Paleomagnetism of the Shimokura Dike Swarm in Northeast Japan

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1. Introduction

A dike swarm is the subterranean volcanism of more than several tens of intrusions. The subaerial volcanism of a single volcano generally persists its activity for 10^4 – 10^5 years (e.g., KUNO, 1976). A dike swarm is also considered to be formed in the same time interval as that of the subaerial one (NAKAMURA, 1977). Such time interval is considered to be sufficient to average out the geomagnetic secular variation (HEKI, 1983). Dike rocks are volcanic ones so that they have thermo-remanent magnetization which can yield reliable paleomagnetic data and that we can date them by some radiometric method. Furthermore, we find that dike swarms have occurred at many places throughout geological time. Dike swarms can be, therefore, used as a good tool to study paleomagnetism in spite of the uncertainty of the time sequence of individual intrusions.

In the present study, the Shimokura dike swarm, formed in the Late Miocene in Northeast Japan, was paleomagnetically investigated to analyze the paleosecular variation and to detect the tectonic movement of Northeast Japan.

2. Geology and Paleomagnetic Measurements

The Shimokura dike swarm is a part of more than one hundred dikes intruding into the Late Miocene tuffs, the Shirasawa Group, Miyagi Prefecture in Northeast Japan (AMANO, 1980; Fig. 1). This area was studied for baked contact test by KATO *et al.* (1954), which indicates the dikes in this area did not thermally affect each other. The dike rocks are composed of basalt, andesite and dacite. The K–Ar ages of about 8MaBP were obtained by TSUNAKAWA *et al.* (1983). Each dike ranges in width from 40 cm to 10 m and cuts the bedding plane of host rocks almost vertically. Because the host tuffs have nearly horizontal bedding plane, the tilting correction is considered to be unnecessary for paleomagnetic results of the dike rocks.

More than four independently oriented samples were taken from each of

Fig. 1. Locality map of the Shimokura dike swarm and the sampling site of Nos. 01–20 ($140^{\circ}43'E$, $38^{\circ}19'N$). Contours of a 50 m interval are also shown.

twenty sites (Nos. 01–20) using gasoline-engine drills and magnetic compasses (Fig. 1). Nos. 3 and 4 samples were collected from the different outcrops of the same dike. Every specimen was subjected to stepwise demagnetization in alternating field and its remanence was measured with a spinner magnetometer. Optimum demagnetization steps were determined for individual dikes by the minimum dispersion criterion. Directions of stable remanent magnetization with precision parameters (k ; FISHER, 1953) larger than 30 were obtained from fifteen dikes. Paleomagnetic results are listed in Table 1.

3. Paleosecular Variation and Tectonic Implications

All dikes showed reversed magnetization. Site-mean directions of remanent magnetization are illustrated in Fig. 2a by Lambert equal area projection. The average direction of site-mean ones and its 95% confidence circle are also shown in Fig. 2a. The directions indicate moderate dispersion around their mean and systematic declination shift by about 20° from the axial dipole field in a counterclockwise sense. This shift will be discussed later. Corresponding virtual geomagnetic poles (VGPs, Fig. 2b) yield an angular standard deviation (ASD) of 14.1° with a 95% confidence interval between 11.4° and 18.7° . In a zone of the Japanese latitude, the paleosecular variation is characterized by the 14° – 15° ASD of VGPs during the Brunhes epoch when averaged over a sufficient time span (McELHINNY and MERRIL, 1975; HEKI, 1983). The between-site ASD for the Shimokura dike swarm at the time of reversed polarity about 8MaBP accords well with this value.

Table 1. Paleomagnetic results and strike directions of the Shimokura dike swarm.

Dike	N	Incl.	Decl.	k	α_{95}	VGP		ODF (mT)	Strike	Rock Type
						Lat.	Long			
01	4	-53.1°	157.9°	625	3.7°	71.6°S	222.9°E	5	N83°E	B
02	4	-62.9	141.0	913	3.0	60.4	255.1	10	63	D
03,04	8	-68.5	145.7	356	2.9	62.6	271.4	10	63	D
05	4	-65.5	140.8	269	5.6	60.2	261.8	15	61	A
06	4	-72.2	150.8	399	4.6	63.1	285.1	10	53	A
07	4	-48.2	173.1	271	5.6	79.3	175.0	5	13	B
08	4	-46.7	163.5	39	14.9	72.8	198.6	5	23	B
09	4	-60.6	167.9	245	5.9	80.2	254.0	10	65	B
10	4	-64.7	161.4	265	5.7	74.0	268.0	10	37	B
11	4	-61.1	157.7	179	6.9	72.6	250.6	10	39	B
12	4	-75.7	156.0	212	6.3	61.4	298.0	10	55	A
13	4	-57.0	173.1	38	15.2	84.5	225.4	10	51	B
15	4	-61.2	177.9	63	11.7	85.7	299.5	15	53	B
16	4	-50.8	162.1	99	9.3	73.9	211.2	15	33	B
17	4	-73.8	195.5	412	4.5	66.3	340.2	15	37	A
Mean field	15	-62.1	162.0	55	5.2	—	—	—	—	
Mean VGP	15	—	—	31	7.0	75.0	261.0	(ASD = 14.1°)		

N: number of samples, Incl.: mean inclination, Decl.: mean declination, k : precision parameter by FISHER (1953), α_{95} : radius of 95% confidence circle. Lat.: latitude, Long.: longitude, ODF: optimum demagnetization field, ASD: angular standard deviation. The 03 and 04 samples were collected from different outcrops of the same dike. The K-Ar ages of 7.9 MaBP (No. 03) and 8.2 MaBP (No. 06) were reported by TSUNAKAWA *et al.* (1983). Rock type: A, andesitic, B, basaltic, D, dacitic.

The between-site mean direction of remanent magnetization for the Shimokura dike swarm has $I = -62.1^\circ$ and $D = 162.0^\circ$ with a 95% confidence circle of 5.2° . This declination shows a counterclockwise shift of about 20° from the axial dipole field. The ASD value of about 14° infers that the mean direction averages out the secular variation. The horizontal bedding plane of the host tuffs indicates no significant tilting after intruding of the Shimokura dikes. The declination shift is, therefore, interpreted as a result of tectonic rotation of this area after 8MaBP. The paleomagnetic results for the Yamadera and Taiheizan samples (see Fig. 1), obtained by OTOFUJI *et al.* (1984), show a similar declination shift. However, TOSHA (1984) reported that the paleomagnetic results of the Oga Peninsula region (see Fig. 1) in the west side of Northeast Japan show a counterclockwise rotation of about 50° during about 15–22 MaBP and that no significant tectonic rotation occurred in the Oga region after about 15 MaBP. We show the mean VGPs obtained by the present study, OTOFUJI *et al.* (1984) and TOSHA (1984) in Table 2 and Fig. 3. It is a serious problem whether or not the tectonic rotation inferred from these paleomagnetic studies is applicable to the surround-

Fig. 2. Paleomagnetic results projected on the equal area net. a) Mean field directions of fifteen dikes (open circles). All dikes show reversed remanences with systematic declination shift from the geocentric axial dipole field (cross symbol). Open star denotes the between-site mean direction with a 95% confidence circle. b) VGP positions in the northern hemisphere obtained from the present study.

Table 2. Mean VGP's in northern hemisphere reported on the Middle to Late Miocene rocks in Northeast Japan.

Locality	<i>N</i>	Lat.	Long.	<i>K</i>	<i>A</i> ₉₅	Age	Ref.
Shimokura	15	75.0°N	81.0°E	31	7.0	8MaBP	This study
Yamadera and Taiheizan	4	70.2	80.7	—	—	11–14MaBP	OTOFUJI <i>et al.</i> (1984)
Oga Peninsula	9	86.0	–87.9	—	—	12–17MaBP	TOSHA (1984)

Fig. 3. Mean VGP positions listed in Table 2. (1) the Shimokura dike swarm by the present study with a 95% confidence circle, (2) the Yamadera and Taiheizan by OTOFUJI *et al.* (1984), (3) the Oga Peninsula by TOSHA (1984).

ding region of sampled areas. Further accumulation of paleomagnetic data will reveal the coherency of tectonic movement in Northeast Japan.

We can estimate the direction of horizontal maximum stress field (σ_{Hmax}) from a dominant strike of dike swarm (NAKAMURA, 1977). The Rose diagram

of strikes for the Shimokura dike swarm is shown in Fig. 4 and indicates a dominant strike of N60E. The σ_{Hmax} is, therefore, inferred to have an *in-situ* direction of N60E. When we take the counterclockwise rotation of about 20° into account, the 8MaBP σ_{Hmax} direction becomes a N80E, nearly an E-W trend. This σ_{Hmax} direction is in accord with that of the E-W compressional stage in the southern part of Northeast Japan since about 8MaBP (TSUNAKAWA, 1985). SATO *et al.* (1982) suggested that the σ_{Hmax} directions are characterized by NE-SW and NW-SE trends in the northern part of Northeast Japan whilst these are by E-W and N-S trends in the southern part (TAKEUCHI, 1981; TSUNAKAWA, 1985). This difference is possibly attributed to the tectonic rotation of the northern part after the Late Miocene.

Fig. 4. Rose diagram of twenty-two dikes in the Shimokura dike swarm. These dikes include those used in the present study (twenty dikes) and others observed within the sampled area (two dikes).

4. Summary

The paleomagnetic study of the Shimokura dike swarm gave the ASD of the paleosecular variation of 14.1° at the time of reversed polarity about 8MaBP. This ASD value is comparable to that observed in Japan in the Brunhes epoch. Mean field direction shows a counterclockwise declination shift of about 20° from the axial dipole field. This shift suggests that the sampled area of the Shimokura dike swarm in the northern part of Northeast Japan has undergone the tectonic rotation in a counterclockwise sense after 8MaBP. Further paleomagnetic studies will clarify more detailed features of the tectonic movement in Northeast Japan.

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