Preliminary Study of Sedimentary Period of Layer by Using Natural Remanent Magnetization in Io To Island in Ogasawara Archipelago

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Abstract

To obtain information about the volcanic activity history of the Io To Island in Ogasawara archipelago, the natural remanent magnetization (NRM) of east coast marine deposits and Kama Iwa deposits, where volcanic sedimentary periods have not been clearly determined, were measured. The two deposits, which may have been deposited in similar environments, showed different magnetic orientations. B*y comparing the NRM results to the geomagnetism change curves for the past 2,000 years in southwest Japan, it was determined that the sedimentary periods were 1,000 years or more apart.*

1. Introduction

Io To Island in Ogasawara archipelago (hereafter referred as "Io To Island") is a volcanic island located at 141°17′ 14″ E longitude and 24°45′ 29″ N latitude, where uplift and volcanic activity are currently ongoing. The entire eruption history is not well understood because of the following reasons: (1) the recorded history of Io To Island corresponds to a short period that began after the start of the Meiji era (in the 19th century); any eruption data that may have been part of the recorded history and any physical evidence of eruptions that occurred on the island were probably lost or destroyed in a furious battle during the Pacific War, and (2) the island is now off limits to civilians. The authors have been executing research to clarify its history of volcanic activity from the past to the present using the terrace chronology determined by ^{14}C dating, rock analyses of pyroclastic materials such as pumices and scoriae, principal component analysis on volcanic glass, and GPS observations of the amount of crustal deformation in recent years. However, no sample suitable for ^{14}C dating was obtained in the key layers for clarifying the volcanic activity history, and the identifications of these layers with sedimentary periods are only presumptions. Thus, the context of each sedimentary layer must be estimated by measuring the natural remanent magnetization (NRM) of a deposit sample collected while carefully preserving its orientation. This can then be compared with the geomagnetism change curve for the past 2,000 years in southwest Japan. This paper reports preliminary results from NRM measurements.

2. Overview of study area

The upheaval activity of Io To Island had been thought to be constant-velocity uplift (Kaizuka et al., 1985), but Ooi and Yarai (2007) divided the magma eruption volcanic activity of Io To Island into four active phases: the Motoyama activity period, Kama Iwa formation period, old Suribachi Yama activity period, and new Suribachi Yama activity period. In addition, Imakiire et al. (2010) indicate the possibility of the existence of an old volcanic island below the present Io To Island and intermittent uplift activity.

A topographical map of Io To Island is shown in Fig. 1. There is a marine deposit layer under the lava bed from the Motoyama activity period beneath the Kongo Iwa rock on the Motoyama east coast. It is thought that this deposit used to have a different environment from the present shingle beach with raging waves (e.g., it was in the caldera basin or at the edge of the caldera), because there was cross-lamination in this marine deposit layer (Imakiire et al., 2010). However, the period of the sample could not be determined by ^{14}C dating, and its sedimentary period is thus not known. However, it is clear that this marine deposit layer is older than about 2,750 cal BP, because ^{14}C dating shows that the age of the carbonization chips that lie between this marine deposit layer and the overlying lava beds is about 2,750 cal BP (Imakiire et al., 2010). On the other hand, the Kama Iwa deposit layer on the west coast of Io To Island is presumed to be equivalent to the rim around the caldera (Kaizuka et al., 1985); it is composed of tuffaceous sand bed. Notably, it exhibits anomalous

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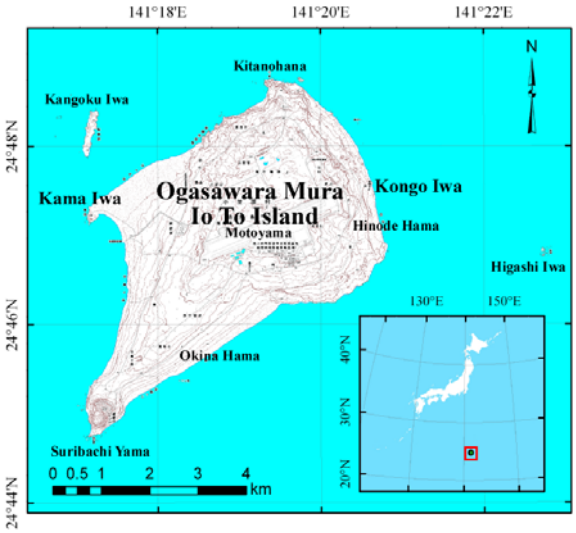

Fig. 1 Topographical map of Io To Island.

cross-lamination and many trace fossils. It is supposed that this layer was deposited in an environment in which the flow direction was frequently anomalous (e.g., in a waterway where the caldera basin was connected with the open sea). However, no sample suitable for ^{14}C dating is obtained even here, and the sedimentary period is uncertain. However, a period of about 2,000 cal BP is shown by ^{14}C dating of a coral fossil found in peperite that abuts on the Kama Iwa deposit layer. Knowledge of whether the marine deposit on the east coast and the Kama Iwa deposit layer that shows a similar sedimentary environment accumulated simultaneously would be useful for determining when such a sedimentary environment was formed and clarifying the history of the volcanic activity. Thus, the authors have collected samples of the east coast marine deposit layer and the Kama Iwa deposit layer while carefully preserving their orientations, measured the direction of geomagnetism recorded by the deposit, and examined the sedimentary period of each deposit layer.

3. Method of study

When sediment is deposited quietly in water and/or on land, it records the orientation of the geomagnetism of that period. The orientation of this geomagnetism recorded in the deposit is called the "detrital remanent magnetization (DRM)." To measure the remanent magnetization, it is necessary to collect the sample while carefully preserving its orientation. In this study, a plastic cube of 10 cc was buried in the deposit layer, and the pitch and dip of the cube bottom were measured using a clinometer. A voltage was induced to the coil when the sample was placed in it at extremely low temperature, and by measuring the three orthogonal elements of the magnetic field with a superconducting three-axis sensor, the remanent magnetization could be calculated. The magnetic orientation in the horizontal bed is obtained to correct the measured magnetic orientation for the pitch and dip of the cube bottom measured in the field. The remanent magnetization was measured with a superconducting remanent magnetometer manufactured by the 2G company and owned by Toyama University.

The secondary magnetization added after deposition is included in the measured remanent magnetization (NRM). In this paper, the NRM is utilized for preliminary study, although it is necessary to remove the secondary magnetization using alternating current demagnetization for accurate discussion.

The geomagnetism change curve for the past 2,000 years has been obtained from the remanent magnetization measured in the burned soil at many ruins in southwest Japan (e.g., Hirooka, 1971; 1977). To determine the sedimentary period from the NRM in the two deposit layers measured in this study, this geomagnetism change curve from southwest Japan was used. However, because the orientation of geomagnetism is different from region to region, the remanent magnetization orientation of Io To Island cannot be simply compared to the geomagnetism change curve for southwest Japan. The inclinations in southwest Japan (Osaka castle: Iw) and Io To Island (Ii) were determined from the relation between latitude and inclination derived assuming that a bar magnet is in the Earth's interior, $\tan I = 2 \tan \lambda$, where I is the inclination and λ is latitude (Kodama, 2000). The measured remanent magnetization in Io To was then plotted on the geomagnetism change curve for southwest Japan after being corrected by the difference between Iw and Ii. The amount of correction for inclination is 11.5°.

Photographs showing each sampling point are shown in Figs. 2 and 3. The east coast marine deposit layer could be divided into four layers using the grain diameter and the difference in the tone, and five NRM measurement samples were collected from each layer, yielding 20 samples

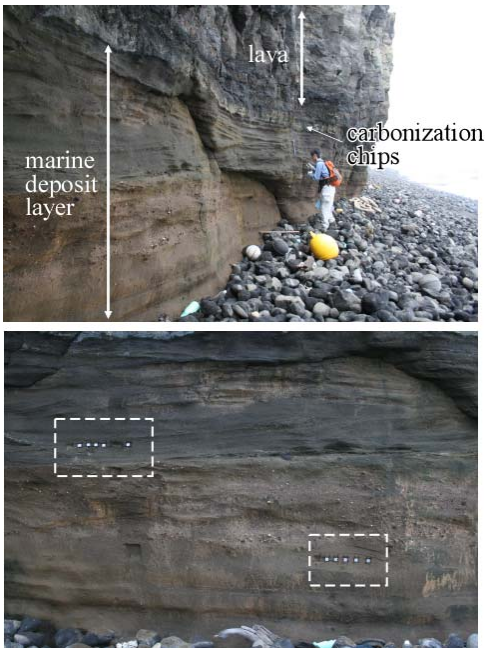

Fig. 2 Sampling points at the marine deposit on the east coast of Io To Island. The upper photo is an overview of the deposit, and the lower photo shows the sampling points.

Fig. 3 Sampling points at the Kama Iwa deposit layer in Io To Island. The upper photo shows the sampling points of the upper unit, and the lower photo shows the sampling points of the lower unit.

in total. It is thought that the sedimentary period is short, because it is supposed that the bedding plane in these layers is indistinct and continuous. The Kama Iwa deposit layer was roughly divided into two units, the upper yellowish brown tuffaceous sand bed and the lower dark grey tuffaceous sand bed, and five samples were collected from each layer, yielding 10 samples in total. These sampling points for the two different units in the Kama Iwa deposit layer are several meters away from each other in terms of layer thickness.

4. Results

The measured NRMs in the east coast marine deposit layer are shown in Table 1, and a stereonet projection diagram is shown in Fig. 4. The black points in figure show the magnetic orientation of each sample, and the ellipse surrounding them shows the 95% confidence ellipse (α95). The NRMs of the east coast marine deposit layer are concentrated around about 21°W declination and 34° inclination, and the error margin is small.

Table 1 Measured NRMs in the east coast marine deposit layer.

Sample No.	Declination (°)	Inclination (°)
IWOKG101218-1	-17.7	29.9
IWOKG101218-2	-28.5	32.0
IWOKG101218-3	-23.6	34.4
IWOKG101218-4	-23.1	37.0
IWOKG101218-5	-23.5	34.9
IWOKG101218-6	-21.1	34.6
IWOKG101218-7	-20.1	34.7
IWOKG101218-8	-15.6	34.1
IWOKG101218-9	-17.0	35.5
IWOKG101218-10	-20.6	36.9
Mean	-21.1	34.4
Error (α95)	2.3	2.8

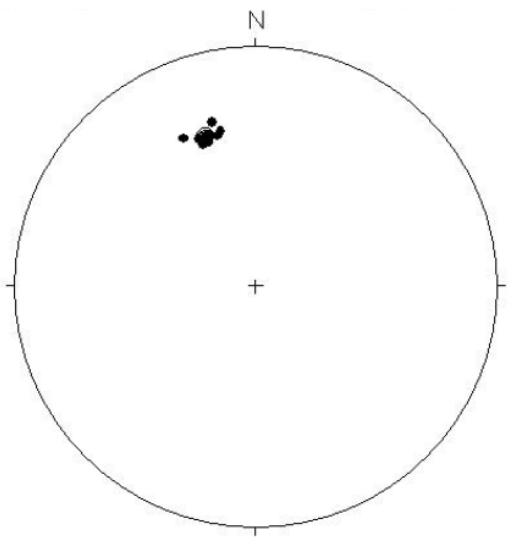

Fig. 4 Stereonet projection diagram of NRMs in the east coast marine deposit layer.

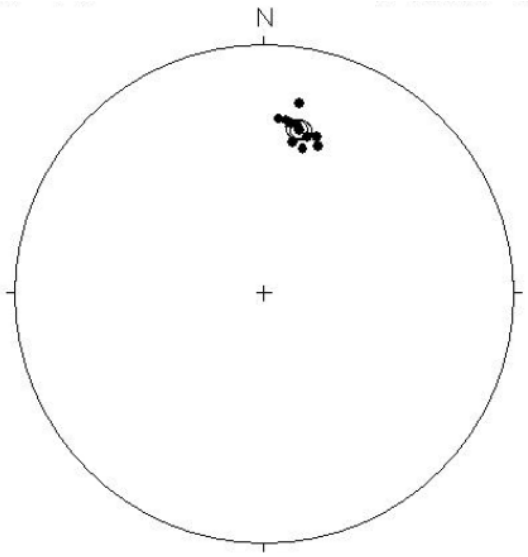

Fig. 5 Stereonet projection diagram of NRMs in the Kama Iwa deposit layer.

The measured NRMs in the Kama Iwa deposit layer are shown in Table 2, and a stereonet projection diagram is shown in Fig. 5. The NRMs of the Kama Iwa deposit layer are concentrated around about 9°E declination and 33° inclination, and the error margin is small. Note that these results show that the sedimentary periods of the two sites are different.

Table 2 Measured NRMs in the Kama Iwa deposit layer.

Sample No.	Declination (°)	Inclination (°)
IWOKM101217-1	1.9	30.2
IWOKM101217-2	8.8	32.2
IWOKM101217-3	7.5	23.4
IWOKM101217-4	15.7	33.8
IWOKM101217-5	4.2	30.3
IWOKM101217-6	6.2	31.3
IWOKM101217-7	17.2	37.0
IWOKM101217-8	12.6	35.0
IWOKM101217-9	12.0	39.5
IWOKM101217-10	7.6	37.9
Mean	9.4	33.1
Error (α95)	3.7	4.5

Fig. 6 shows each mean magnetization orientation plotted on the geomagnetism change curve for southwest Japan with inclination correction. The geomagnetism change curve is plotted every 50 years, and the points are labeled every 200 years. When the magnetic orientation of a sample of uncertain period is plotted on this geomagnetism change curve, the line with the shortest perpendicular distance from the plot point to the curve is drawn, and the intersection of this line and the curve indicates the estimated period.

Here, it is not possible to determine the period of the east coast marine deposit from the magnetization change curve, because this deposit is thought to be older than about 2,750 years. However, this point is located to the west of the orientation of the geomagnetism 2,000 years ago (0 A.D.) at a similar declination, and it is thought that this plot location is reasonably accurate, judging from the movement of the change curve near this point. On the other hand, the sedimentary period of the Kama Iwa deposit layer is estimated to be about 1,670 A.D. (about 340 years ago) from the change curve. However, this point is some distance from the curve, and it is possible that the period could be about 400 or 1,370 A.D., as well.

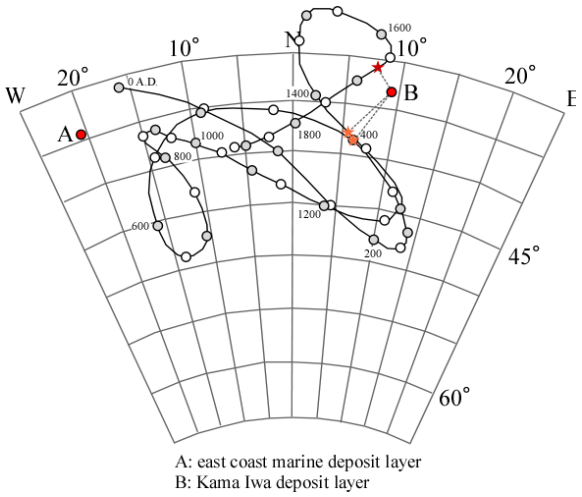

Fig. 6 Mean magnetization orientations plotted on the geomagnetism change curve for southwest Japan with inclination correction. The stars indicate the estimated period.

5. Discussion

The Kama Iwa deposit layer is presumed to have been deposited either 340, 640, or 1,600 years ago from the remanent magnetization orientation, while the east coast marine deposit layer is presumed to be older, deposited about 2,750 years ago, from the ^{14}C dating of the carbonization chips in its upper layer. These sedimentary periods are about 1,000 years apart at least, although it is supposed that both were deposited in a similar environment.

The formation of a caldera and a volcanic island older than the present Io To Island is presumed to have occurred before the formation of the east coast marine deposit layer. It is supposed that the east coast marine deposit layer consists of erosion detritus from the volcanic island, deposited in a tranquil environment such as that inside the caldera bay. Afterward, it is thought that during the Motoyama activity period beginning about 2,750 years ago, a large amount of lava and pyroclastic material were discharged and the majority of the present Io To Island was formed (Ooi and Yarai, 2007). The boundaries of the Motoyama activity period are uncertain, and it is supposed that the cross-lamination layer was formed from erosion detritus deposited under the influence of waves inside the caldera rim near the present Kama Iwa deposit 1,000 years or more after the Motoyama activity period. The Kama Iwa deposit layer was formed with roughly two units, and the magnetization orientation of the NRMs of each unit indicated almost the same orientation, although the sampling points of the NRM measurement samples were several meters away from each other in terms of layer thickness. Therefore, it is believed that a large volume of erosion detritus was deposited in a comparatively short period. This NRM measurement result shows that the sedimentary period of the Kama Iwa deposit layer is newer than the period found by Ooi and Yarai (2007), which was determined to be about 2,000 years ago by ^{14}C dating of a coral fossil found in peperite that abuts on the Kama Iwa deposit layer.

6. Conclusions

To obtain information about the volcanic activity history of Io To Island, the sedimentary period was examined for the east coast marine deposit layer and the Kama Iwa deposit layer, where the sedimentary period had not been clearly determined, by measuring the NRM of the deposits and comparing it to the geomagnetism change curve for the past 2,000 years. As a result, it was suggested that both layers were deposited in a similar environment but that the period differed by 1,000 years or more, indicating that an environment like a caldera bay either existed for a long time or was formed several times. Moreover, the Kama Iwa layer was found to have been deposited about 340–1,600 years ago by this study, although the sedimentary period of the layer was previously indirectly determined to be about 2,000 years ago. In the future, the authors intend to obtain a more accurate magnetic orientation (DRM) by removing the secondary magnetization using the alternating current demagnetization method for these samples.

Acknowledgments

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