Problems the Izu-Oshima eruption in 1986 left to volcanology about magma supply systems

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The 1986 eruption of Izu-Oshima Volcano left interesting problems for both scientific studies and hazard mitigation. Considering discussions made at the time of the eruption and new information added after the present paper reexamines some problems related to magma supply to the eruption.

The eruption consists of a sequence of events. On November 15-19, 1986 effusing magma first filled the summit crater and overflowed the summit cinder cone. In the climax of the eruption on November 21, magma generated new fissures on a line from the summit to the northwest flank and violently effused with eruption columns higher than 10 km. More than ten thousand people living in this volcanic island evacuated during the night of this volcanic activity and stayed outside the island for a month. Four small events followed the activity each with sudden subsidence of lava in the summit crater till October, 1990.

At that time it was considered without doubt that there was a magma chamber just below the summit crater. According to leveling surveys made in the northwest part of the volcano the summit area had subsided over several years before the eruption. Although anomalous electric resistance and volcanic gases as well as volcanic tremor were observed several months before the eruption the coordinating committee of volcanic eruption prediction inferred that there would be no big eruption because of the evidence of summit subsidence. Actual big eruptions denied this prediction.

Noting that the leveling data covered only the northwest side of the volcano and that seismic activities were dominant in this area during and before the summit eruption the author proposed that the eruption might be fed with magma in a chamber below the northwest flank of the volcano (Ida, JVGR, 66, 53-67, 1995). This idea was consistent with the tilt observation at two points along the caldera rim that showed subsidence of the northwest flank during the summit event. At the small event on November 18, 1987 that was accompanied by a 40 m subsidence of lava a clear uplift was observed around a point 3 km northwest of the summit with the newly installed tilt network. This phenomenon was explained by the model that magma had been drained back to the predicted magma chamber during this event. However, many volcanologists still kept a firm belief of magma chamber below the summit.

After the eruption some evidence favorable to the magma chamber northwest of the summit is added. A high-density GPS network revealed that uplift had started in the northwest area of the volcano implying that inflation of the same magma chamber began toward the next eruption. It was also accepted that the Unzen eruption in 1991-95 was supplied with magma from a chamber below Tachibana bay and that there was a deep magma chamber of Sakurajima below Kagoshima bay. A magma chamber that does not sit just below the summit crater is now not regarded as abnormal at all.

The fissure eruption on November 21, 1986 gave another problem about magma supply system. Many volcanologists assumed that there should be another magma chamber for the eruption that had been more explosive and had ejected more andesitic lava than the summit eruption. The author supposed, however, that the same chamber as in the summit event worked because the fissures were located over the chamber. The explosive nature of the event with andesitic lava can be explained by crystallization differentiation of magma during ascent processes in newly generated cool paths. This interpretation is consistent with observed large scattering of lava compositions that may reflect different cooling processes. Unfortunately, the idea has not yet well examined among volcanologists.

Keywords: Izu-Oshima eruption, magma supply system, summit crater, magma chamber, fissure eruption, crystallization differentiation

Reexamination of the eruption types and their origin for Izu Oshima Volcano

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The origin of the eruption types of Izu Oshima Volcano, Japan, was reexamined mainly by geological and historical data. We once revealed the detailed syn- and post-caldera eruptive history of Izu Oshima Volcano by tephra and loess stratigraphy (Koyama and Hayakawa, 1996, J.Geogr.). Twenty-four tephra layers, which overlie the slope outside the caldera, show that 24 explosive eruptions occurred for the past 1500 years.

Reexamining the relationship between the level of magma head and the period of ash spouting in the final stage of each eruption, we reclassified all the eruptions including effusive/small ones of Izu Oshima Volcano into five types:

1) effusive eruption with small-middle discharge mass of magma, occurred repeatedly during 1876-1974: a period of high magma head
2) explosive eruption with middle discharge mass of magma, associated with deposition of ash falls outside the caldera but with no dike intrusion (5 eruptions)
3) explosive eruption with middle discharge mass of magma, associated with deposition of scoria falls outside the caldera and with dike intrusion (7 eruptions including the 1986 eruption),
4) explosive eruption with middle-large discharge mass of magma, associated with deposition of scoria and ash falls outside the caldera and with dike intrusion (or possible dike intrusion) (9 eruptions),
5) phreatomagmatic eruption with middle-large discharge mass of magma, associated with deposition of scoria and ash falls outside the caldera and with dike intrusion (or possible dike intrusion) (3 eruptions).

Keywords: Izu Oshima Volcano, eruptive history, eruption type, origin, reexamination, level of magma head

Magma volume budget of the 1986 Izu-Oshima summit eruption

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Introduction

Mismatches between DRE volume of erupted lava and deflation volume of magma chamber inferred by ground deformation data are widely recognized. Such mismatch of the volume budget is recognized for the 1986 Izu-Oshima summit eruption. One possible reason for the mismatch is due to magma compressibility. Further, from the estimation of the compressibility, there is a possibility to extract information about physical properties and gas content in a magma chamber of Izu-Oshima volcano.

Extrusive and deflation volumes of 1986 summit eruption

Temporal sequence and a total DRE volume of extruded lava of the 1986 summit eruption were reported by e.g. Endo et al. (1988). The estimated total amount of lava is $1.4*10^7$ m^3. Further, ground deformation suggesting subsurface deflation by volumetric strain and tilt meters, as to synchronize with the lava extrusion. Yamaoka inferred the deflation source parameters to be 5 km-depth and deflation volume of $5*10^6$ m^3 by introducing a spherical pressure source. Based on these researches, volume ratio of erupted material to deflation becomes about 2.7.

Magma effective properties

Magma is composed of solid (crystal), liquid (melt) and gas phases. Therefore, to calculate effective properties such as density and bulk modulus, it is needed to be known properties and fraction of each phase. As for solid phase, Fujii et al. (1988) and Nakano et al. (1988) reported that phenocryst content is 5- 10 wt. % and most of phenocrysts are plagioclase for the 1986 summit eruption. Melt compositions are measured for plagioclase-hosted melt inclusions of the 1986 summit eruption by Hamada et al. (2007). Dissolved H_2O contents are 0.2 –1.4 wt.%. Bulk modulus is calculated to be about 16 GPa by using the measured composition and equation of state for melt (e.g., Spera, 2015). Bulk modulus of gas phase equals to pressure as long that ideal gas is to be assumed. For lithostatic pressure at the depth of 5 km inferred by Yamaoka (1994), the bulk modulus of gas becomes to be about 0.13 GPa. Finally, large uncertainty of fractions for liquid and gas phases remains to predict the bulk properties of magma.

Volume ratio

Volume ratio between erupted material and deflation depends on a shape of the deflation source, and on a ratio between rigidity of host rock and magma bulk modulus. If we assume a spherical magma at the depth of 5 km and adopt 30 GPa of host rock rigidity, the ratio exceeds 3 even for gas-free magma, and it is difficult to explain the ratio of 2.7 based on observation. In order to discuss the volume ratio and further to estimate the gas content, we will reexamine source parameters and the rigidity of the host medium.

Keywords: Izu-Oshima volcano, ground deformation, physical properties of magma

Petrological review on the magma plumbing system of Izu-Oshima volcano

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Izu-Oshima is an active volcano located on the volcanic front of the Izu arc. It erupts low-K island arc tholeiite magma. During the past 150 years, it has erupted repeatedly at intervals of 30-40 years (1876-1877, 1912-1914, 1950-1951, and 1986-1987). Thirty years has already passed since its last eruption (1986-1987); therefore, the next eruption is expected in the near future.

In this presentation, the hypothesis that the next eruption of Izu-Oshima volcano is triggered by an aftereffect of the M9 Tohoku-Oki earthquake, which took place on March 11th, 2011, is considered. In both the 9th century and the period between the 17th century and the 20th century, volcanism of Izu-Oshima volcano seems to have been activated in association with earthquakes occurring near the volcano. While some eruptions occurred after earthquakes, others occurred before earthquakes. It is possible that regional tectonic stress can trigger both major earthquakes and intense volcanic activity, although this hypothesis should be tested at Izu-Oshima volcano and/or elsewhere.

Petrological studies of Izu-Oshima volcano will also be reviewed to understand its magma plumbing system and to provide useful information in order to prepare for its next eruption. The geochemical variations in aphyric volcanic rocks (liquids) of Izu-Oshima volcano fall between two endmember trends, namely higher- and lower-Al/Si trends. Higher- and lower-Al/Si trends can be explained by crystallization differentiation of H_2O-saturated magmas at 9-km-deep magma chamber (~5 wt.% H_2O in melt) and 4-km-deep magma chamber (~3 wt.% H_2O in melt), respectively, based on melting experiments of hydrous basaltic magmas. Polybaric crystallization differentiation of H_2O-saturated magmas proceeds beneath the volcano. The H_2O-rich nature of the basaltic magmas beneath the volcano suggests that a future eruption of Izu-Oshima volcano could be highly explosive if dissolved volatiles in melt are not sufficiently degassed from magma ascending through the conduit.

Keywords: Izu-Oshima volcano, Magma plumbing system, Island arc tholeiite, Ca-rich plagioclase, Polybaric crystallization differentiation

An andesitic melt-bearing gabbroic xenolith of Izu-Oshima 1986 eruption: a preliminary result

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Izu-Oshima 1986 eruption started at Nov. 15 from strombolian eruption of basaltic magma at the central cone (A vent), followed by sub-plinian fissure eruption of andesitic magma at Nov. 21 from the caldera floor (B vent). Glass-bearing gabbroic xenoliths are rarely included in fall deposits from B vent. The gabbro xenoliths may have information about pre-eruptive process of andesitic magma erupted from B vent. In this study, we report the results of textural observation and chemical analysis of minerals and glass in the gabbro xenolith and discussed about pre-eruptive process of andesitic magma from B vent.

In this study, we investigate a glass-bearing gabbroic xenolith collected at ca. 1km NE from B vent. This gabbroic xenolith is chiefly composed of euhedral-subhedral grains of plagioclase and olivine embedded by interstitial glass. The glass is brown and vesicular. Fine clinopyroxene and magnetite grains are found in the glass. Overgrowth rims of <10 microns thickness are observed at melt-plagioclase and melt-olivine interfaces. Overgrowth rims of plagioclase and olivine are respectively lower An [=100Ca/(Ca+Na)] and lower Fo [=100Mg/(Mg+Fe)] values compared to inner parts. Glassy melt inclusions are found in plagioclase and olivine.

We measured major element compositions of minerals and glass in the gabbroic xenolith using EPMA at Earthquake Research Institute, University of Tokyo. Interstitial glass is almost homogeneous and have an andesitic composition with SiO2 ~ 56.6 wt.%. Composition of the glass is very similar to those of volcanic ejecta from B vent. Overgrowth rim of plagioclase shows narrow range of An value of ca. 83, which is in equilibrium with interstitial melt under wide range of melt H_2O content condition. By combining plagioclase- and olivine-liquidus thermometers of putirka (2008), we estimated equilibrium temperature-melt H_2O content conditions of the interstitial melt to be ~1057 deg. C and ~3.4 wt.% H_2O. The estimated temperature is almost identical to those estimated for lava and ejecta from B vent (Fujii, 1988). The estimated melt H_2O content is similar to saturation solubility at pressure of ~118 MPa, corresponding to ~4.4 km depth. This depth is almost the same as that of the shallower magma reservoir beneath the volcano, inferred from Ida (1995). Although melt inclusions in plagioclase and olivine are also andesitic (SiO2 ~ 55-56 wt.%), their compositions are slightly different from that of interstitial melt. Plagioclase-hosted melt inclusions are enriched in MgO, and olivine-hosted melt inclusions are enriched in Al2O3 and CaO and depleted in FeO compared to interstitial melt. These differences may be attributed to post-entrapment re-equilibrium between melt inclusions and host minerals.

Andesitic melt inclusions in plagioclase and olivine with compositions slightly different from interstitial melt indicate that the gabbro is a cumulate from andesitic melt. The estimated equilibrium depth of ~4.4 km is similar to that of magma reservoir inferred for basaltic magma from A vent (e.g., Hamada et al., 2011). This suggests that andesitic magma reservoir was located near the basaltic magma reservoir, and fissure eruption from B vent might be triggered by pressure increase in basaltic magma reservoir. Thin overgrowth rims of plagioclase and olivine suggest that physic-chemical conditions of interstitial melt changed immediately before the eruption. In further work, the mechanism triggered B fissure eruption will be clarified by detailed investigation of the overgrowth rim texture in the gabbro xenolith.

Keywords: Izu Oshima, xenolith, gabbro, magma reservoir, andesitic magma, pre-eruptive condition

30-year secular variation in helium isotope ratios in Izu-Oshima volcano

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Izu-Oshima is an active volcanic island located around 100 km SSW of Tokyo. The center of the island is occupied by a caldera complex with a diameter of 3 km. A large post-caldera cone known as Mt. Mihara is located at the south-western quadrant of the caldera. During the last 10,000 years, large-scale eruptive activities have occurred repeatedly once every 100-150 years. The historical activity of the present Izu-Oshima volcano, including Mt. Mihara was well documented since 7th century A.D. The last magmatic eruption occurred in 1986, followed by small eruptions emitting volcanic ash and steam until 1990. Secular variations in $^{3}He/^{4}He$ ratios of steam from an observation well located about 3 km north of Mt. Mihara have been intermittently collected and analyzed since October 1986, about a month before the beginning of the last magmatic eruption. The $^{3}He/^{4}He$ increased to 5.5 Ra, where Ra denotes the atmospheric $^{3}He/^{4}He$ ratio of 1.4×10^{-6}, resulting from an increase in relative contribution of magmatic helium. After the $^{3}He/^{4}He$ peak in 1988, the $^{3}He/^{4}He$ ratios of the steam well gases decreased gradually due to depletion of magmatic gas emission and subsequent mixing with atmospheric helium entering the hydrothermal system (Sano *et al.*, 1991; 1995; Shimoike and Notsu, 2000; this study). The present $^{3}He/^{4}He$ value of the steam gas is around 1.4 Ra, which is close to the value observed before the 1986 eruption (1.7 Ra), indicating magmatic helium discharge has returned to the level before the last activity.
The corrected $^{3}He/^{4}He$ ratios for the atmospheric contamination based on $^{4}He/^{20}Ne$ ratio range from 5.9 to 6.5 Ra during the last activity between 1987 and 1990. The isotope ratios of helium dissolved in hot-spring water collected from a well 50 m east of the observation steam well in 2001 and 2016 were about 6.3 Ra after air-contamination. It is unlikely that mixing ratio of crustal helium (dominantly ^{4}He) and magmatic helium in the hydrothermal system has been constant for 30 years, thus the air-corrected $^{3}He/^{4}He$ ratio can be regarded as that of the magma. These indicate magmatic helium with $^{3}He/^{4}He$ ratio of ca. 6.3 Ra still has discharged without significant change in isotope ratio since the last eruption. The $^{3}He/^{4}He$ value of the magma is lower than the typical mantle value (8 ±1 Ra), suggesting crustal helium contamination to the magma chamber.

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Keywords: helium, isotope, Izu-Oshima, volcanic gas, hot spring

Geomagnetic dip changes associated with the 1950 eruption of Izu-Oshima volcano, central Japan: Implications to the magma plumbing system of the 1986 eruption.

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Rikitake (1951) conducted repeat geomagnetic dip surveys during the first stage (Phase I: July-September, 1950) of the 1950 eruption of Izu-Oshima volcano, central Japan and found a large amount of changes in the dip. He devised a method to find an eccentric dipole from the surface magnetic observations and applied it to obtain a source for such magnetic changes as a thermally demagnetized sphere of radius 2.5 km at a depth of 5.5 km. His result bears an important suggestion to the magma sources of this volcano even for the 1986 eruptive activity. The magma extruded in the fissure eruptions in 1986 was strongly differentiated (SiO_2 contents larger than 70 %): Aramaki and Fujii (1987) proposed that it came from a reservoir at a shallow depth which might have been formed by a past intrusive event. We investigate here if Rikitake's results are supportive of such an event. We reexamined the validity of his model by applying the present-day technique of magnetic source inversion, i.e. the genetic algorithm (GA) (Currenti, et al., 2005). A constraint is that the source should be consistent with the magnetic structure beneath around Izu-Oshima volcano which has been clarified by the recent aeromagnetic surveys. A source for the observed magnetic changes was found as a flat, slightly inclined to the north, triaxial ellipsoid located shallower than 5 km depth as shown in Fig. 1. Implications of such a magma reservoir are discussed for the magma plumbing system of Izu-Oshima volcano, which was proposed by Watanabe (2012). This study is based on the paper by Sasai (2013).

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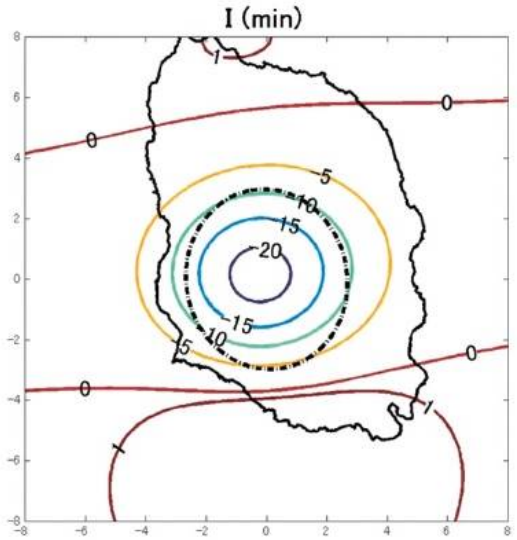
Keywords: Izu-Oshima Volcano, 1950 Eruption, Geomagnetic Dip Change, Thermal Demagnetization, Genetic Algorythm, Magma Plumbing System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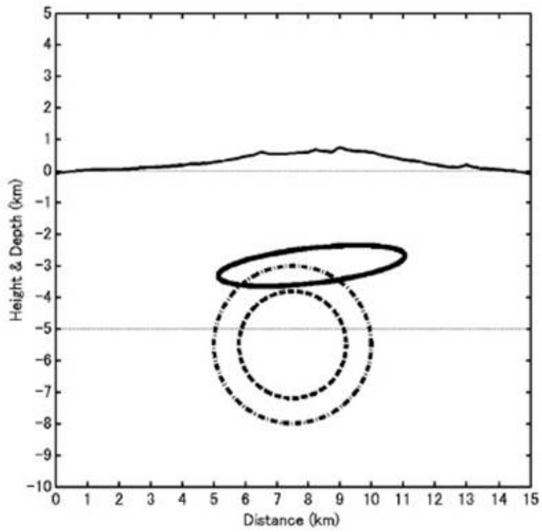
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Review of diagnostic criteria of the volcanic alert levels at Izu-Oshima volcano by the Japan Meteorological Agency

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1. Introduction
After the Ontake-san eruptive accident in September 2014, the Japan Meteorological Agency (JMA) is reviewing the diagnostic criteria of the volcano alert levels at Ontakesan and other active volcanoes and has published them for some volcanoes (Yamasato et al., 2016). Also for Izu-Oshima, JMA has reexamined the criteria of the volcano alert levels with the Volcanic Disaster Mitigation Council.

2. Outline of the review
In the volcano alert level at Izu-Oshima, the levels 1-5 and each criteria are defined according to the countermeasures of the local governments referring the eruption scenario made by the Izu Subcommittee of the Coordinating Committee for Prediction of Volcanic Eruptions (2008). In the present review, we improved the criteria in the following three stages and clarified conditions as quantitatively as possible.
(1) Summit eruption of Miharayama
(2) Fissure eruption in the caldera and the flank of the island
(3) Plinian eruption or caldera forming eruption
In the scenario of the Izu Subcommittee, there are two categories; the summit eruption and the flank eruption. We classified them into three types as followings.
(a) Eruption at the summit of Miharayama and in the caldera
(b) Eruption at the outside of the caldera (far from the residential area)
(c) Eruption at the outside of the caldera (neighborhood of the residential area)

3. Criteria for summit eruption of Miharayama
We examined the upgrading criteria to level 2 with volcanic tremor activity reviewing the case of the 1986 eruption (e.g. Hashimoto et al., 1989). We set large amplitude tremor or continuous tremor that were observed 1-2 months before the 1986 eruption as new upgrading criteria. Besides them, we included fumarolic activity, volcanic glowing, seismic activity beneath the summit into the criteria.
In the previous criteria, Strombolian eruption at Miharayama had been classified into level 3, however, ballistic bombs from such eruption reached almost within 1 km from the summit crater, therefore, we redefined such eruption as level 2. If the lava flow exceeds 1 km from the crater or the eruption becomes more explosive and ballistic bombs frequently reach more than 1 km distant from the crater, the alert level must be upgraded to level 3.
As the criteria is made according to the 1986 activity, we examined the level simulation using them for the 1950-1974 eruption at Miharayama. Although the precursors of the start of the 1950 eruption could not detected because there was only one Wiechert seismograph at Oshima Weather Station, the high sensitive seismic observation after the start of the eruption detected volcanic tremors before some eruptions. We recognized that every eruptions took place in the alert level 2 or 3 in the level simulation using the modified criteria.

4. Criteria for fissure eruption
We examined the criteria for the activity in the 1986 fissure eruption. The activity in the eruption on 21

November 1986, was as followings.
a) 14:10 : Vigorous earthquake swarm and ground deformation
b) 16:15 : Start of fissure eruption on the caldera floor
c) 17:47 : Fissure eruption at the NW flank
New criteria are set as level 3, 4 and 5 at the stages a), b) and c), respectively. At the stage a), the alert area is enlarged to the outside of the caldera.

5. Alert level for large eruption
In the previous criteria, level 4-5 were defined only for lave flow and fissure eruption near the coast and did not include Plinian eruption or caldera forming eruption. In the new criteria, we included such eruption cases. For the example, when Plinian eruption occurs and volcanic plume reaches more than 10 km height, the alert level will be upgraded to level 4; when large amount of scoria or ash fall in the residential area, to level 5.

6. Acknowledgements
We would like to thank Prof. Yuichi Morita and volcanologists in the Volcanic Disaster Mitigation Council for useful suggestions in our review.

Keywords: Volcanic Alert Level, Izu-Oshima, diagnostic criteria, volcanic tremor, Mihara yama, fissure eruption

The tsunami caused by the volcanic eruption of Izu Ooshima Island on September 18th, 1684

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Volcano Izu-Ooshima island began to be active on March 31st, 1684, and it became the stage of climax in 9th, August of the same year. The volcanic activity stopped in 1690. Fifty nine years after the finishing of the volcanic activity, "Izu-Ooshima Sashidashi-cho (The geographical and historical report of Izu Ooshima Island)" was published. In this report, there is a description of a tsunami which had hit Niijima Village (Motomachi Town at present) in August, 1684 as the following: "Niijima Village in Ooshima Island, in August of 1684, more than sixty trading and fishing vessels were carried away by a tsunami, and in addition that four people and more than 60 houses were swept away." The date of the tsunami is not mentioned explicitly, but it is recorded by another documents that the volcanic eruption became most active on 8th August, so, the tsunami was probably generated on the same day. The total number of houses in Ooshima village was 253 in 1749, and was 245 in 1793, so it was considerable to be about 250 also in the year of the tsunami, 1684.
The number of tsunami swept away houses was about 60, so about quarter of total houses were swept away in Niijima village. We made ground height measurement in Motomachi town at a point on the contour line which separates about quarter part of the residential area of Motomachi Town, Izu-Ooshima. We found that the ground height at the point was 13.9 meters (above T.P. 0m). We estimated that the tsunami height was in minimum 13.9 meters, and it is possible, sea water rose up to the level of fifteen meters above the mean sea level.
Acknowledgement: This study was achieved as a part of the commissioned research named "Study on the historical tsunamis in the Pacific coast of Japan (2016)" on disaster prevention for nuclear facilities proposed by the Nuclear Regulation Authority, Japan.

Keywords: Tsunami caused by a volcanic eruption, Izu Ooshima, Historical Tsunami, Cauchy-Poisson's waves

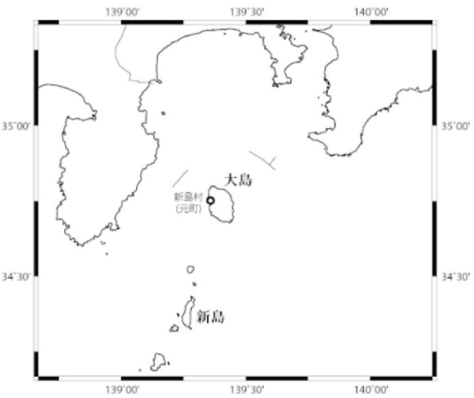

図1　新島村と新島は別の地名である

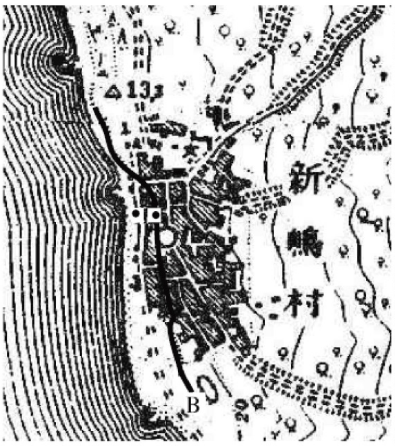

図2　大正3年(1914)の大島新島村の地形図
太実線は流失家屋範囲限界

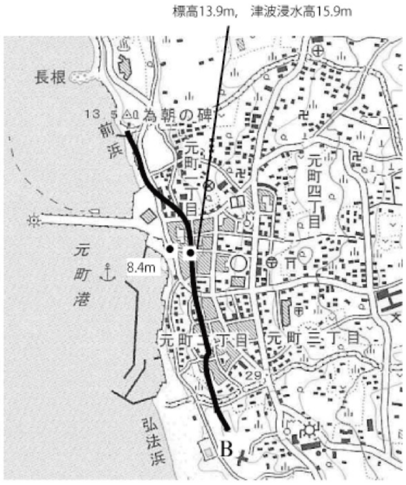

図3　現代の大島元町の地形図
太実線は流失家屋範囲限界