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Paleomagnetic Study of Miocene Granitic Rocks in the Goto Islands and Tsushima

Haruaki ITO, Katsuyasu TOKIEDA and Yukio NOTSU
Department of Physics, Faculty of Science, Shimane University, Matsue 690, Japan
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Abstract

Miocene granitic rocks are exposed in the Goto Islands and Tsushima. Two bodies of granitic rocks with both normal and reversed NRM directions in the same mass were found in Hisaka-jima and Tsushima. Directions of the NRM of Goto and Tsushima granitic rocks are significantly consistent with each other, and it is concluded that the consistency in NRM directions demonstrates the contemporaneity of plutonic activity in both the regions. The VGP positions obtained from intermediate polarity directions were situated in the Southern Pacific Ocean without one site in the Goto Islands.

1. Introduction

Paleomagnetic study of granitic rocks was started by one of the authors (H.I) in 1963 with two principal objectives: (1) to reveal a reversal mechanism of the geomagnetic field by a paleomagnetic analysis of the cooling history of an intrusive body, and (2) to ascertain the contemporaneity of plutonic activity in an area by employing the NRM directions of granite bodies in the area.

Relatively small bodies of granitic rocks in Tertiary age lie scattered in the Japanese Islands of Hokkaido, Honshu, Shikoku, Kyushu and the other small Islands. It has been frequently found that granite bodies with a few kilometers in diameter have both the normal and reversed NRM directions in the same mass (e.g. Ito, 1965; Ito and Tokieda, 1978; Tokieda and Ito, 1978). In Japan, we have preliminary encountered with about fifteen granite bodies which have two antipodal remanent vectors in a single mass. It implies that such a granite body had been emplaced immediately prior to a polarity transition of the geomagnetic field and gradually cooled during and after the transition. Therefore, a record of the polarity reversal should be retained in such granite bodies.

Magnetic minerals in granitic rocks are mainly magnetite-rich titanomagnetite. About 90 per cent of the NRM of such magnetic minerals is blocked within the temperature interval of 580°C and 560°C (Dodson et al., 1978). It is assumed that the cooling rate of granite bodies exposed is usually quite different from each other. However, granite bodies with suitable dimensions could be gradually cooled from the chilled margin of the contact to inner part of the mass. It is therefore expected that a

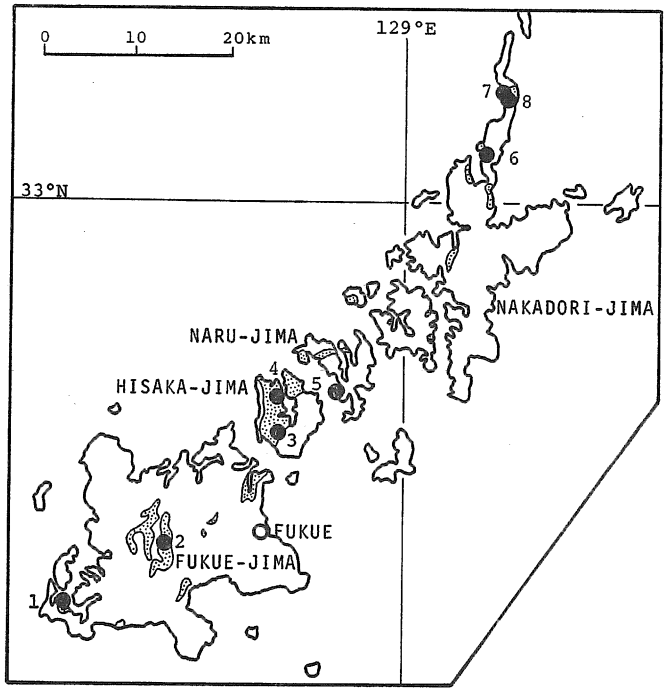

Fig. 1. Map of the Goto Islands showing sampling sites with stable and reliable NRM.

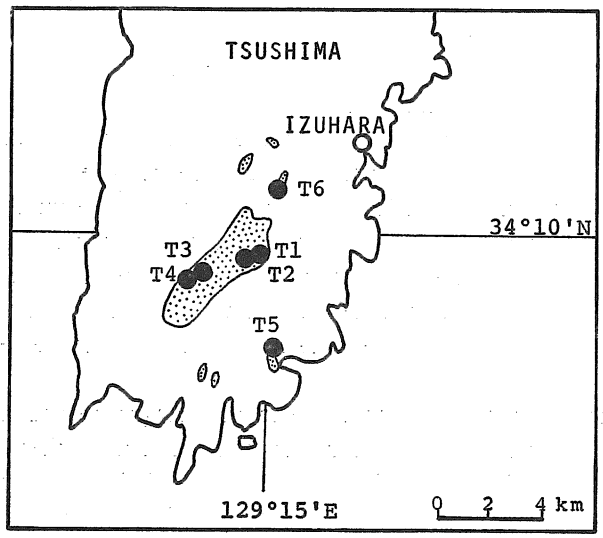

Fig. 2. Map of the southern part of Tsushima showing sampling sites with stable and reliable NRM.

configuration of remanent vectors formed inside of a granite mass corresponds with a record of the cooling history of the mass less than 580°C.

On the other hand, although granitic rocks have been occasionally affected by some crustal movements after the intrusion, granite bodies with the stable NRM are likely to behave as a single stable block to their crustal movements. It is for the reason that there have been many instances in which the NRM directions of a number of samples taken from an exposed mass are unwaveringly close to a mean except for those of the transition zone (Ito and Tokieda, 1978; Tokieda and Ito, 1978). This convenient behavior of granite masses implies that we can paleomagnetically estimate the influence of crustal movements after the emplacement of the masses.

2. Geological setting

Small stocks or dikes of Miocene granitic rocks are mainly exposed in Fukue-jima, Hisaka-jima, Naru-shima and Nakadori-shima in the Goto Islands and Tsushima, Nagasaki Prefecture (Geological Map "*Nagasaki-ken*", Scale 1:200,000, 1960). The granitic rocks in the Goto Islands have been dated as late Miocene from geological observations that they were intruded into the Goto group and the Goto volcanic complex of early or middle Miocene (Ueda, 1961; Matsui, 1969). A few bodies of biotite granites in Tsushima are exposed in and around the Uchiyama village, Izuhara-cho. The Uchiyama granite is a stock of about 5 km in diameter and was intruded into the Taishu formation in early Tertiary age (Matsumoto et al., 1962). Sampling sites with the stable and reliable NRM in the Goto Islands are shown in Fig. 1 and those in Tsushima are shown in Fig. 2.

3. Samples and measurements

Two hundred forty-two hand samples for paleomagnetic study were collected from 21 sites of 11 stocks or dikes in the Goto Islands. One hundred twenty-one hand samples were collected from 12 sites of 6 stocks in Tsushima. Two core specimens with 23 mm in diameter and 23 mm long were drilled from each sample in the laboratory.

The NRM was measured in a spinner magnetometer having a noise level of $\lesssim 10^{-7}$ emu. Stepwise alternating field (AF) demagnetization was applied to one core specimen per sample and specimens of all samples were demagnetized at progressive steps. A few core specimens of each sampling site were subjected to stepwise thermal demagnetization to 585°C. Criteria used to select samples exhibiting stable and reliable directions of NRM were to give rise to minimum dispersions for groups of specimens from each sampling site. Sixty six samples taken from 8 sites in the Goto Islands and 23 samples from 6 sites in Tsushima were allowed to be possessed of stable and reliable polarity directions. An example of thermal and AF demagnetization

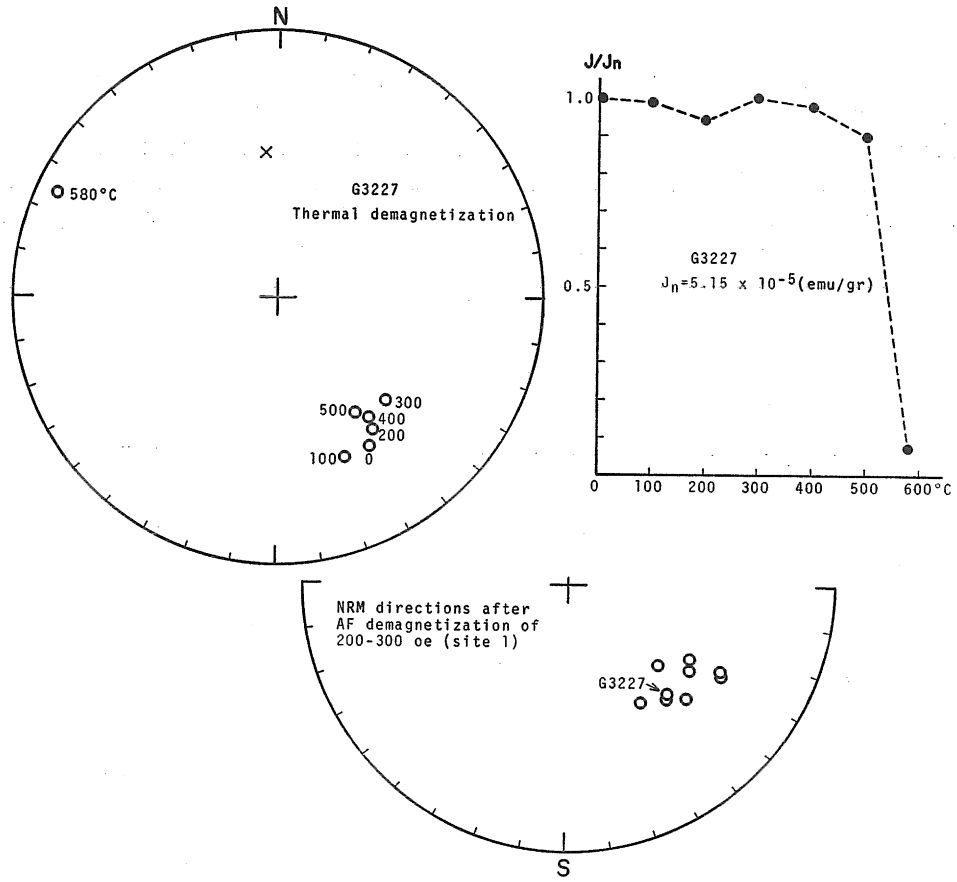

Fig. 3. Thermal demagnetization and AF cleaning for samples of site 1.

analysis for the same sample at site 1 are shown in Fig. 3. The NRM directions of stable samples selected are well consistent with each other after thermal and AF demagnetization treatment as seen in Fig. 3. The paleomagnetic data from each sampling site after AF cleaning are summarized in Tables 1 and 2. Site mean directions of the NRM after AF cleaning are also shown in Fig. 4.

4. NRM direction

Samples at site 3 within a stock exposed in Hisaka-jima were normally magnetized, and samples at site 4 in the same mass were reversely. Intermediate samples in the Goto Islands are taken from sites 1, 4, 6 and 7. Samples at sites 2, 3 and 5 were normally magnetized and their site mean directions are approximately close to the present field direction, and samples at site 8 was reversely and the site mean direction is anti-

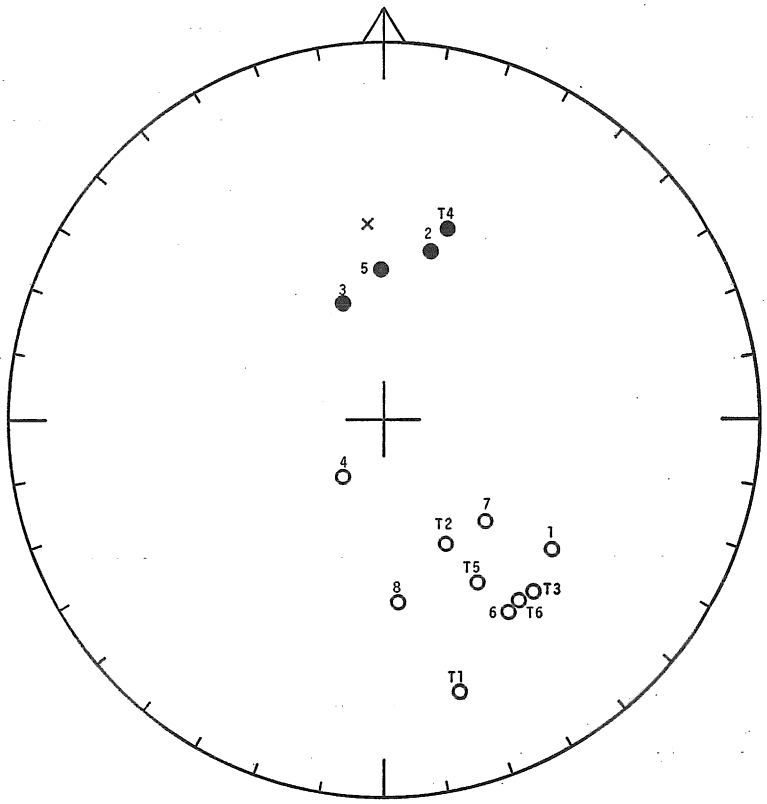

Fig. 4. Site mean directions of the NRM after AF demagnetization. Solid circles represent positive inclination and open circles represent negative inclination. Cross mark is the present geomagnetic field direction.

parallel to those of the sites 2, 3 and 5 as seen in Fig. 4.

The Uchiyama granite in Tsushima was reverse at sites T1, T2 and T3, and normal at site T4. Unfortunately confirmed distance between these sampling sites and the chilled margin of the contact is not well known. Some minor bodies of the granite (sites T5 and T6) exposed around the Uchiyama granite were reversely magnetized and the directions appear to accord with those of the sites T1, T2 and T3. The K–Ar age of the granite in Tsushima is 12 m.y. by Kawano and Ueda (1966).

The normal and reversed NRM directions of the sites 3 and 4 belonging to the same mass are somewhat deviated from the present field direction. This result may indicate that the mass was slightly affected by crustal movements after the intrusion. However, it may be important for us that intermediate NRM directions of the Goto granitic rocks are significantly consistent with those in Tsushima. A considerable similarity between intermediate NRM directions of different reversal records or reversal

Table 1. Paleomagnetic data for granitic rocks in the Goto Islands.

	Locality	n	P	D	I	k	α_{95}	I_n (emu/gr)	VGP Lati-tude	VGP Longi-tude	dp	dm
1	Fukue-jima	10	R	128.3°	−42.3°	69.8	5.8°	2.61×10^{-5} (200–300 oe)	44.3°S	137.8°W	4.4	7.2
2	〃	5	N	15.8°	51.3°	24.9	15.6°	8.61×10^{-6} (200–300 oe)	76.7°N	142.4°W	14.4	21.2
3	Hisaka-jima	10	N	340.5°	63.0°	84.1	5.3°	3.79×10^{-5} (200 oe)	70.9°N	82.1°E	6.5	8.3
4	〃	10	R	214.7°	−75.6°	20.8	10.9°	5.81×10^{-6} (300–400 oe)	52.9°S	25.4°W	18.3	19.9
5	Naru-shima	8	N	359.3°	57.1°	176.3	4.2°	7.90×10^{-6} (200 oe)	85.1°N	122.3°E	4.4	6.1
6	Nakadori-shima	6	N	146.5°	−39.1°	14.6	18.1°	4.22×10^{-6} (400–500 oe)	58.5°S	152.6°W	12.9	21.6
7	〃	6	R	134.7°	−59.3°	46.2	10.0°	4.87×10^{-6} (400 oe)	53.3°S	116.7°W	11.2	14.9
8	〃	11	R	176.1°	−50.0°	162.3	3.6°	9.41×10^{-5} (150 oe)	85.9°S	174.9°W	3.2	4.8

n : Number of samples
P : Polarity; N=normal; R=reversed.
D : Declination.
I : Inclination.
I_n : Intensity of the NRM after AF demagnetization.
k : Fisher's precision parameter.
α_{95}: Semi-angle of cone of 95 percent confidence for the site mean direction.
dp, dm: Semi-axes of ovals of 95 percent confidence.

Table 2. Paleomagnetic data for granitic rocks in Tsushima.

Locality	n	P	D	I	k	α_{95}	I_n (emu/gr)	VGP Lati-tude	VGP Longi-tude	dp	dm
T1	5	R	164.2°	−26.1°	351.4	4.1°	2.66×10^{-5} (300 oe)	65.1°S	168.1°E	2.4	4.4
T2	4	R	153.1°	−59.9°	95.9	9.4°	2.79×10^{-5} (200 oe)	67.8°S	115.6°W	10.7	14.2
T3	5	R	139.0°	−39.8°	72.0	10.9°	3.18×10^{-7} (200 oe)	52.4°S	147.6°W	7.9	13.1
T4	4	N	18.8°	45.5°	43.3	14.1°	1.05×10^{-5} (200 oe)	72.3°N	159.6°W	11.4	17.9
T5	2	R	150.2°	−48.5°	—	—	4.53×10^{-6} (200 oe)	64.4°S	142.6°W	—	—
T6	3	R	143.1°	−40.0°	—	—	3.74×10^{-6} (200 oe)	55.9°S	168.5°W	—	—

Symbols are as in Table 1.

ages has been occasionally observed in Japan (e.g. Ito, 1970) or in other countries (Dodson et al., 1978), but it should be noted that granite stocks with the normal and reversed polarity directions were severally found in both the regions of the Goto Islands and Tsushima.

According to Ueda (1961), the age of the Goto granitic rocks is likely to correlate with that of the Okueyama granitic rocks in the Soboyama area of central Kyushu as 13.8 ± 0.9 m.y. (Shibata, 1980) and the Omogo granitic rocks in Shikoku dated as 14.2 ± 2 m.y. (Shibata and Nozawa, 1968). Shibata (1978) recently concluded, from re-determined K–Ar data for the Outer Zone granites, that all of the Tertiary granites in the Outer Zone of Southwest Japan have a K–Ar age of 14×1 m.y., and he suggests that this fact demonstrates the contemporaneity of the post-kinematic plutonism in the Shimanto orogeny. Unfortunately dependable paleomagnetic data of the Okueyama and Omogo granitic rocks is very few at present. We have, however, found several granite masses which appear to have both of the normal and reversed NRM directions within a single mass from the Outer Zone granites in Kyushu, Shikoku and Kii peninsula in the Kinki District.

5. Discussion

Fig. 5 shows the VGP positions obtained from the Goto and Tsushima granitic rocks. As seen in the figure, the VGP positions from intermediate NRM directions at sites 1, 6, 7, T3 and T6 are in the Southern Pacific Ocean. This result is quite different from that obtained from Miocene and Pliocene rocks of Southwest Japan (Ito, 1970). Although only the VGP from site 4 is consistent with that from Miocene and Pliocene rocks of Southwest Japan, it is interesting that the other VGP positions (sites 1, 6, 7, T3 and T6) are closely situated on two similar pole paths obtained from the Laurel Hill intrusion of the Pliocene age (K–Ar age is 8.2 ± 0.55 m.y.) and the Tatoosh intrusion of the Miocene age (K–Ar ages of 18.05 ± 0.45 m.y. for hornblende and 16.23 ± 0.13 m.y. for biotite are given). This is an example that VGP paths of different reversal records were fortunately consistent with each other, but the ages of these reversal records are not obviously identical. It implies that a similarity between VGP paths does not usually demonstrates the contemporaneity of field reversal. In view of the variety involved in various reversal records, it would not be advisable to attempt to correlate VGP path with any other. However, it would be wise to take note of two antipodal remanent vectors observed in a single mass of granitic rocks.

In conclusion, we will propose an idea that Tertiary granitic rocks in Japan were mainly emplaced at the time of polarity transitions of the geomagnetic field, because significant granite masses with both of the normal and reversed NRM directions have been frequently observed in Tertiary granitic rocks throughout Japan. In other words, it is anticipated that the plutonic activity in Tertiary age was especially intensive at the time of polarity transitions. It is accordingly concluded that the Goto and

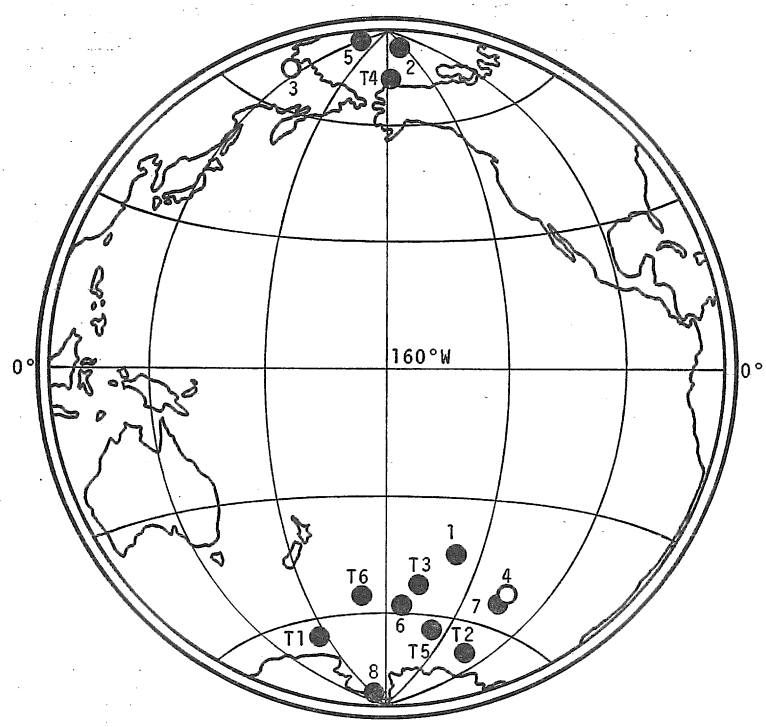

Fig. 5. VGP positions for the Goto Islands (1 to 8) and Tsushima (T1 to T6). Solid circles represent to be upper hemisphere and open circles to be lower hemisphere.

Tsushima granitic rocks were mostly emplaced at the time of polarity transitions of the geomagnetic field, but it is not known whether the granite bodies of both the regions were simultaneously intruded at the time of the same field transition.

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