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Paleomagnetic Study of the Higashi-Izu Monogenetic Volcano Group and Pyroclastic Flow Deposits in Kagoshima Prefecture: Paleosecular Variation During the Last 40,000 Years in Japan

Kosuke HEKI

Geophysical Institute, University of Tokyo, Tokyo, Japan

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1. Introduction

The standard way to detect the amount of the ancient geomagnetic secular variation (paleosecular variation, PSV) is to calculate the angular dispersion of virtual geomagnetic poles (VGP) of a certain set of paleomagnetic data such as those of successive lava flows of a stratovolcano. For Japanese region, there have been reported few estimates of PSV in spite of the vigorous activity of many young volcanoes. The only estimate of recent PSV is that of OZIMA and AOKI (1972) which is obtained from the archeomagnetic data of the last 9,500 years compiled by KINOSHITA (1970). They reported anomalously small angular dispersion which largely deviates from global trend. Later, BAAG (1974) criticized that this small PSV might be due only to the insufficiency of the total time span, that is, the time span of 9,500 years is less than the period of the wobbling motion of the geocentric dipole and is too short to provide an adequate estimate of total secular variation. The estimate of PSV is presumably in close relationship with the time span covered by paleomagnetic samples. Generally speaking, an angular dispersion of VGPs obtained from the samples of relatively short time span in comparison with major periods of geomagnetic secular variation is considered to be smaller than those with longer time spans having sufficient temporal coverage over the periods of geomagnetic secular variation. Hence, it is important to reveal the relationship between the time span and the angular dispersion of VGPs and to clarify which value represents PSV in Japan.

In this paper, a PSV study is reported from a set of paleomagnetic data obtained from the Higashi-Izu monogenetic volcano group and pyroclastic flow deposits in Kagoshima Prefecture which have a time span of about 40,000 years (from 40,000 years before present to the present). Its angular dispersion of VGPs is compared with several paleomagnetic and archeomagnetic data sets of various time spans thus far reported in Japan and the appropriate width of the time span is discussed.

2. Geology

2.1 The Higashi-Izu monogenetic volcano group

The Higshi-Izu monogenetic volcano group is composed of about 70 monogenetic volcanoes scattered over an area of more than 400 km^2 in the middle and eastern part of Izu Peninsula, Central Japan (Aramaki and Hamuro, 1977; Hamuro, 1978). The volcanic activity began in the Late Pleistocene after the extinction of a series of Quaternary stratovolcanoes such as Amagi, Usami, Tenshi, etc. These monogenetic volcanoes were formerly referred to as Omuroyama volcano group and Amagi lateral volcano group. Aramaki and Hamuro (1977) suggested that these volcanoes might be grouped as a single group on the basis of the homogeneity of the modes of volcanism, the nature of magma, and the ages of eruptions. They proposed the name Higashi-Izu monogenetic volcano group because the nature of each eruptive episode was monogenetic, and inferred that this volcanism took place during the last 40,000 years. Samples for this paleomagnetic investigation were collected from twenty-two lava flows (Fig. 1, HI series). From each lava flow, six to seven core samples were taken by using gasoline-powered drills.

2.2 Pyroclastic flow deposits in Kagoshima Prefecture

Late Pleistocene pyroclastic flow deposits are distributed widely over the southern area of Kyushu Island. Volcanism was especially vigorous in and around Kagoshima Bay, and great amount of pyroclastic flows were effused and deposited in

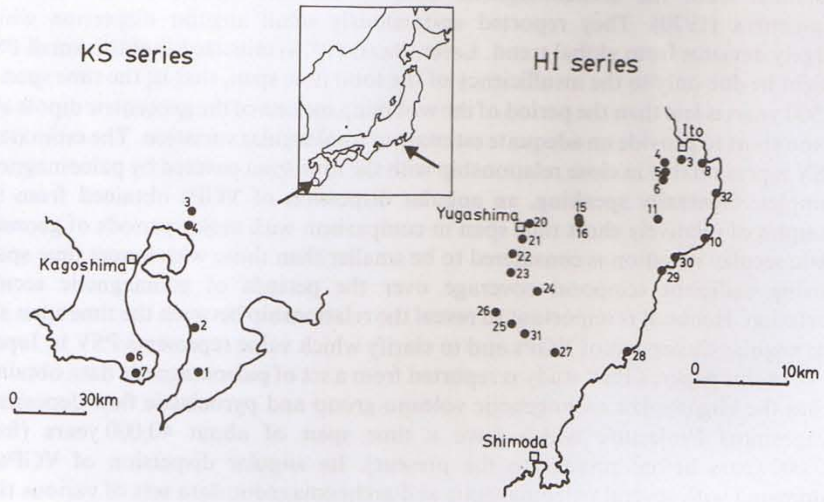

Fig. 1. Paleomagnetic sampling localities of Higashi-Izu monogenetic volcano group (HI series) and pyroclastic flow deposits in Kagoshima Prefecture (KS series). Names of these lava/pyroclastic flows are given in Table 1.

this region. Geology and stratigraphy in this region is reported by ARAMAKI and UI (1966), ARAMAKI (1969) and others. Five pyroclastic flows and one dacite lava flow were sampled (Fig. 1, KS series) for this paleomagnetic study. The oldest of them is Ata pyroclastic flow whose radiocarbon age is about 30,000 years before present. Each sample was taken with a hammer as an oriented block and afterwards cut into a core specimen in the laboratory.

3. Experimental Procedures and Results

Schonstedt spinner magnetometer model SSM-1A was used in the measurement of natural remanent magnetization (NRM), and stepwise alternating field (AF) demagnetization was performed for each specimen in more than six steps until the original NRM intensity is mostly destroyed. Median destructive fields (MDF) showed the distribution from 7.5 mT to more than 50 mT but were typically between 10 and 20 mT. Ancient geomagnetic field direction was determined from the mean direction of remanent magnetization at the optimum step of the successive AF demagnetization. Optimum steps were determined for individual sites by the criterion of minimum dispersion. Table 1 summarizes paleomagnetic results with their statistical results after Fisher (1953). Mean field directions and corresponding VGPs are plotted by Lambert equal area projection in Fig. 2a, b. VGPs are found to be moderately scattered with a certain elongation and their average is well coincident with the geographical north pole.

In this paper, I define PSV conventionally as an angular standard deviation (ASD) of VGP sets around their mean. This ASD (S_{total}) contains both within-site ASD (S_w) and between-site ASD (S_b). The latter represents true PSV and is isolated by subtracting the contribution of within-site dispersion. 95% confidence limits of the ASD were calculated from the table presented by COX (1969). The VGP corresponding to the present geomagnetic field in Izu Peninsula is added to the VGP set and the ASD was calculated on 29 VGPs in total. The obtained ASD was 13.9° with 95% confidence interval between 11.7° and 16.9°.

4. Discussion and Conclusion

The estimate of PSV from the ASD value of VGPs may, to some extent, be correlated with the width of a time interval covered by the age of the samples. From this viewpoint, it is meaningful to collect various paleomagnetic data sets in Japan and to compare their ASDs among these VGP sets of different time spans.

Japanese archeomagnetic data were compiled over 500–1950 AD by HIROOKA (1971) and an ASD of 9.1° (+2.0°, −1.4°) using 30 VGPs of these archeomagnetic data is reported in HIROOKA *et al.* (1977). On the other hand, OZIMA and AOKI (1972) reported PSV study with 28 VGPs of the last 9,500 years picked up from a review article by KINOSHITA (1970). They calculated an ASD of 10.2° (+2.3°, −1.6°) and suggested possible "quiet secular variation" in Japan. MCELHINNY and MERRILL (1975) calculated ASDs from Japanese paleomagnetic data over two longer age

Table 1. Paleomagnetic data.

Site	N	Inclination (°)	Declination (°)	R	k	α_{95} (°)	—VGP— Lat. (°N)	Long. (°E)	MDF (mT)	ODF (mT)	Name
HI-3	7	52.7	−12.9	6.9885	520	2.6	79.2	43.9	12.5	2.5	Jōboshi
HI-4	7	73.2	42.8	6.9750	240	3.9	53.7	174.7	10	15	Kadono-1
HI-5	7	68.5	28.6	6.9838	370	3.1	63.5	180.7	30	15	Kadono-2
HI-7	6	44.3	7.5	5.9869	382	3.4	79.0	281.2	20	40	Ōmuroyama-1
HI-8	7	67.9	19.3	6.9915	709	2.3	68.8	174.3	25	15	Komuroyama
HI-10	7	48.2	0.7	6.9981	3127	1.1	84.3	313.0	40	0	Ōmuroyama-2
HI-11	6	65.8	23.9	5.9892	461	3.1	67.9	185.2	10	10	Dainoyama
HI-15	7	35.4	−3.3	6.9784	278	3.6	74.4	330.6	20	5	Jizōdō-3
HI-16	7	33.2	−3.5	6.9884	519	2.7	73.0	330.4	10	15	Jizōdō-2
HI-20	7	55.6	11.3	6.9642	168	4.7	80.7	217.9	7.5	5	Nagano
HI-21	7	60.2	16.8	6.9633	163	4.7	75.4	198.6	10	40	Yoichizaka
HI-22	7	53.4	0.0	6.9725	218	4.1	89.1	318.9	12.5	10	Hachikuboyama
HI-23	6	53.5	−2.6	5.9893	467	3.1	87.7	29.6	10	10	Hontanigawashiryū
HI-24	7	55.8	−1.2	6.9794	291	3.5	88.2	106.7	25	5	Hacchōrindō
HI-25	7	56.5	−0.3	6.9972	2164	1.3	87.7	132.9	10	10	Numanokawa-1
HI-26	7	59.5	−17.7	6.9849	396	3.0	75.0	75.6	10	10	Numanokawa-2
HI-27	7	55.9	0.5	6.9922	768	2.2	88.3	152.5	10	10	Hachiyama
HI-28	6	55.6	16.5	5.9932	737	2.5	76.5	218.5	30	10	Inatori-2
HI-29	7	57.0	18.3	6.9770	261	3.7	75.0	213.2	30	15	Akakubo
HI-30	7	39.2	−8.3	6.9925	800	2.1	75.4	351.1	15	10	Iyūzan
HI-31	7	48.9	−9.0	6.9668	181	4.5	80.9	18.2	20	0	Noboriominami
HI-32	7	60.0	10.0	6.9880	501	2.7	80.1	189.1	7.5	15	Chikubo-gairinzan
KS-1	7	34.1	−7.2	6.9795	292	3.5	75.9	340.0	25	5	Tashiro
KS-2	7	31.8	−1.6	6.9930	861	2.1	75.8	317.1	50	10	Ata
KS-3	7	43.5	4.8	6.9402	100	6.1	82.3	276.2	25	10	Ito
KS-4	4	49.6	0.0	3.9695	98.5	9.3	88.7	306.8	20	1	Iwato
KS-6	6	51.5	−3.3	5.9469	94.1	6.9	87.0	60.1	70	40	Ikeda
KS-7	7	53.8	6.0	6.9715	210	4.2	84.1	187.1	30	60	unnamed
Present field*	—	47.5	−6.1	—	—	—	81.9	0.2	—	—	—
Averaged VGP	29	—	—	28.1802	34.1	4.6	87.3	220.4	—	—	—

N, number of specimens measured; R, length of resultant vector; k, precision parameter of FISHER (1953); α_{95}, half angle of the cone of 95% confidence; Lat., latitude of VGP; Long., longitude of VGP; MDF, median destructive field; ODF, optimum demagnetizing field; Name, name of the volcano/pyroclastic flow.

*Present geomagnetic field in the area of the Higashi-Izu monogenetic volcano group.

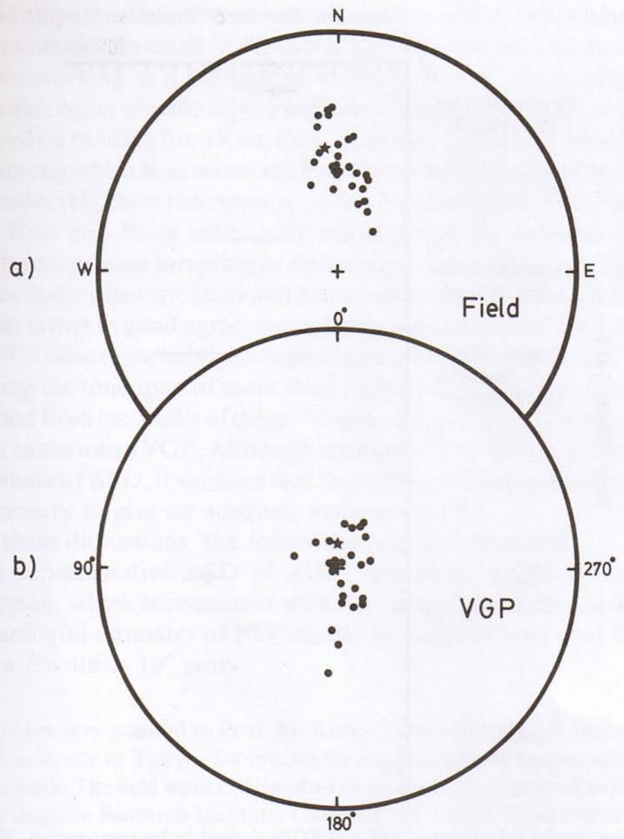

Fig. 2. (a) Site mean field directions of Higashi-Izu monogenetic volcano group and pyroclastic flow deposits in Kagoshima Prefecture plotted by Lambert equal area projection. Star indicates the direction of present geomagnetic field in Higashi-Izu area. All are positive inclinations. (b) Virtual geomagnetic poles (VGP) of Higashi-Izu monogenetic volcano group and pyroclastic flow deposits in Kagoshima Prefecture. Star indicates the VGP which corresponds to the present field direction in Higashi-Izu area.

intervals (Brunhes epoch and the last 5 Ma). They reported ASDs of 13.7° (+1.7°, −1.4°) for Brunhes epoch and 18.3° (+1.4°, −1.2°) for the last 5 Ma. These ASDs and an ASD derived in this study are illustrated with their 95% confidence intervals in Fig. 3. VGP sets of short time spans (less than 10,000 years), namely archeomagnetic data over the last 1,500 years (9.1°) and over 9,500 years (10.3°) show relatively small ASD values. On the other hand, the ASDs of the Higashi-Izu monogenetic volcano group and Kagoshima pyroclastic flow deposits (13.9°) and Japanese data compiled over Brunhes epoch (13.7°) by McElhinny and Merrill (1975) are slightly larger.

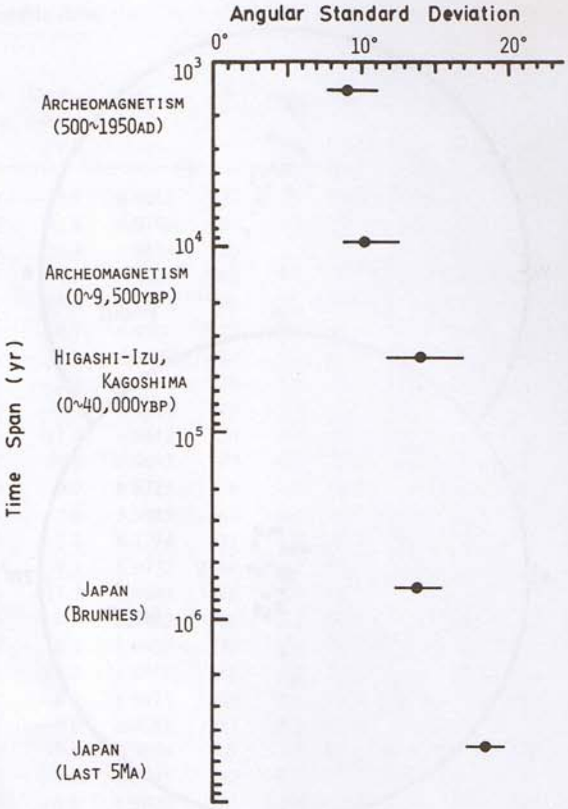

Fig. 3. Angular standard deviations (ASD) of VGPs derived in Japanese region. The ordinate denotes the time span covered by paleomagnetic samples.

These ASDs of 13.9° and 13.7° are both in good agreement with the PSV data derived from the other areas situated around the latitude of about 35°N compiled and listed in McELHINNY and MERRILL (1975) for the Brunhes normal epoch, which suggests that the ASD value of about 14° represents the PSV in Japanese region. As for the longer time span data, the ASD for Japanese data compiled over the last 5 Ma shows a little larger value (18.3°). This may be due to the integrated effect of some disturbance caused by tectonic movements because Japanese region has been tectonically active region during that time range. However, ASDs show similar values for the time spans of 40,000 years (HI and KS) and 680,000 years (Brunhes epoch), and so the contribution of tectonic disturbance to the ASD is not substantial when the time span is narrower than a few times 10^5 years. It is reasonably concluded that too short time spans, say less than 10^4 years may yield apparently small ASDs.

Hawaiian region is one of the areas where most intensive paleomagnetic surveys were carried out. DOELL and COX (1972) reported an ASD of 10.8° in Hawaii which is too small in comparison with those from other areas of the similar latitude. In order to explain the anomalously small ASD, they suggested some lateral inhomogeneity of the lower mantle working as a permanent screen to subdue the nondipole field in the Central Pacific region (Pacific dipole window). The original ASD of DOELL and COX (1972) is based on the data from Kau, Puna, Kahuku, Hamakua, Ninole, Pololu, Oahu and so on, among which Kau series and Puna series were suggested by COE *et al.* (1978) to be of considerably short time span, say a few hundred years. They suggested that the data from Kau and Puna series may unduly bias the estimate of ASD due to unrepresentatively dense sampling in rather narrow time interval. They also showed that VGPs excluding historic lavas and Kau and Puna series show an ASD which is not too small but rather in good agreement with the value expected from the global trend. COE *et al.* (1978) also reported eight original paleomagnetic data from ^{14}C-dated recent lavas covering the time span of more than 15,000 years. It is very interesting that the ASD obtained from the VGPs of these ^{14}C-dated lavas show such a high value as 15.5° with respect to the mean VGP. Although the number of VGPs is too small to provide a reliable estimate of ASD, it suggests that the minimum time span of more than 10,000 years is necessary to give an adequate estimate of PSV.

From these discussions, the followings may be concluded;

1) The representative ASD of VGPs caused by the PSV is around 14° for Japanese region, which is consistent with the value expected from the global trend.

2) Meaningful estimates of PSV should be made at least over the time span of more than a few times 10^4 years.

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