012).

In these years the activity of Niijima volcano has been calm except that tectonic earthquakes sometimes occur in the sea area around the volcano.



1:50,000 Scale Topographic Map (Oshima) published by the Geospatial Information Authority of Japan





50,000 Scale Topographic Map (Kozushima, Niijima) published by the Geographical Survey Institute

Figure 22. Network for continuous monitoring in Niijima as of June 2012 (Japan Meteorological Agency, 2013).

Description of stops

Oshima

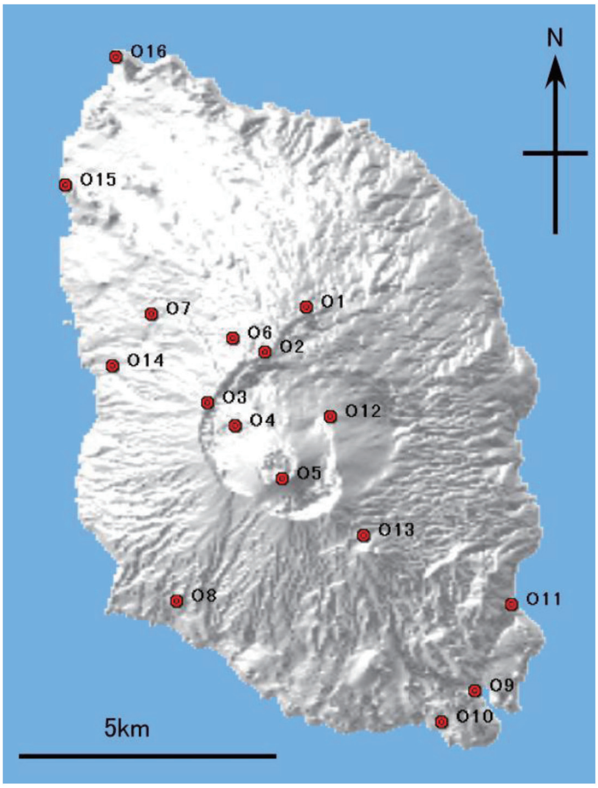


Figure 23. Stop Points in Oshima.

Stop O1: The Oshima onsen hotel view of the caldera and fallout deposits of the Younger Oshima group

We will see the summit caldera and central cone, Miharayama, as well as several lava flows, such as the 1986 "B lava flows" (LB-I, -II, -III). In the parking lot, the tephra sequence of the Younger Oshima group can be seen. The thin, white rhyolite ash layer, belonging to the N_3 unit of the Younger Oshima group, consists of exotic rhyolite ash erupted from the southwestern Kozushima volcano in the 9th century.

Stop O2: View of the caldera from the northern caldera rim

We will see another view of the caldera, Miharayama, "B fissure," and the lava flows fed from this fissure in 1986.

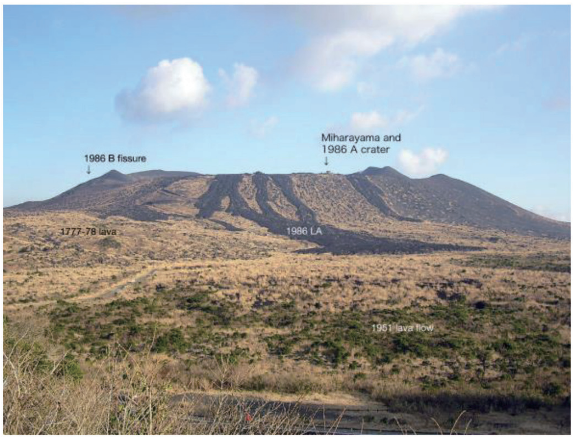


Photo 1. View of the Miharayama from Stop O3,, mound of 1777-78 (Y1) lava, 1951 lava flow and 1986 "A lava flow".

Stop O3: Gojinka-jaya

Gojinka-jaya is a lookout on the NW rim of the caldera of Izu-Oshima volcano. Miharayama, the central cone, lies just in front of us beyond the caldera floor, and the 1950-51 and 1986 lava flows from the Miharayama summit crater can be seen. The ridge to the left of the cone is the

Photo 2. View of the Miharayama pit crater from Stop O5.

spatter rampart along the "B fissure" of the 1986 eruption. The low hummocky mounds in the foreground of the "B fissure" are the vent areas of the 1777-1778 lava flows.

Stop O4: 1986 "A lava flow" and Miharayama cone

Along the new trail up to the Miharayama, we will see driblets from the cone-forming eruption in 1777-1778. At a sharp bend in the trail, we will see the succession of erupted materials after 1778. The driblets are covered by surge deposits, which in turn are covered by thin layers of scoria and Pele's hair, the earliest ejecta of the 1986 eruption. This covering layer is then overlain by 1986 "A lava flow" and 1986 "B scoria."

Stop O5: View of the pit crater of Miharayama

The trail ends at a viewing site near the pit crater of Miharayama. The pit is about 350 m in diameter and about 100-150 m in depth. A same-sized pit that existed before the 1986 eruption had filled up with lava from the 1986 "A crater" and formed a lava lake. On November 16, 1987, a large explosion took place, causing rapid withdrawal of magma back into the conduit, which regenerated the pit crater.

Stop O6: 1986 "C fissure"

At 17:45 hours of November 21, 1986, an eruption fissure propagated from inside the caldera to the outer slope of Izu-Oshima volcano. Eleven vents successively opened within an hour as the NE-SW-trending fissure propagated. A lava flow fed from the "C3-C6 craters" poured down along the valley toward the town of Motomachi, the largest town in Izu-Oshima.

Stop O7: 1986 "C lava flow"

A few hours after the opening of the "C fissure" on November 21, 1986, the lava flow reached the entrance to the inhabited area. Water-cooling operations were undertaken to stop the lava flow from reaching the houses. We will walk on the surface of the lava flow and see a tree mold on the road across the lava.

Stop O8: "The Great Road Outcrop" of the fallout deposits of Izu-Oshima volcano

We will see a spectacular exposure of the multiple alternations of airfall scoria and ash intercalated by weathered ash, as well as several lava flows between the fallout deposits **(Photo 3)**. Each sequence of scoria, ash, and weathered ash corresponds to one eruptive event. The thick scoria deposit (O_{95}) fell about 20,000 years ago. There are some unconformities where the upper strata obliquely truncate the lower strata. At the uppermost level of the outcrop, we will see the S_2 flow deposit and bomb sag generated by the large phreatic eruption that occurred at the summit about 1,700 years ago.

Photo 3. The Great Road Outcrop (Chiso Dai-setsudan-men in Japanese) of the fall deposit of the Izu Oshima volcano.

Stop O9: Habu-minato crater

Habu-minato crater is an explosion crater 400 m in diameter, with explosion breccia and surge deposit distributed around it. The breccia belongs to the N_3 unit of the Younger Oshima group and intercalates adventitiously with white rhyolite ash erupted from southwestern rhyolite volcanoes in the 9th century. In 1703, a large tsunami broke the southern rim of Habu-minato crater and connected it to the sea. After that, residents have been used as a fishing port by dredging the waterway.

Stop O10: Toushiki

Flank eruption occurred in the southeastern part of the island in Y_4 (A.D. 1421?). The fissure reached the seashore, and a phreato-magmatic eruption occurred. The explosion breccia of that time has been exposed to the cliff and contains large amounts of quenched scoria. From a distance, we will see the feeder dike of the fissure eruption at the sea cliff.

Stop O11: Fudeshima

Izu-Oshima volcano overlies three older dissected volcanoes. We will see one of them, Fudeshima volcano, on the sea cliff **(Photo 4)**.

Many dikes cut the layered lava flows and pyroclastic deposits. Fudeshima, an isolated candle-like rock is made of pyroclastic vent breccia.

Photo 4. View of Fudeshima Island from Stop O11. Dyke intrusions are exposed on the cliff along the coast.

Stop O12: Okuyama Sabaku (desert)

An area with poor vegetation called *Okuyama sabaku* spreads to the east of Miharayama. Strong winds, fall deposits, and volcanic gases prevent plant growth in this location; in addition, the surface of the *sabaku* is covered by 1986 scoria. This area is in the older eastern caldera, the rim of which is almost buried by later volcanic materials.

Stop O13: Futagoyama Monitoring Station

The JMA (Japan Meteorological Agency) and the ERI (Earthquake Research Institute, University of Tokyo) have installed a seismometer, a GPS, a tiltmeter, and other monitoring equipment at Futagoyama station.

Stop O14: Izu-Oshima Museum of Volcanoes

The Izu-Oshima Museum of Volcanoes opened in 1990 provides details on the 1986 eruption and the growth history of Izu-Oshima volcano, as well as extensive information about volcanoes in general.

Stop O15: Akappage

Akappage, which literally means "red baldness," is a flank volcano of the Older Oshima group formed about 2,000 years ago. We will observe a section of oxidized agglutinate.

Stop O16: Nota-hama

Nota hama is a famous diving spot for tourists. Izu peninsula and Mt. Fuji are visible on the opposite shore. We can see Omuroyama volcano in Izu peninsula, which belongs to the Higashi Izu Monogenetic Volcano group. On the sea bottom between Izu-Oshima and Izu peninsula, submarine volcanoes belonging to the Izu-Oshima and the Higashi Izu Monogenetic Volcano group overlap. On a hill on the northern side of the beach are outcrops of Okata volcano, one of the basement volcanoes of Izu-Oshima.

Niijima

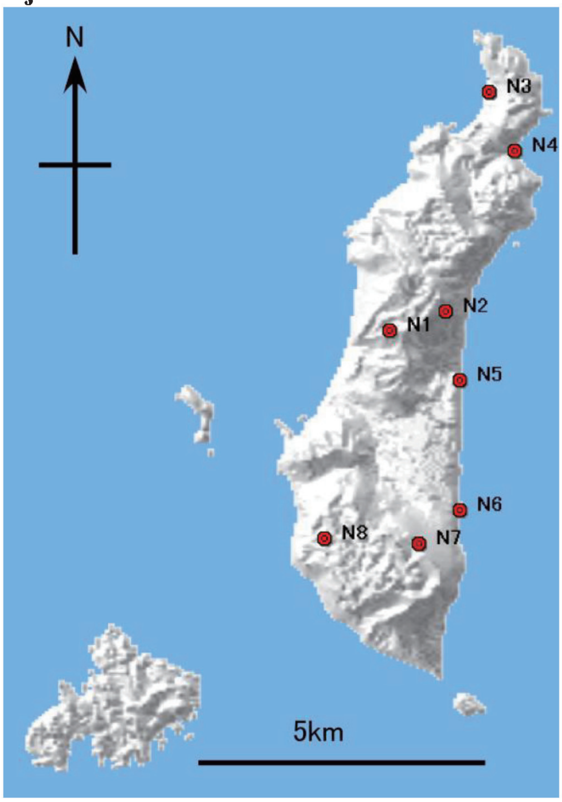


Figure 24. Stop Points in Niijima

Stop N1:Fujimi Pass

Topographical overview of southern Niijima island and adjacent island volcanoes

Niijima volcano consists of a number of viscous rhyolitic lava domes that form plateau-like features and pyroclastic deposits that spread on lowlands. We can see topography of the southern part of Niijima island from this viewing point. The front tabular edifice consists of Mukaiyama lava extruded from an Omine pyroclastic cone, the western part of which was destroyed as the lava expanded toward the southwest. The flat plane in front of the

Photo 5. View of the southern part of Niijima Island from Stop N1.

Mukaiyama lava and Omine cone consists of the Habushiura pyroclastic flow and surge deposit. All these units were erupted in the latest eruption of Mukaiyama in A.D. 886 **(Photo 5)**.

On a fine day, we can enjoy from this spot fantastic views of volcanoes; Kozushima, Miyakejima, and Mikurajima islands; volcanoes on Izu peninsula; and Hakone and Fuji volcanoes.

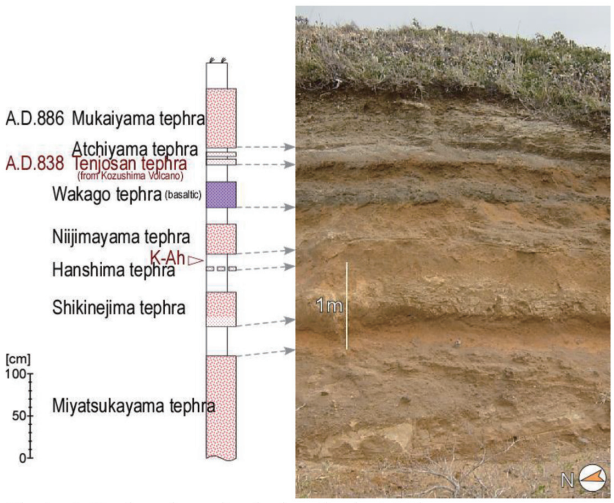


Photo 6. Tephra deposits during the last 17kyr on Akazakinomine lava. Tehpra names are based on Yoshida (1992).

Tephra layers during the last 17kyr

Several tephra layers from the last ca. 17kyr are exposed along the road cut on the Akazakinomine lava dome **(Photo 6)**. The pyroclastic flow deposit in the lowermost horizon at this point was erupted from Miyatsukayama and is correlated to the O_{55} member on Izu-Oshima volcano (at Stop O8). Bubble wall-type volcanic glass can be detected from the weathered ash layer below the Niijimayama tephra, which is correlated to the K-Ah tephra erupted at 7.3ka from Kikai caldera to the south of Kyushu. The dark-gray basaltic tephra is Wakago tephra, which includes accretionary lapilli. The rhyolitic ash layer below the Mukaiyama tephra is Tenjosan tephra from the A.D. 838 Kozushima eruption. This tephra can be observed at Stop O1 on Izu-Oshima.The uppermost pumice layer of this outcrop is the middle to distal facies of the Habushiura pyroclastic flow and surge deposit. The ^{14}C age of this layer (1,120+-75yBP; Isshiki, 1973) supports the correlation of this eruption to the A.D. 886 event recorded in historical documents.

Stop N2: Heisei Niijima Tunnel

A swarm of earthquakes accompanied by lateral magma intrusion in the A.D. 2000 eruption of Miyakejima volcano shook the Niijima and Kozushima areas. The M6.3 earthquake occurred near Niijima island on July 15, 2000 (Japan Meteorological Agency, 2006), causing the collapse of many cliffs; the debris blocked the main road connecting the central and northern villages. Isobe and Itoh (2003) reported their geological observations along the newly excavated, 2.9km-long Heisei Niijima Tunnel. According to their report, a new volcanic edifice called “Hinokiyama lava” has been identified,

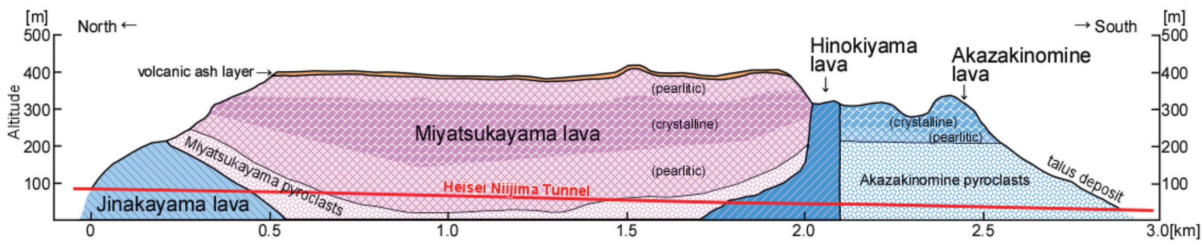


Figure 25. Cross section of the Heisei Niijima Tunnel (after Isobe and Itoh, 2003)

and the Miyatsukayama lava has a thickness of not less than 350 m **(Fig. 25)**.

Stop N3: Wakago area
Basaltic base surge deposits

Niijima volcano mostly consists of rhyolite, but basaltic pyroclastic deposits are distributed in the northern part of Niijima island. At Stop N3 (Izawaiso Bay), a basaltic base surge deposit about 50m in thickness can be seen. This deposit contains some accessory rhyolites, especially in its lower part. On the other hand, juvenile rhyolite glass is rarely included in the basaltic fragment. At this stop, parallel and cross-bedded sedimentary structures can be clearly observed **(Photo 7)**.

Photo 7. An exposure of Wakago basaltic base surge deposit erupted about 3ka along the Wakago coast.

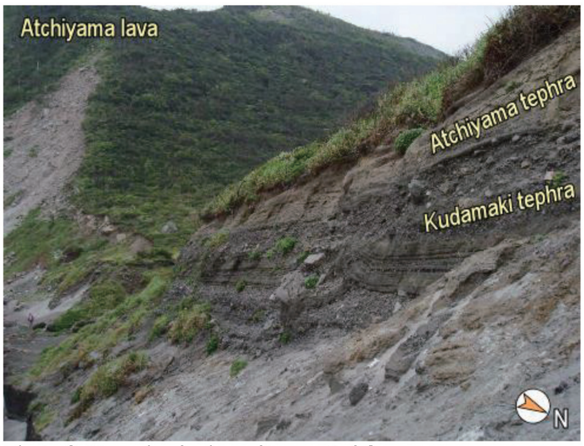


Photo 8. Pyroclastic deposits erupted from Kudamaki-Atchiyama in the 9th century

Stop N4: Awaiura Bay
Pyroclastic deposit and lava block erupted from Kudamaki-Atchiyama in the 9th century

We can observe the depositional sequence of the Kudamaki - Atchiyama eruption in the 9th century **(Photo 8)** from this spot. The lower part of this outcrop is a basalt-dominant pyroclastic deposit ejected in the Kudamaki eruption. The breccia of the Kudamaki eruption characteristically contains a cauliflower-shaped bomb and basaltic fragments that include a small amount of porous rhyolite. A rhyolitic pyroclastic deposit directly overlies Kudamaki breccia originated from the Atchiyama eruption.

We can see two rhyolitic lava domes from here: Niijimayama lava (5.5ka biotite + cummingtonite rhyolite) to the north side of the bay and Atchiyama lava (biotite rhyolite from the last stage of the Kudamaki - Atchiyama eruption in the 9th century) to the south. The Atchiyama lava has a large amount of mafic enclaves **(Photo 9)**.

Photo 9. Rhyolitic Atchiyama lava block including mafic enclaves. The scale bar is 1m.

Stop N5: Northern part of Habushiura coast
Rhyolite block brought by a tsunami?

This biotite rhyolitic lava block called *Meishi* **(Photo 10)** is located about 80m from the Habushiura coastline. This block was not carried from the closest lava domes, Minejiyama and Akazakinomine, which are located not less than 500m away and do not contain biotite phenocrysts. The long axis of this block points NW, obliquely to the coastline, and an imbricate structure can be recognized. A solution hole, characteristically seen in coastal lava blocks, can be observed on the side of the block. The evidence suggests that this lava block was possibly carried by a tsunami (Isobe, 2012).

Photo 10. Rounded lava block possibly brought by a tsunami (Isobe, 2012) and believed to contain the spirit of a deity in Niijima island.

Distal facies of pyroclastic flow deposit from the A.D. 886 Mukaiyama eruption

A 7km-long coastline of Habushiura that lies nearly parallel to the direction of the pyroclastic flow in A.D. 886 can be closely observed from this continuous outcrop **(Photo 11a)**, as we can discuss the lateral variation of the rhyolitic Habushiura pyroclastic flow from a phreato-magmatic eruption. The eruption center of this pyroclastic flow is estimated to be at the south end of Niijima island, about 5.5km south of this stop. The thickness of the pyroclastic deposit at this stop is about 15m.

Stop N6: Southern part of Habushiura coast proximal facies of pyroclastic flow deposit from the A.D. 886 Mukaiyama eruption

This stop is located about 3.5km from the estimated eruption center. The height of the cliff is about 35m, and the single bed is thicker than that at StopN5. We can observe a large pumice layer and a layer with a concentration of lithic basement rock. About 40 flow units can be recognized, and valuable sediment structures **(Photos 11b. 11c)**.

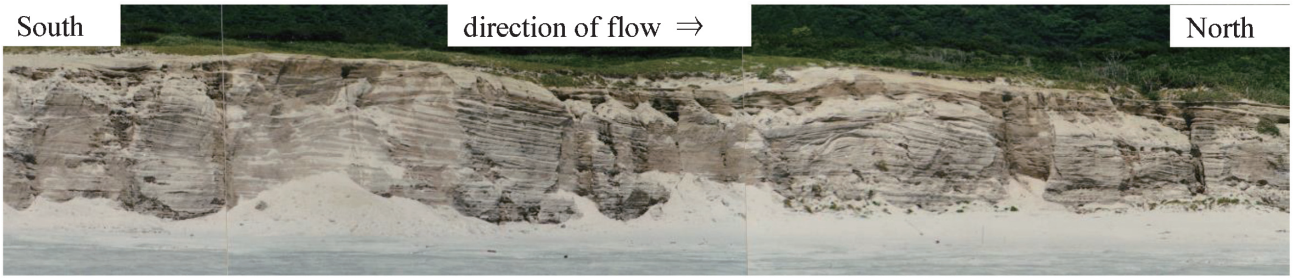
Stop N7: Omine
Pyroclastic cone deposit from the A.D. 886 Mukaiyama eruption

Rhyolitic pyroclastic cones sit on the preceding pyroclastic flow deposit. At this road-cut stop, stratified lithic fragments and ash layers are exposed along the cross section of the cone

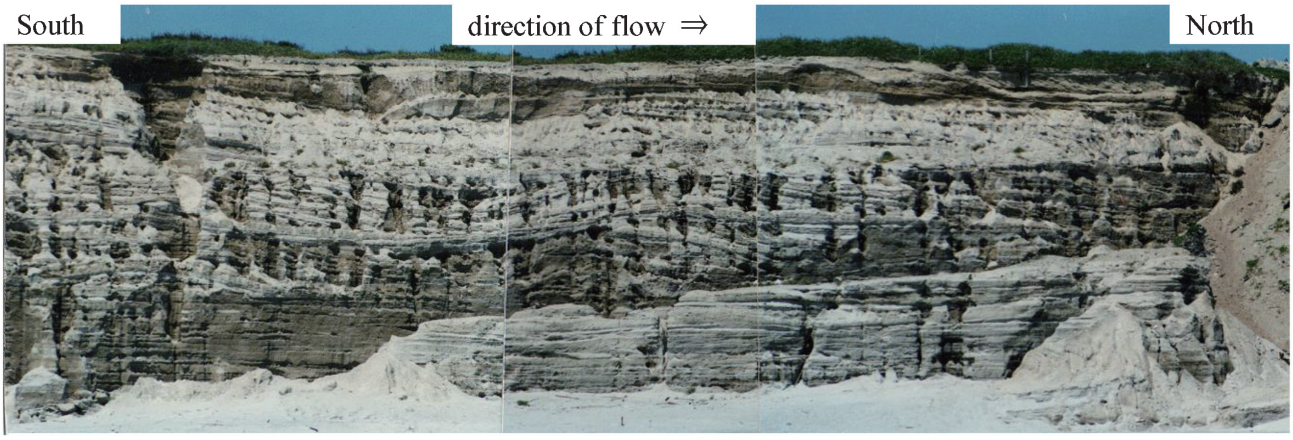
Stop N8: Ishiyama Quarry
Lava flow from the A.D. 886 Mukaiyama eruption

We will walk a short distance on the surface of the Mukaiyama lava dome (biotite rhyolite), the latest product of the A.D. 886 Mukaiyama eruption **(Photo 12)**. Because it is less dense and more fire-resistant, the upper, vesicular-rich part of Mukaiyama lava, called *Koga-seki*, has long been quarried as building material in the village.Mukaiyama lava contains a small amount of dark inclusion of andesitic to dacitic composition. This inclusion was formed by the mixing of rhyolitic magma and basaltic magma in the magma chamber (Koyaguchi, 1986).

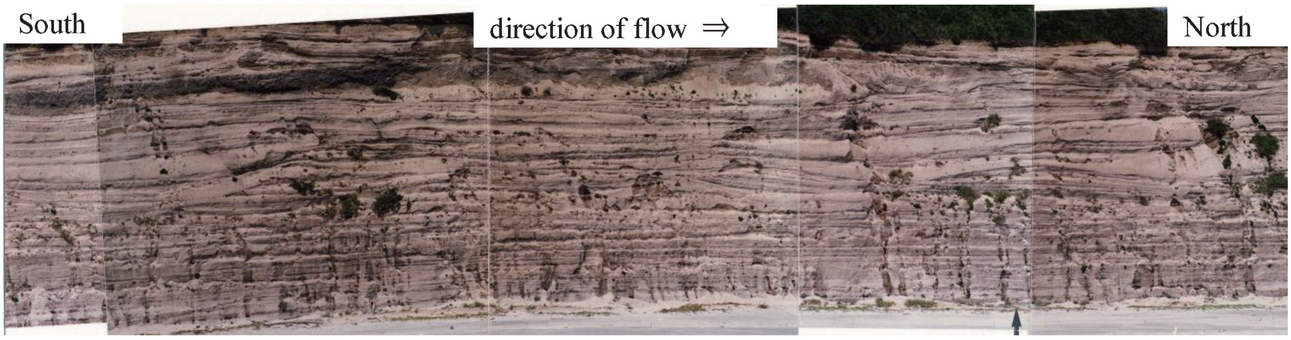
Photo 12. Ishiyama quarry in Mukaiyama lava.



a. Habushiura pyroclastic flow deposit in distal area. Cross laminated structure are developed in distal area. This photograph was taken at about 5km from the estimated eruptive center.

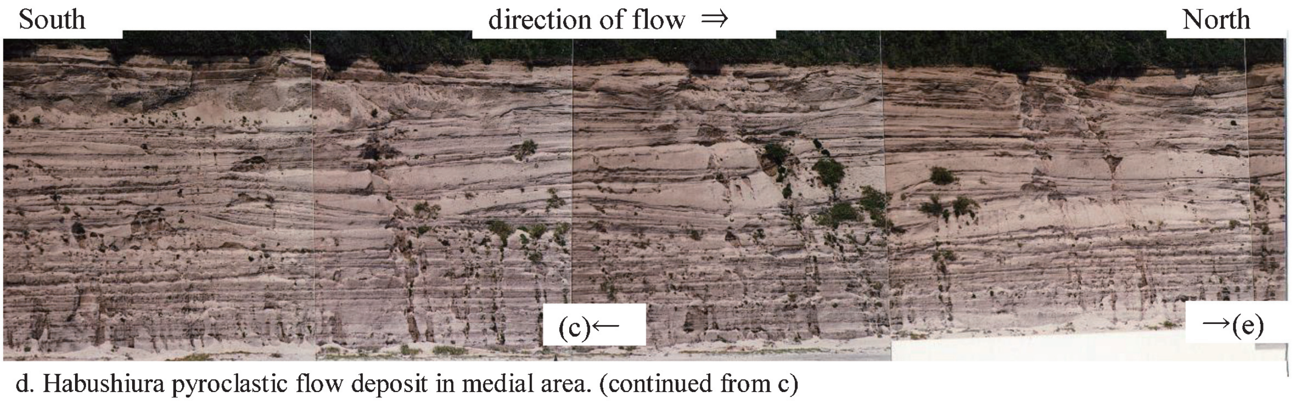


b. Habushiura pyroclastic flow deposit in medial to distal phases. Large-scaled wavy bed form, that is 20 m in wave length, is developed. This photograph was taken at about 4km from the estimated.

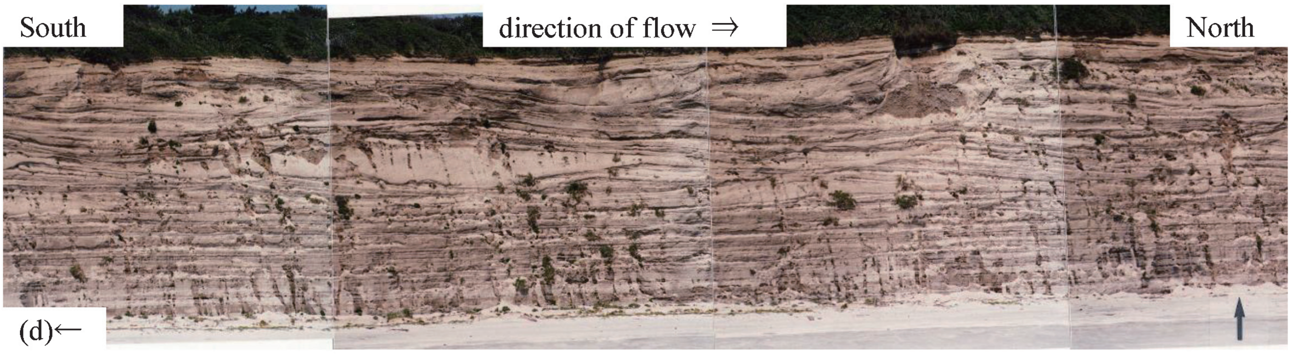


c. Habushiura pyroclastic flow deposit in medial area. Large-scale wavy bed form, that is about 30-40 m in wave length, is developed. The bed forms as "anti-dune structure". This photograph was taken at about 3km from the estimated eruptive.

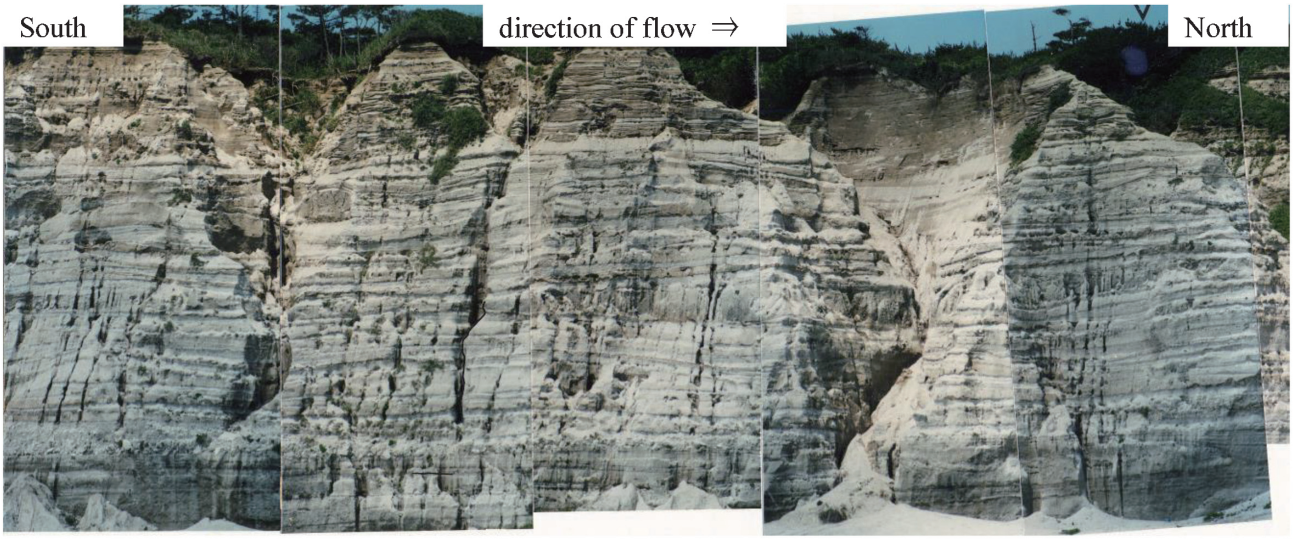
Photo 11. Lateral variation of Habushiura pyroclastic deposit.



d. Habushiura pyroclastic flow deposit in medial area. (continued from c)



e. Habushiura pyroclastic flow deposit in medial area. (continued from d)



f. Habushiura pyroclastic flow deposit (HPFD) in medial to proximal area. The bed form of HPFD is almost flat. HPFD is overlaid by the Mukaiyama base surge deposit. This photograph was taken at about 2km from the estimated eruptive center.

Photo 11. (Continued)

References

Aramaki, S. and Fujii, T. (1988) Petrological and Geological Model of the 1986-1987 Eruption Izu-Oshima Volcano. Bull. Volcanol. Soc. Japan, 33, S297-S306. (in Japanese with English abstract)

Aramaki, S. and Ui, T. (1982) Japan. inAndesites (Thorpe R. S. ed.).259-292. John Wiely& Sons.

Endo, K., Chiba, T., Taniguchi, H., Sumita, M., Tachikawa, S., Miyahara, T., Uno, R. and Miyaji, N. (1988) Tephrochronogical Study on the 1986-1987 Eruptions of Izu-Oshima Volcano, Japan. Bull. Volcanol. Soc. Japan, 33, S32-S51. (in Japanese with English abstract)

Ezawa, T., Taniguchi, H. and Itoh, J. (2001) Hydration Experiment of Obsidian and Hydration-rind Dating of Izu-Niijima Volcano. Abstracts, Japan Earth and Planetary Science Joint Meeting, V0-001.

Fujii, T., Aramaki, S., Kaneko T., Ozawa, K., Kawanabe, Y. and Fukuoka, T. Petrology of the Lavas and Ejecta of the Novenber, 1986 Eruption of Izu-Oshima Volcano. Bull. Volcanol. Soc. Japan, 33, S234-S254. (in Japanese with English abstract)

Hayashi, K. and Tsukui, M. (2005) Analysis of Magmas Erupted from Fissures, Izu-Oshima Volcano (abs.). 2005 Programme and Abstracts Volcanol. Soc. Japan, 41-41. (in Japanese)

Ishizuka, O., Kawanabe, Y., Geshi, N.. Ogitsu, I., Tsujino, T., Nakano, S., Arai, K., Sano, K., Yamamoto, S., Sakamoto, I. and Taylor R.N. (2009) Bathymetric mapping and ROV survey of the submarine part of Izu-Oshima Volcano, Japan(abs.). 2009 Programme and Abstracts Volcanol. Soc. Japan, 46-46. (in Japanese)

Isobe, I. (1996) Geographical Features, “History of Niijima Village”, 1-40. (in Japanese)

Isobe, I. (2012) Introduction and Consideration on Traditions for Tsunami and Gigantic Stone Called “Meishi.” An Annual Bulletin of Niijima Village Museum for Fiscal 2011, 53-68. (in Japanese)

Isobe, I. and Itoh, J. (2003) Report on a Long Tunnel Excavated at Niijima Volcano in the Northern Part of IzuLslands, Central Japan. Chishitsu News, 592, 35-43. (in Japanese)

Isshiki, N. (1973) ^{14}C age of Mukai-yama Volcano of Nii-jima Island, Izu Islands. Bull. Volcanol. Soc. Japan, 18, 169-170. (in Japanese)

Isshiki, N. (1982) Geology of the Kozushima District. Quadrangle Series, Scale 1:50000, Geological Survey of Japan, 75p, 1 sheet. (in Japanese with English abstract)

Isshiki, N. (1984) Geology of the Oshima District. Quadrangle Series, Scale 1:50000, Geological Survey of Japan, 133p, 1 sheet. (in Japanese with English abstract)

Isshiki, N. (1987) Geology of the Nii Jima district. With Geological Sheet Map at 1:50,000, Geol. Surv. Japan, 85p. (in Japanese with English abstract)

Itoh, J. (1993) Process of A.D.886 Mukaiyama Eruption in Niijima Volcano and Comparison with Ancient Manuscripts. Report on Planning Research for “Scale and Characteristic Feature of Volcanic Disaster,” Scientific Research Fund for Natural Hazard, The Ministry of Education, Science, Sports and Culture, 125-134. (in Japanese)

Itoh, J. and Aramaki, S. (1992) Petrology of Volcanic Rocks on Niijima and vicinity islands. Tokyo Metropolitan Government [ed], Reference Data in the Investigation and Research for Characteristics of Volcanic Disaster and Mitigation on Izu Islands –Earth Science–, 7-21. (in Japanese)

Itoh, J and Isobe, I (2007) New 14C age from pre-Mukaiyama volcano, called as Mamashitaura Volcano, at the southern part of Niijima Island, Izu-Bonin Arc. JPGU 2007, V156-P026.

Japan Meteorological Agency (2006) Report on the eruption of Miyakejima volcano and seismic activity around Niijima and Kozushima in 2000. Technical Report of the Japan Meteorological Agency, 128. 295p.

Japan Meteorological Agency (2013) National catalogue of the active volcanoes in Japan (The fourth edition) in press.

Kawanabe, Y. (1991) Petrological Evolution of IzuOshima Volcano. Bull. Volcanol. Soc. Japan, 36, 297-310. (in Japanese with English abstract)

Kawanabe, Y. (1998) Geological Map of Izu-Oshima Volcano, 1:25,000. Geological Map of Volcanoes, 10, 1sheet. (in Japanese with English abstract)

Kawanabe, Y. (2012) New ^{14}C ages of the Younger Oshima Group, Izu-Oshima volcano, Izu - Ogasawara arc, Japan. Bull. Geol. Surv. Japan, 63, 283-289.

Kawanabe, Y., Ishizuka, O. and Geshi, N. (2010) Drilling survey at the eastern summit caldera of Izu-Oshima Volcano, Japan. Programme and Abstracts, the Volcanol. Soc. Japan, 2010, 123. (in Japanese)

Koyaguchi, T. (1986) Evidence for Two-Stage Mixing in Magmatic Inclusions and Rhyolitic Lava Domes on Niijima Island, Japan. Jour. Volcanol. Geothrm. Res., 29, 71-98.

Koyama, M. and Hayakawa, Y. (1996) Syn- and Post-caldera Eruptive History of Izu Oshima Volcano based on Tephara and Loess Stratigraphy. Jour. Geograph. 105, 133-192. (in Japanese with English abstract)

Kuno, H. (1960) High-almina basalt. Jour. Petrol., 1, 121-145.

Matsui, R., Nakamura, M., Yoshiki, K., Yoshida, T., Suzuki, Y. and Nagahashi, Y. (2009) A petrological study on the magma plumbing systems in the Niijima and Shikinejima volcanoes, Izu Islands. JPGU 2009, V160-P005

Mikada, H., Watanabe, and Sakashita, S. (1997) Evidence for subsurface magma bodies beneath Izu-Oshima volcano inferred from a seismic scattering analysis and possible interpretation of the magma plumbing system of the 1986 eruptive activity. Phys. Earth. Planet. Inter., 104, 257-269.

Nakamura, K. (1964) Volcano-Stratigraphic Study of Oshima Volcano, Izu. Bull. Earthq. Res. Inst. Univ. of Tokyo, 42,649-728.

Nakamura, K. (1977) Volcanoes as possible indicators of tectonic stress orientation – principle and proposal. J. Volcanol. Geotherm. Res., 2, 1-16.

Nakano, S., Togashi, S. and Yamamoto, T. (1988) Bulk and Mineral Chemistry of Products of the 1986 Eruption of Izu-Oshima Volcano. Bull Volcanol. Soc. Japan, 33, S255-S264. (in Japanese with English abstract)

Soya, T. (1976) Chemistry and Mineralogy of the 1974 Scoria erupted from Mihara Crater of Oshima Volcano, Izu Islands. Bull. Volcanol. Soc. Japan, 21, 153-166. (in Japanese with English abstract)

Soya, T., Sakaguchi, K., Uto, K., Nakano, S., Hoshizumi, H., Kamata K., Sumii, T., Kaneko, N., Yamamoto, T., Tsuchiya, N., Suto, S., Yamazaki, H., Yamaguchi, Y., Okumura, K. and Togashi, S. (1987) The 1986 Eruption and Products of Izu-Oshima Volcano. Bull. Geol. Surv. Japan, 38, 609-630. (in Japanese with English abstract)

Suga, K., Kobayashi, K., Kanemaki, M., Miyahara, T. and Endo, K. (1992) Pyroclastic Deposits in Southern Part of Kozushima. Bull. Volcanol. Soc. Japan, 37, 71-83. (in Japanese with English abstract)

Sugihara, S., Otuka, S. and Kobayashi, S. (1967) Archaeological Remain That is Called Tawara Remain within Jyomon-Yayoi era in Niijima Island, Tokyo, Japan. Kokogakushu kan, 3, 45-80. (in Japanese)

Taniguchi, H. (1980) The Relationship between the Hydration Layer Observed in the Glassy Groundmass of Kozu-shima Rhyolite and the Extrusion Ages of the Lava Domes. Bull. Volcanol. Soc. Japan, 25, 102-103. (in Japanese with English abstract)

Tsukui, M. and Suzuki, Y. (1998) Eruptive History of Miyakejima Volcano during the Last 7000 Years. Bull. Volcanol. Soc. Japan, 43, 149-166. (in Japanese with English abstract)

Tsukui, M., Saito, K., Hayashi, K. (2006) Frequent and Intensive Eruptions in the 9th Century, Izu Islands, Japan: Revision of Volcano-Stratigraphy Based on Tephras and Historical Document. Bull. Volcanol. Soc. Japan, 51, 327-338. (in Japanese with English abstract)

Tsukui, M., Dangi, K., Sato, S. and Hayashi, K. (2009) Izu-Oshima Volcano: Precise Sequence and Mitigation Program of the Latest Three Large-Scale Eruptions Revealed by Historical Documents. Bull. Volcanol. Soc. Japan, 54, 93-112. (in Japanese with English abstract)

Watanabe, H. (1987) Eruption mechanism of Izu-Oshima volcano as viewed from volcanic tremors. Earth Monthly, 9, 475-480. (in Japanese)

Watanabe, H., Okubo, S., Sakashita, S., and Maekawa, T. (1998) Drain-back process of basaltic magma in the summit conduit detected by microgravity observation at Izu-Oshima volcano, Japan. Geophys. Res. Lett., 25, 2865-2868.

Watanabe, H. (1998) Precursors to the 1986 eruption and the magma plumbing system of Izu-Oshima volcano, Japan. Bull. Volcanol. Soc. Japan, 43, 271-282. (in Japanese with English abstract)

Watanabe, H. (2012) Magma plumbing system and eruption prediction of Izu-Oshima

volcano. Planetary People, 21, 198-205. (in Japanese)
Yamaoka, K., Watanabe, H. and Sakashita, S. (1988) Seismicity during the 1986 eruption of Izu-Oshima volcano. Bull. Volcanol. Soc. Japan, 33, S91-S101. (in Japanese with English abstract)
Yamamoto, T. (2006) Pyroclastic Density Current from the Caldera-forming Eruption of Izu-Oshima Volcano, Japan: Restudy of the Sashikiji 2 Member Based on Stratigraphy, Lithofacies, and Eruption Age. Bull. Volcanol. Soc. Japan, 51, 254-271. (in Japanese with English abstract)
Yoshida, Y. (1992) Eruptive History of Nii-jima Volcano. Programme and Abstracts of Volcanol. Soc. Japan, 1992(2), 63. (in Japanese)
Yoshida, Y. (1996) Eruptions occurred within a short period in the 9th century on Izu Islands: Kozushima Tenjosan Tephra and Niijima Mukaiyama Tephra. Inventory of Quarternary Outcrops -Tephras in Japan-, Japan Association for Quarternary Research 40th Aniversary Special Publication, 221. (in Japanese)
Yoshiki, K., Nakamura, M., Suzuki, Y., Yoshida, T. and Nagahashi, Y. (2006) Evolution of the magma plumbing system in Niijima volcano, Izu islands. JPGU 2006, V102-010
Yukutake, T., Yoshino, T., Utada, H., Watanabe, H., Hamano, Y., and Shimomura, T. (1990a) Changes in the electrical resistivity of the central cone, Mihara-yama, of Oshima volcano observed by a direct current method. J. Geomag. Geoelectr., 42, 151-168.
Yukutake, T., Utada, H., Yoshino, T., Watanabe, H., Hamano, Y., Sasai, Y., Kimoto, E., Otani , K., and Shimomura, T. (1990b) Changes in the geomagnetic total intensity observed before the eruption of Oshima volcano in 1986. J. Geomag. Geoelectr., 42, 277-290.