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29. *Palaeomagnetic and Geologic Researches for the Volcanic Rocks around Lake Suwa. —Palaeomagnetic Researches for the Pliocene Volcanic Rocks in Central Japan (2)—*

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Summary

Palaeomagnetic research for Pliocene lava-flows of the Enrei formation in Central Japan supplied a lot of reliable evidence concerning palaeomagnetic variations in geologic times. It seems likely that the pole position might have migrated westward encircling the present position of the Earth's rotation axis through the whole time range of the Enrei formation.

The geomagnetic field might rather be stable only in the case when the dipole axis was close to the rotation axis, and the geomagnetic reversal might have taken place in an way unconnect with the rotation axis through the span of time when geomagnetic unstability was introduced by some causes.

It has become possible to infer the geologic age of various volcanic rocks of late Cenozoic times by means of palaeomagnetic considerations.

1. Introduction

In his preceding paper[1] the senior author presented his opinions about the geomagnetic variation in Younger Tertiary times based upon his rock-magnetic studies of various volcanic rocks in Central Japan. In that discussion, the results obtained from the Enrei formations were an important part of the available data for the confirmation of his conclusion. This is the second paper in which the authors are to refer to some more evidences found in the Enrei formations.

1) K. MOMOSE, *Jour. Geomagn. Geoelectr.*, **10** (1958), 12.

As was formerly reported, the senior author[2a, b)] made for the first time in 1954 a notable finding that the magnetic polarization of the so-called "*Teppeiseki*" from a famous quarry at Fukuzawa-yama was reversed. Since that time, the two junior authors have been co-operating with the senior author in his field work and geologic considerations.

Lake Suwa (36°2′N. Lat.; 138°5′E. Long.) which is situated in the mountainous district of Central Japan, is thought to have originated from structural depression which might have taken during the Pleistocene. In the earliest days of geological research, Harada[3)] expressed his opinion that Lake Suwa might originate from a huge crater perhaps of *Maar*. Apart from this sort of problematic opinion, we can find around Lake Suwa a complex of pyroclastic formations consisting of an enormous quantity of tuff-breccias and associate lava-flows over a wide extent perhaps of 200 Km^2. or more[4),5),6)]. It is a well-known fact that some lava-flows in the Enrei formation are markedly platy-jointed and are called "*Hira-ishi*" or "*Teppeiseki*" (the name signifies "*Iron-flagstone*"). Both features of jointed structures and remarkable lateral extension of lava-flows are dominant characteristics of andesites of the Enrei formation. Another peculiar feature of the Enrei formation is that water-deposited signs of tuffaceous parts are recognized lithologically in many places and especially in the upper part of the formation. The summit level of the upland consisting of the Enrei formation is therefore thought to be a depositional surface.

In the light of the results obtained from rock-magnetic researches, the traditional and conventional methods of interpretation which are concerned with the sequence of volcanism in this area need several revisions.

Leading articles which will be mentioned in the text are expressed briefly as following:

(1) According to observed magnetic polarization of rock samples, the age of the Enrei formation may be assigned to the Younger Pliocene.

(2) Calculated pole positions seem accordingly to record the feature

2a) T. NAGATA, S. AKIMOTO, S. UYEDA, K. MOMOSE, & E. ASAMI, *Jour. Geomagn. Geoelectr.*, **6** (1954), 182.

2b) K. MOMOSE, *Science* (*Kagaku*), **25** (1954), 257.

3) T. HARADA, (1888); *See Maumann, E.* (1893) *Pethermanns Mitt.*, **108**. Ergänzungsheft, 26.

4) N. YAMAZAKI, *Shinsai Yobo Chosakai Hokoku*, **20** (1898).

5) F. HOMMA, *Geology of Central Shinano, Kokon Shoin, Tokyo* (1931).

6) K. SAWAMURA & E. OWA, *Geological Map and its Explanatory Text* (1: 50,000), *Suwa sheet*; *Geol. Survey Japan* (1953).

of secular variations of geomagnetic field during the Younger Pliocene.

(3) The feature of secular variation of the geomagnetic field, may also afford a valid base of correlation for Pliocene chronology.

(4) The traditional method in which we have attempted to make correlations of various volcanic rocks based mainly upon their lithological characteristics, was recognized not to be a decisive one.

(5) By means of *AC*—demagnetization and some other treatments, it has been proved that a series of rock samples which maintains anomalously strong magnetism might have been given by lightning.

(6) Based upon geologic field evidences, no significant hiatus was recognized as intervening between Kirigamine Volcano and the Enrei formation. Although a slight transitional feature of lithology might be recognized among these volcanic rocks, the volcanic activity which have built Kirigamine Volcano should be referred to that of the final or later stage of the Enrei Volcanism.

(7) Kirigamine Volcano which has long been assigned as an example of shield volcanoes[7] may be a member of the Enrei formation and accordingly the necessity of origination of such a flat type of volcanic cone may easily be understood.

(8) Considering that the Enrei formation is to be Younger Pliocene in age and that the base level is averagely at an altitude less than 1,500 m, the following conclusion which offers a serious bearing on geomorphology of this area, may be introduced. The highest erosion surfaces which truncate the mountain ranges bordering the outer margin of the Enrei formation and which are at the level higher than 1,500 m might have originated since late Tertiary times or perhaps the late Miocene.

2. Labolatory Tests

1. *Examination of stabilities of rock magnetism*

In order to carry out reliable studies of palaeomagnetism, it is required to conduct close examinations[8] related to the stabilities of rock magnetism. Since the samples which the authors have treated were so many, it was hardly possible to test their stabilities by applying the full procedures proposed. Most samples have therefore been tested by making use of a slightly simplified method as described in the following.

(1) First, it is highly likely that the *R.N.R.M* (*Reverse N.R.M.*)

7) H. KUNO, *Volcano and Volcanic Rocks* (Tokyo 1954), *Iwanami, Tokyo*.
8) K. MOMOSE, *loc. cit.*, 1).

retained in rocks has long been under the influence of the geomagnetic field which is nearly opposite to it in direction. The fact that we still observe reversed magnetizations seems to indicate the stableness of the *R.N.R.M.* retained in rocks.

Secondly, it should be examined whether or not the *R.N.R.M.* is caused by self-reverse magnetization[9),10),11),12)]. For this purpose, several samples were heated up to 600°C in a non-magnetic electric oven and cooled in the geomagnetic field in order to observe the nature of *T.R.M.* All the samples thus treated show that their *T.R.M.* are of normal type indicating that their magnetic directions agree in every case with that of the geomagnetic field.

There still remains a slight possibility that the self-reversal mechanism of magnetization might once have affected the magnetism of our samples as was suggested by Kawai and others[13)], who have detected the existence of self-reversal mechanism originated from exsolution of magnetic rock-forming minerals. In this respect, however, the authors are unable to offer any plausible proof.

(2) The authors found in Central Japan many examples which might have been influenced by peculiar magnetizations due to thunderbolts. In order to recognize magnetizations of this kind, some of the samples were demagnetized by *AC*-demagnetization assay. This way of demagnetization is also useful for the detection of occurrence of any unstable component (i.e. *I.R.M.*).

(3) The value of Jn/JTc

On the assumption that the intensities of geomagnetic field in the past is roughly comparable with that of the present, the samples of which the values of Jn/JTc are within a range from 0.2 to 1.0 are treated here.

From the above-mentioned standpoint, the tests made on rock samples from various localities will be discussed in the following. The following notations are adopted in the figures and tables.

Jn ・・・・・・・intensity of natural remanent magnetism.

JTc ・・・・・・intensity of thermo-remanent magnetism.

Jn-T ・・・・・mode of thermal demagnetization of *Jn* by heating up to T and cooling down to T_0 in non-magnetic space (T_0: room temperature).

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9) T. NAGATA, S. UYEDA, and S. AKIMOTO, *Jour. Geomagn. Geoelectr.*, **4** (1952), 22.
10) T. NAGATA, S. UYEDA, and S. AKIMOTO, and N. KAWAI, *ibid.*, **4** (1952), 102.
11) T. NAGATA, S. AKIMOTO, and S. UYEDA, *ibid.*, **5** (1953), 168.
12) S. UYEDA, *Jap. Jour. Geophys.*, **2** (1958), 1.
13) N. KAWAI, S. KUME, and S. SASAJIMA, *Proc. Jap. Acad.*, **30** (1954), 588.

JTc-T ····mode of thermal demagnetization of *JTc* by heating up to T and cooling down to T_0 in non-magnetic space (T_0: room temperature)

Js-T ·····mode of saturation magnetization with respect to change of temperature T.

$(Jn)\tilde{H}$ ····mode of demagnetization of *Jn* by alternating magnetic field whose maximal intensity is H.

$(JTc)\tilde{H}$ ···mode of demagnetization of *JTc* by alternating magnetic field whose maximal intensity is H.

2. *Basic test applied to the samples taken from Fukuzawa-yama near Suwa.*

As the samples taken from Fukuzawa-yama have offered a standard

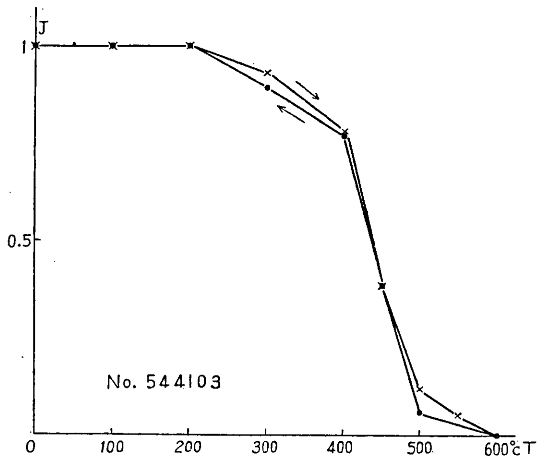

Fig. 1. Modes of variation of *JTc* through heating and cooling processes (andesite at Fukuzawa-yama).

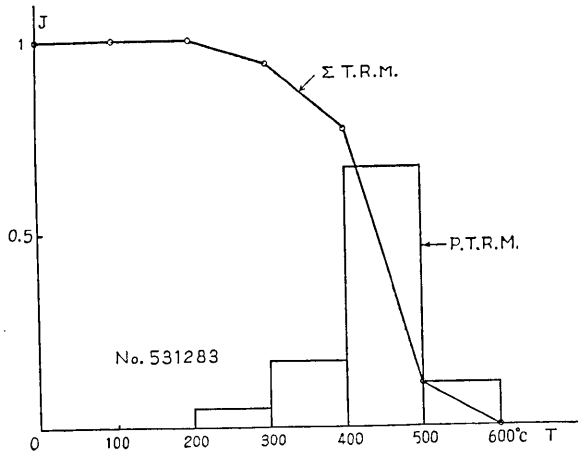

Fig. 2. The thermo-remanent magnetization curve showing that it coincides with the total sum Σ of partial thermo-remanent magnetism (*P.T.R.M.*) produced by cooling in the present geomagnetic field. (andesite at Fukuzawa-yama).

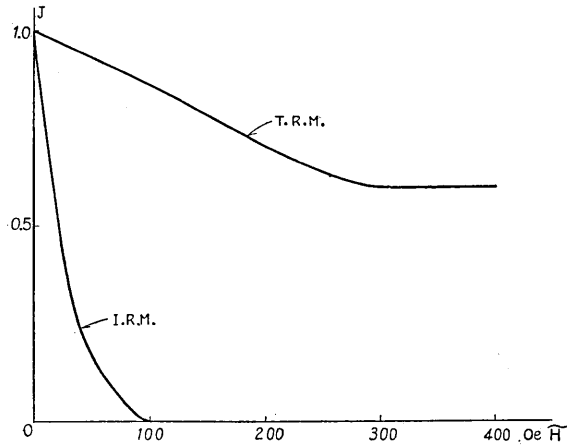

Fig. 3A-3G. Curves of *AC*-demagnetization applied to *N.R.M.* (*Jn*)$\widetilde{H}$ and to *T.R.M.* (*Jtc*) $\widetilde{H}$.

Fig. 3A. Samples from Mt. Utsukushi-ga-hara (Upper lava).

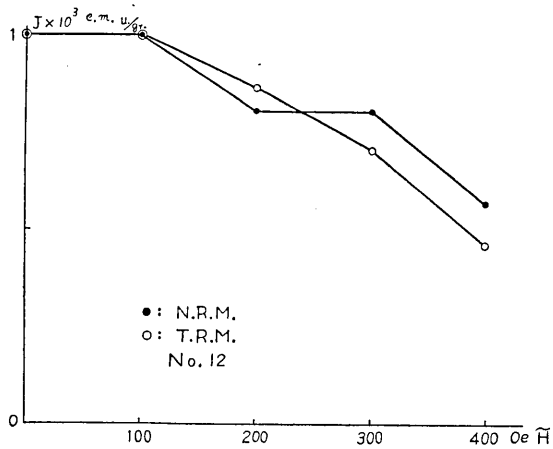

Fig. 3B 1. Samples from Mt. Takao-san.

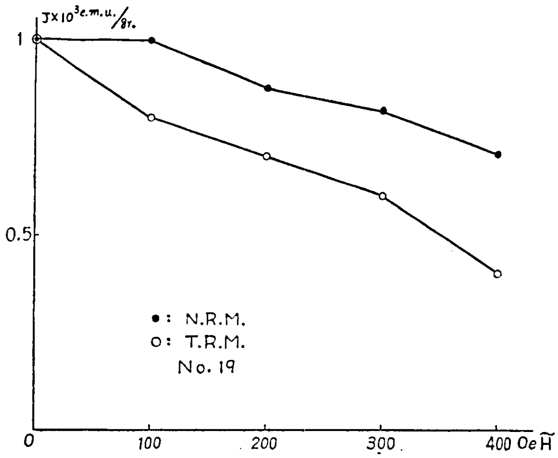

Fig. 3B 2. Samples from Mt. Takao-san.

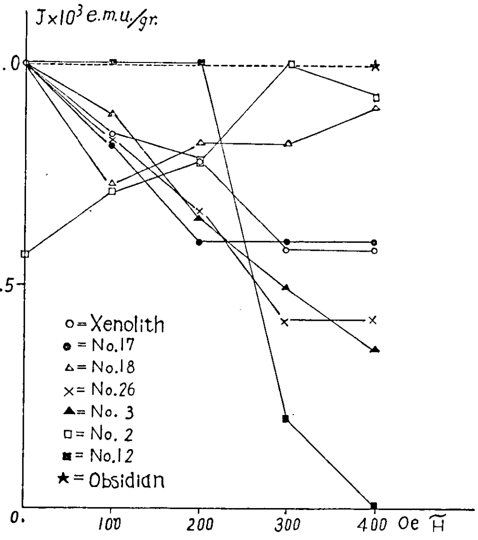

Fig. 3 C. Samples from the pass of Wada-toge.

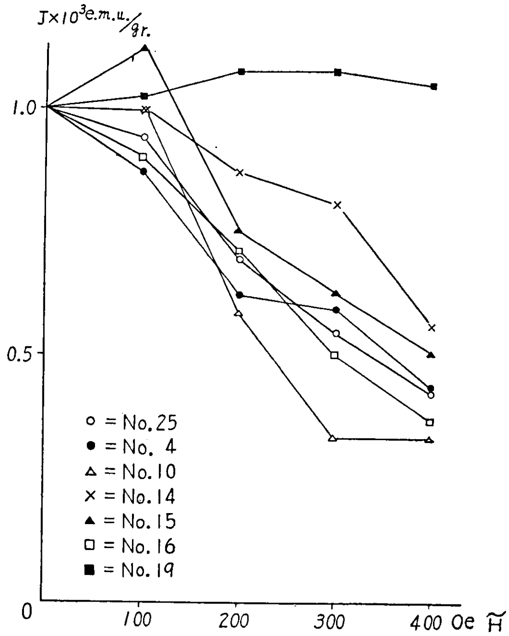

Fig. 3 D. Samples from Kawagishi.

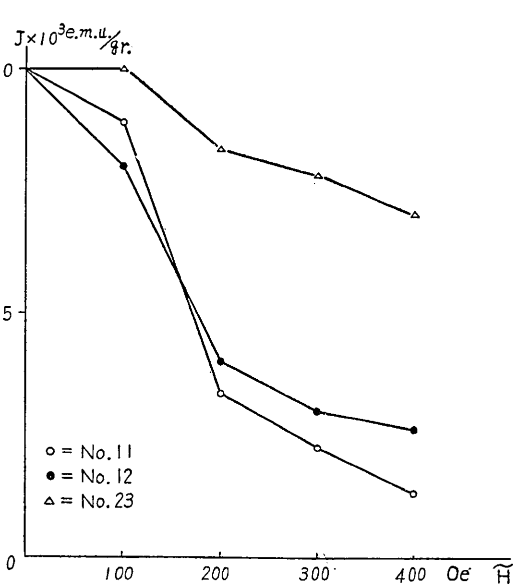

Fig. 3 E. Samples from Mt. Mitsu-mine.

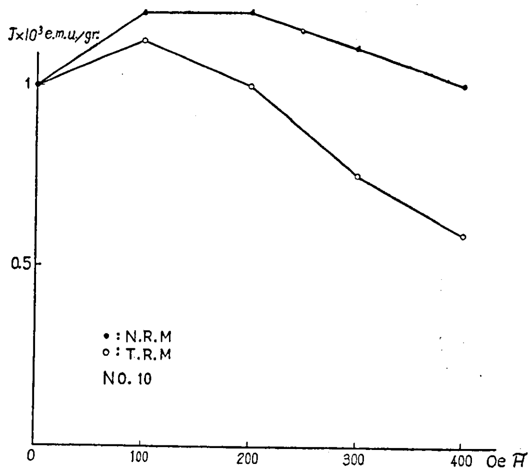

Fig. 3 F. Samples from Mt. Utsukushi-ga-hara.

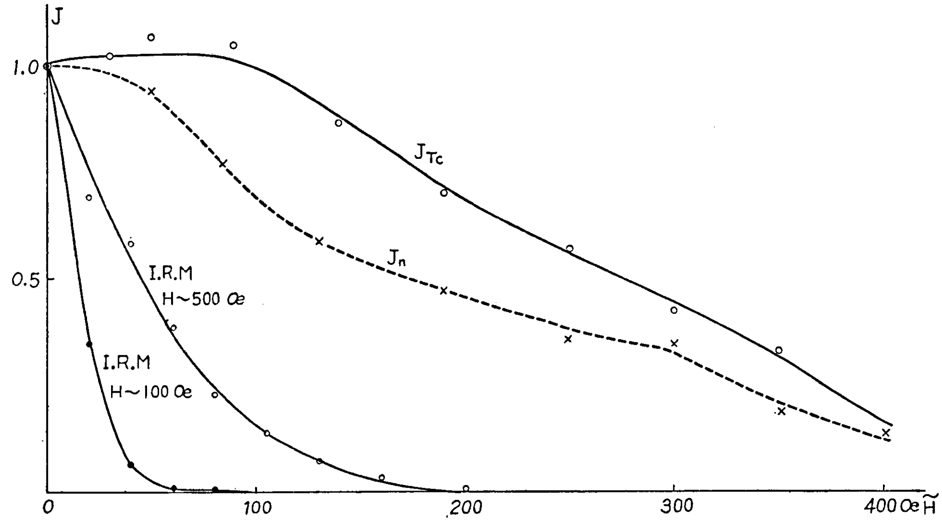

Fig. 3 G. Samples from Fukuzawa-yama.

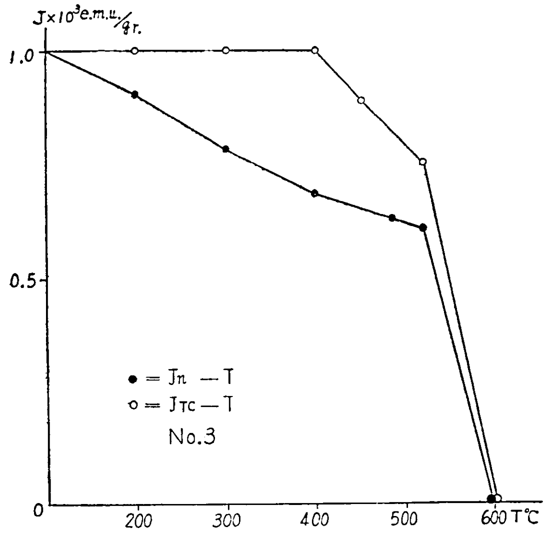

Fig. 4 A 1. Samples from Mt. Takao-san.

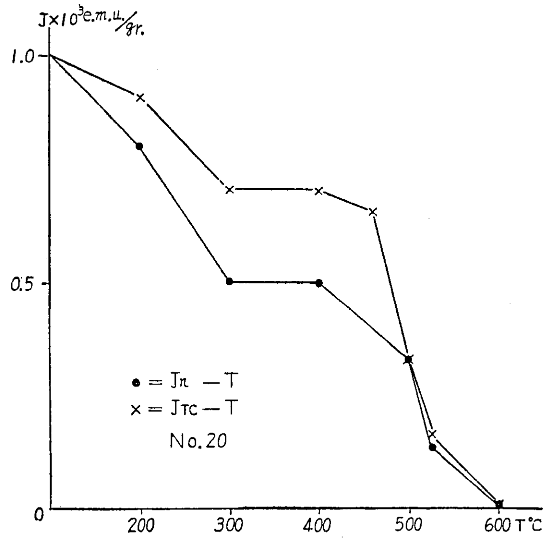

Fig. 4 A 2. Samples from Mt. Takao-san.

Fig. 4A 1-4 B 2. Curves of thermal demagnetization applied for both *Jn* and *Jrc*.

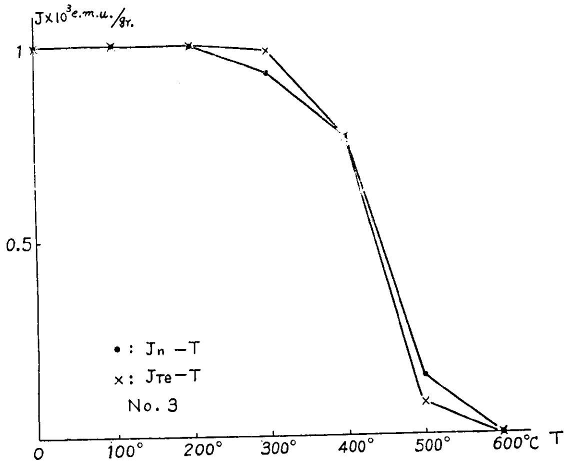

Fig. 4 B 1. Samples from Fukuzawa-yama.

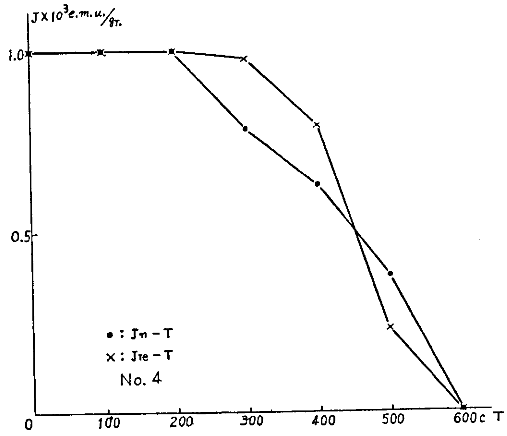

Fig. 4 B 2. Samples from Mt. Fukuzawa-yama.

Fig. 5A 1-5 B. Saturation magnetization (*Js*) curves through heating and cooling processes [*Js-T*]. (After Akimoto's measurements)

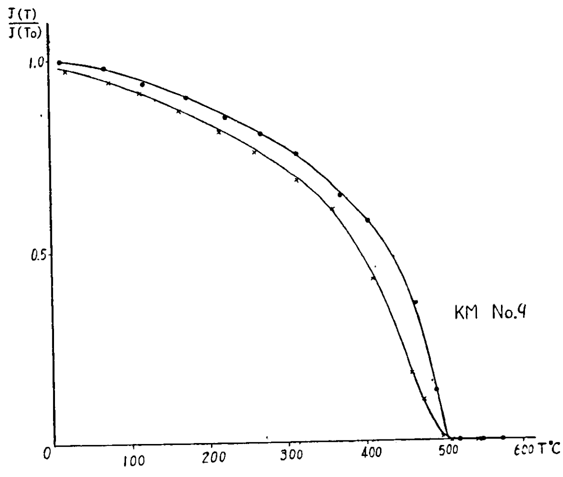

Fig. 5 A 1. Samples from Mt. Takao-san.

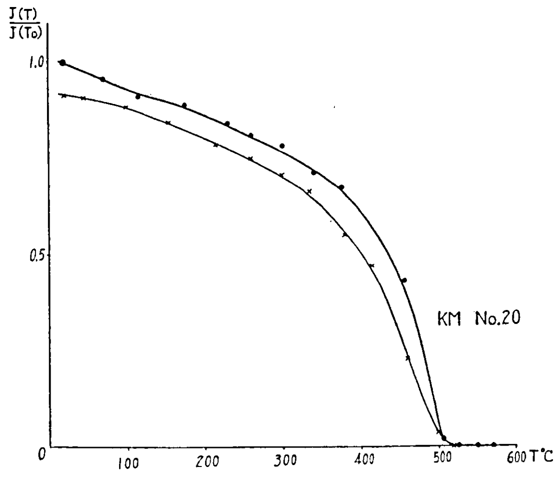

Fig. 5 A 2. Samples from Mt. Takao-san.

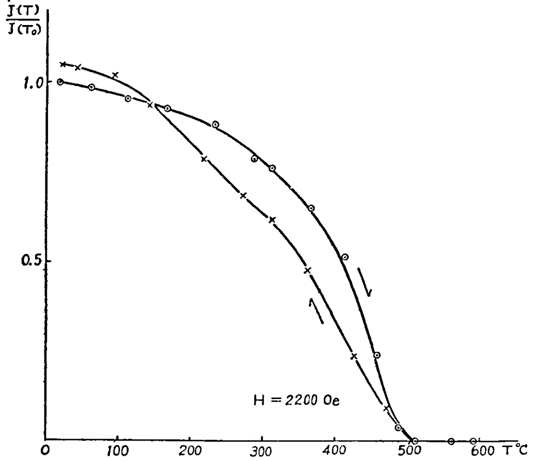

Fig. 5 B. Samples from Fukuzawa-yama.

basis for our succeeding work, the authors[14] have examined the nature of *R.N.R.M.* by applying various tests as will be described in the following (Figs. 1 and 2). Fig. 1 indicates the *JTc*-*T* curves. The sum of each partial thermo-remanent magnetism (*P.T.R.M.*) which was produced through cooling process from 600°*C* is compared with the intensity of of *T.R.M.* which was produced through the process of cooling from 600°*C* down to the room temperature as shown in Fig. 2.

3. *Magnetization caused by thunderbolts.*

Magnetic polarizations of samples taken from the summit region of Mt. Utsukushi-ga-hara are utterly scattered in direction, while the highest value of Jn/JTc was observed to be $122/4 = 30.5$. This sort of magnetism is different from usual "*N.R.M.*".

The result obtained from *AC*-demagnetization also suggests that their magnetism might be due to an abnormal magnetization perhaps that caused by lightning[15]. *T.R.M.* of these samples were made and *AC*-demagnetization assays were again applied to them with the results that the mode of *AC*-demagnetization is expressed on the average as that shown in Fig. 3 A.

On the other hand, an experiment of *AC*-demagnetization applied to *I.R.M.* suggests that it is very unstable (Fig. 3 A). As shown in the figure, the mode of *AC*-demagnetization which was applied by Momose[16] to the assumed thunderbolt-magnetism is not dissimilar to that of *AC*-demagnetization applied to *I.R.M.*.

In additional to the above series of test, the authors made one more test as follows. A slab of platy-jointed andesite was brought to our laboratory from the peak of Ogahana of Mt. Utsukushi-ga-hara and was cut into 48 pieces. Magnetic directions and intensities of every piece

14) T. NAGATA, *et al.*, *loc. cit.*, 2a).
15) H. MATSUZAKI, K. KOBAYASHI, & K. MOMOSE, *Jour. Geomagn. Geoelectr.*, **6** (1954), 53.
16) H. MATSUZAKI, *et al.*, *loc. cit.*, 15).

are enumerated in Table 1 and illustrated also in Fig. 6. The observed values of both the directions and intensities are so scattered that we

Table 1. Observed magnetic directions and intensities of every piece of a rock mass.

Samples No.	Direction		$Jn \times 10^2$ *e.m.u./gr.*	Samples No.	Direction		$Jn \times 10^2$ *e.m.u./gr.*
521120 1	62°W	17°	4.33	25			
2	59° 〃	21°	4.19	26	45°W	21°	5.00
3	56° 〃	8°	3.79	27	38° 〃	33°	0.43
4	55° 〃	7°	0.35	28	55° 〃	7°	4.32
5	59° 〃	7°	3.21	29	57° 〃	11°	3.98
6	64° 〃	15°	4.41	30	57° 〃	8°	3.94
7	56° 〃	12°	0.44	31			
8	51° 〃	13°	4.17	32			
9	54° 〃	12°	3.78	33	34° 〃	67°	0.45
10	54° 〃	8°	3.78	34	49° 〃	26°	4.36
11	54° 〃	5°	2.84	35	55° 〃	13°	3.94
12	55° 〃	4°	2.79	36	52° 〃	8°	4.14
13	54° 〃	14°	0.44	37			
14	51° 〃	10°	4.47	38	69° 〃	68°	4.99
15	54° 〃	10°	4.28	39	58° 〃	36°	4.22
16	51° 〃	5°	0.40	40	53° 〃	26°	4.27
17	52° 〃	3°	0.37	41	58° 〃	17°	0.43
18	54° 〃	7°	3.40	42	87° 〃	73°	6.89
19	61° 〃	16°	4.60	43	74° 〃	57°	0.45
20	48° 〃	27°	4.55	44	58° 〃	19°	4.17
21	50° 〃	18°	4.76	45	64° 〃	28°	
22	54° 〃	19°	4.27	46	89° 〃	56°	0.66
23	55° 〃	14°	0.39	47	84° 〃	84°	4.67
24	56° 〃	13°	0.38	48	58° 〃	7°	4.11

must admit existence of remarkable disturbance even in such a small slab of only 900 cm^2.

If the main part of *N.R.M.* of these rocks were originated from *T.R.M.* which they acquired in the former times, the mode of *AC*-demagnetization applied to *N.R.M.* (Fig. 3 A). Several stone idols are standing on the peak of Ogahana, altitude 1,998 m. They were brought up from a quarry at the foot of Mt. Utsukushi-ga-hara and are lithologically referred to the lower type of the Utsukushi-ga-hara lava. We found an anomalously strong magnetization in these idols which is likely to have been caused by thunderbolts after they were brought up there. The fact would suggest that care should be taken of the magnetization

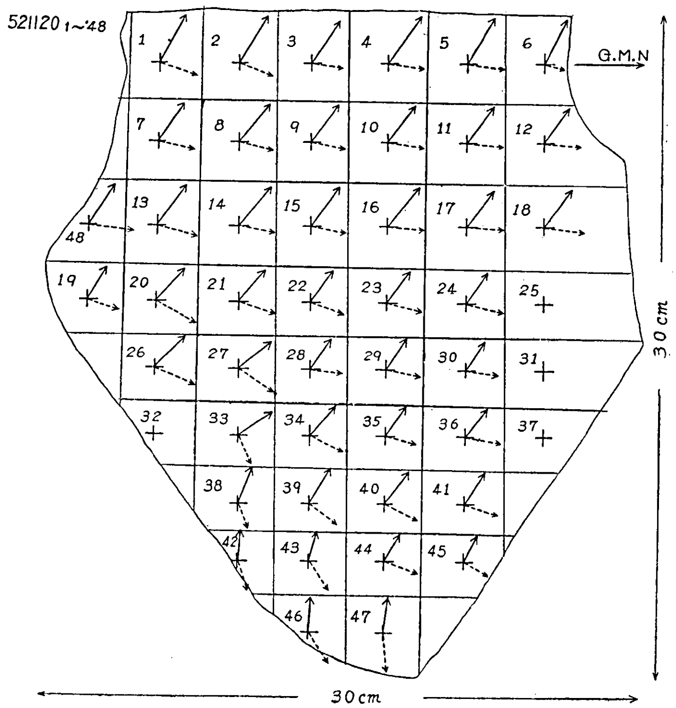

Fig. 6. Scattering magnetic polarizations measured from every piece of a rock mass. Arrow signs drawned by continuous line show the declination and those drawned by broken line show the inclination.

due to lightnings when rock samples are collected from the top of a mountain.

3. Measurements of Magnetic Directions

1. *Magnetic properties of Takaosan andesite.*

Among many samples, only a set of those from Mt. Takaosan have shown *N.N.R.M.* Since *N.N.R.M.* is seldom observed in our field, several tests in addition to *X*-ray analysis have been specially applied to the samples from Mt. Takaosan.

Mt. Takaosan is a type of volcanic neck and is capped by thin horizontal sediments, so that it is conceivable that remarkable dislocations have never taken place there since the formation of this rock bodies.

Fig. 7 illustrates the observed magnetic directions by means of stereographic projection.

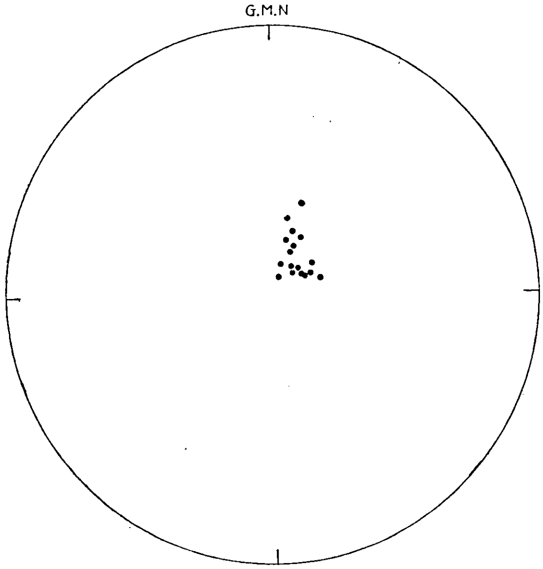

Fig. 7. Magnetic directions of the samples collected from Mt. Takaosan. (*N.N.R.M.*).

Samples were collected from 3 localities each of which the altitudes are different from each other.

Unexpectedly, we observed scattered declinations ranging from N 11°E to N 74°E, whereas the inclinations took values around 70°. Such a random distribution of directions raises a doubt as to whether they were disturbed by thunderbolts. As shown in Fig. 3 B 1 and 3 B 2, however, the results obtained from application of *AC*-demagnetization as-

Table 2. Various magnetic properties of the samples taken from the pass of Wada-toge showing the directions, calculated directions of the centred dipoles, the intensities and the values of *Jn*/*JTc*.

Localities	Samples No.	Rock Names	Directions		Directions of the Centred Dipole		$Jn \times 10^3$ *e.m.u./gr.*	*Jn*/*JTc*
Wa 1a	2	(Ol.)-2-Py. And.	171°W	42°	30°S	124°E	0.20	0.154
	3		166°E	−49°	76°S	160°W	0.79	0.760
Wa 1b	Xenolith	(Ol.)-2-Py. And.	176°W	−38°	75°S	115°E	1.49	0.920
	4–6	Liparite	177°W	−36°	73°S	112°E		
Wa II	8–10	(Ho.)-2-Py. And.	151°W	53°	16°S	110°E	0.14	0.113
Wa III	11–13	(Ho.)-2-Py. And.	180°	− 2°	56°S	135°E	0.36	0.218
Wa V	17	2-Py.-And.	175°W	−41°	78°S	115°E	0.85	0.859
	18	2-Py.-And.	164°E	11°	46°S	160°E	0.43	0.476
Wa VI	20	obsidian	86°E	−60°			2	
WaVII	24–28	Liparite	164°W	−62°	76°S	5°E	0.24	0.50

says demonstrate that *N.R.M.* of the samples which are within a range of $2.0 - 0.85 \times 10^{-3}$ *e.m.u./gr.*, is hardly influenced by a field of the order of 100 *Oe* $\widetilde{H}$. Fig. 4 A1 and 4 A2 show the modes of thermal demagnetization of each *Jn* and *JTc* which were applied to 2 samples. With respect to samples No. 3 and No. 20, it can be seen that both the modes of demagnetization of *Jn* and *JTc* are homologous with one another. Fig. 5 A1 and 5 A2 show the modes of saturation magnetization with

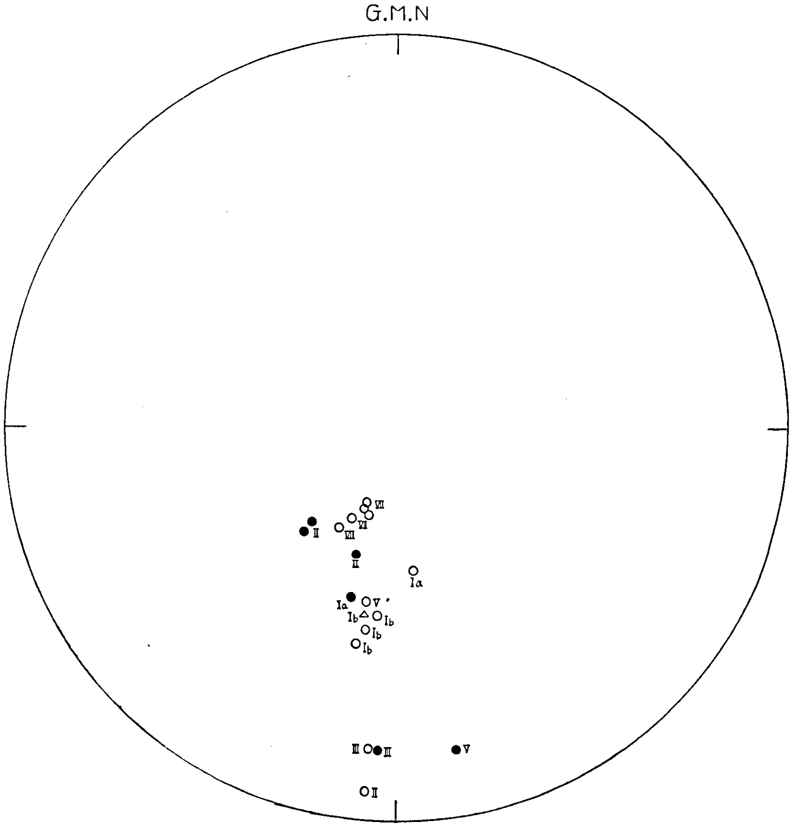

Fig. 8. Magnetic directions of the samples collected from the pass of Wada-toge (*R.N.R.M.*).

respect to changes in temperature. The modes of variation through both heating and cooling processes are also homologous with one another, so that no different mechanism of magnetization stands through both the processes.

In the samples No. 12 and No. 19[17], the values of Jn/JTc were observed to be $1.06/0.97 = 1.09$ and $0.85/1.00 = 0.85$ respectively.

In the application of X-ray analysis to magnetic minerals of these samples, the lattice constants were measured to be $8.396 \pm 0.003\,\mathring{A}$ (in the case of the sample No. 9 of Takaosan) and $8.394 \pm 0.002\,\mathring{A}$ (in the case of the sample No. 20) respectively. Curie points were also measured to be 505°C in the former and 510°C in the latter. The results thus obtained would imply that the magnetic mineral which is responsible for the magnetization considered may be identified to pure magnetite (Fe_3O_4) in $TiFe_2O_4$—Fe_3O_4 series. If so, the magnetic properties are highly stable. The observed magnetization might have been unchanged[18], though it is the only *N.N.R.M.* found in the author's study.

2. *Magnetic properties of rocks from the pass of Wada-toge and at Nishimochiya.*

As was mentioned in the foregoing chapter, several rock-types of volcanites are found in the environs of the pass of Wada-toge. Judging from the flow-structures and extensions of andesitic lavas, no remarkable dislocation is likely to have taken place in this area. The localities from which the samples were collected are all denoted in the geologic map.

Magnetic directions of samples collected from the pass of Wada-toge and from Nishimochiya are projected stereographically in Fig. 8 and the averages of each group of declinations and of inclinations are enumerated in Table 2.

As can be seen in Table 2 and Fig. 3 C, magnetic directions of most samples are reversed and point downwards except for those of obsidian samples No. 20 at the pass of Wada-toge.

Fig. 3 C shows the modes of *AC*-demagnetization applied to *N.R.M.* of samples collected from various localities. As the authors already examined[19] with respect of the results of *AC*-demagnetization applied to the assumed thunderbolts-magnetism, the modes shown in Fig. 3 C are analogous to those of *AC*-demagnetization applied to *T.R.M.* though there are a few exceptional instances.

The values of Jn/JTc are shown in Table 2. The directions of artificial mode *T.R.M.* produced during the cooling process 600°C to the

17) Both Samples No. 12 (here mentioned) and No. 9 (their result obtained from which is illustrated in Fig. 5 A1) were collected from the same rock mass; similarly, both samples No. 19 and No. 20 (Fig. 5 A2) were collected from the same rock mass.
18) S. UYEDA, *Jap. Jour. Geophys.*, **2** (1955) 1.
19) MATSUZAKI, *et al.*, *loc. cit.*, 15).

room temperature in the present geomagnetic field agree with the direction of the present geomagnetic field. The magnetic directions of the samples collected from one locality are centerized. Synthetizing the above-noted facts, the magnetism now under consideration may be due to that of *N.R.M.* different from those of the self-reversal and of *I.R.M.*, and is therefore stable.

Andesitic lava-flows of *Teppeiseki* type represented by the samples from Loc. Wa Ia is intruded by the Wada-toge liparite represented by the samples from Loc. Wa Ib and a contact spot is found at a locality near Nishimochiya. We can see several xenolithic blocks of andesite in the liparite body close to the contact plane. The average magnetic direction of liparite was measured to be N 171°W and −36°. Coinciding with this value, andesitic xenolith included in the former proved to be N 170°W and −38° in direction. Such a coincidence as noted above may imply that andesitic xenolith has acquired the *N.R.M.* after it was caught in the liparite.

Sample No. 3 is, however, located at a point only 2 m. distant from the contact plane and is doubtlessly a xenolithic block of andesitic host rock. The reason why such a peculiar direction was observed with respect to sample No. 3, might perhaps be attributed to the fact that it was affected by both the magnetic properties represented by those of samples from Loc. Wa Ia and Loc. Wa Ib. On the other hand, it is quite difficult to explain why the samples from Loc. Wa V are so scattered in direction. Moreover it is noteworthy that *Jn* of obsidian were observed to have particularly larger values, while it was never influenced by the application of the field of 400 *Oe* $\tilde{H}$ in *AC*-demagnetization assay.

Seeing the stableness proved by *AC*-demagnetization assays, Uyeda made an experimental test to examine if the obsidian might contain the minerals of the self-reversal type, with the result that he obtained a negative conclusion.

3. *Magnetism of Kawagishi Andesite.*

In those days preceding 1957, the authors were convinced that Kawagishi andesite would be reversed in magnetic direction because they are embedded in thick tuff-breccias which can be assigned lithologically to the so-called Enrei formation. The lavas are well-jointed and well-extended horizontally indicating that no dislocation has taken place since their extrusion.

Measured directions and corresponding pole position, the values of *Jn* and *Jn/JTc* are shown in Table 3, magnetic directions are also plotted in Fig. 9. All the observed directions are those that can be referred

Table 3. Various magnetic properties of the samples taken from Kawagishi showing the directions, calculated directions of the centred dipoles, the intensities and the values of Jn/JTc.

Localities	Samples No.	Rock Names	Directions		Directions of the Centred Dipole		$Jn \times 10^3$ $e.m.u./gr.$	Jn/JTc
Kw I	1-5	Ho.-2-Py. And.	160°W	−30°	64°S	85°E	0.410	0.640
Kw III A_1	10-12	Ho--2-Py. And.	160°W	−38°	67°S	78°E	0.240	0.462
Kw III A_2	13-14	Ho.-2-Py. And.	160°W	−35°	65°S	83°E	0.330	0.643
Kw III B	16-17	Ho.-2-Py. And.	168°E	−42°	74°S	174°W	0.920	0.726
Kw IV	19-20	(Ol.)-2-Py. And.	141°E	−27°	49°S	156°W	0.820	0.283
Kw V	23-27	(Ol.)-2-Py. And.	180°	−44°	81°S	135°E	0.640	0.515

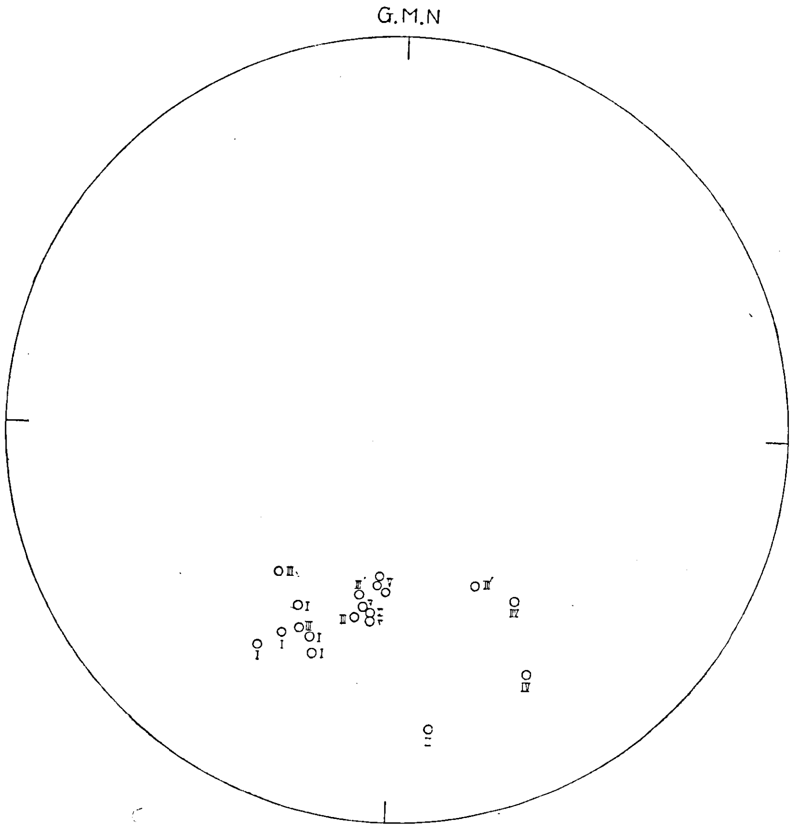

Fig. 9. Magnetic directions of the samples collected from Kawagishi (*R.N.R.M.*).

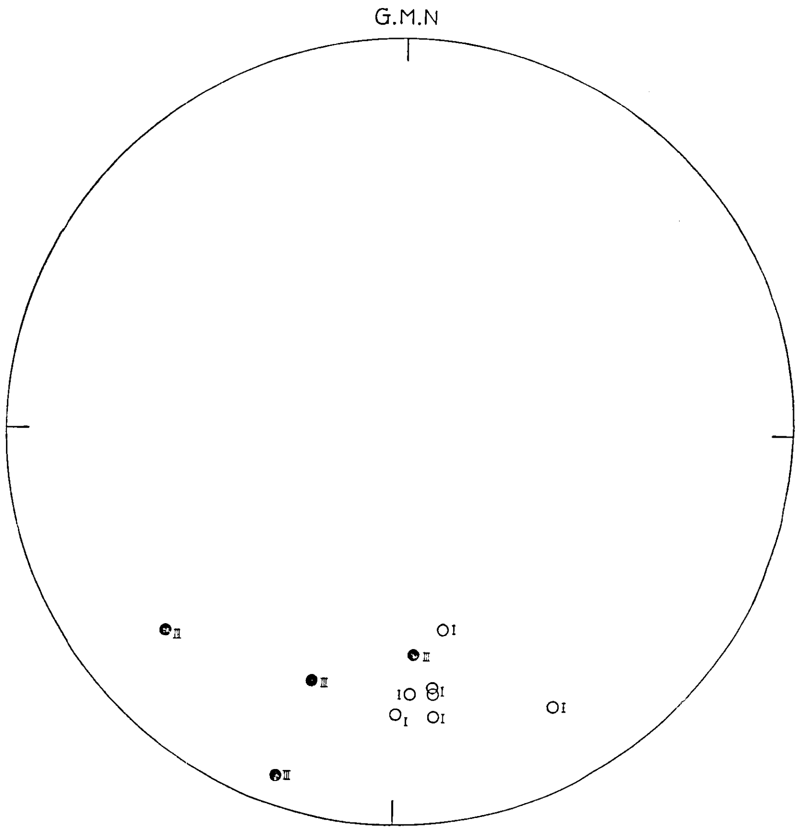

Fig. 10. Magnetic directions of the samples collected from Mt. Mitsu-mine (*R.N.R.M.*)

Table 4. Various magnetic properties of the samples taken from Mt. Mitsu-mine showing the directions, calculated directions of the centred dipoles, the intensities and the values of *Jn/JTc*.

Locali-ties	Samples No.	Rock Names	Directions		Directions of the Centred Dipole		$Jn \times 10^3$ *e.m.u./gr.*	*Jn/JTc*
Mi I	9.11.-16	(Ol.)-2-Py. And.	N 168°E	−19°	64°S	161°E	0.810	0.750
Mi III	21	(Bl.)-ho. -2Py- And.	176°E	31°			0.19	0.24
	22	〃	131°W	15°				
	23	〃	162°W	23°			0.14	0.15
	24	〃	161°W	5°				
Mi III	22*	〃	133°W	16°				

* Direction obtained from the sample (Mi III 22) 2 months after the first measurement.

to *R.N.R.M.*, most of which are westward with a few exceptions.

As are shown in Fig. 3D, their stablenesses were warranted by the applications of *AC*-demagnetization assay. The directions of *T.R.M.* have also shown a marked coincidence with the present geomagnetic field.

Judging from the results thus obtained, we may conclude that the directions of *N.R.M.* can be regarded as the trustworthy records of geomagnetic field in the past.

4. *Magnetism of Mt. Mitsu-mine Andesite*

As noted proviously, Mitsu-mine andesites are referred to a member of the Enrei formation. The samples from Loc. Mi I are very platy-jointed and indicate lithologically the same rock facies as those in the environs of Suwa and Mt. Utsukushi-ga-hara.

In Table 4, magnetic directions, the pole positions calculated and the values of *Jn/JTc* are denoted, while their magnetic directions are plotted in Fig. 10. The observed directions of the samples from Loc. Mi III are scattered, whereas those of the samples from Loc. Mi I show a striking concentration (Table 4). As read from these, the directions of the samples from Loc. Mi I are reversed and eastward, and those from Loc. Mi III are reversed and westward. It should however be stressed that the former is considered stratigraphically younger than the latter.

As are shown in Fig. 3 E., the mode of *AC*-demagnetization applied to *N.R.M.* indicates a resemblance to that for *T.R.M.* of the samples from Utsukushi-ga-hara. It has been proved that the *T.R.M.* artificially made also agrees with the present geomagnetic field in direction. The magnetic directions of Mitsu-mine andesite thus measured and tested may be available as the records of geomagnetic field in the past.

5. *Magnetism of Utsukushi-ga-hara lavas*

Mt. Utsukushi-ga-hara, which has been called "Lava plateaus", shows a peculiar geomorphic feature (Fig. 16). The even summit as wide as 4 km^2. in area, is 2,000 m. high on the average and the highest peak called Peak Ogato reaches up to 2,034 m. As seen in Fig. 17 a,b, the summit exhibits in many parts good exposures of extended lava-flows dipping very slightly eastward. Lava-flows are platy-jointed and show lithologically a striking resemblance with that of *Teppeiseki* at type-locality near Suwa. The authors are now of opinion that the Utsukushi-ga-hara lavas are all assigned to the middle part of the Enrei formation in age.

Samplings have been made at 4 localities, i.e. Ut I (1,900 m in height), Ut II (1,450 m in height) Ut III (1,800 m in height) and Ut IV (1,900 m in height).

Table 5. Various magnetic properties of the samples taken from Mt. Utsukushi-ga-hara showing the directions, calculated directions of the centred dipoles, the intensities and the values of Jn/JTc.

Localities	Samples No.	Rock Names	Directions		Directions of the Centred Dipole		$Jn\times10^3$ $e.m.u./Jr.$	Jn/JTc
Ut I_a	1-3	(Ol.)-2Py.-And.	142°E	−29°	56°S	156°W	1.07	0.79
Ut I_b	6-10	(Ol.)-2Py.-And.	157°E	−27°	61°S	175°W	0.65	0.41
Ut II	K1-8	(Ho.-Ol.)-2Py. And.	104°E	16°			0.67	0.24
Ut III	K3-10	(Ol.)-2Py.-And.	143°E	64°			5.70	1.30
Ut IV	1-4	(Ol.)-2Py.-And.	158°E	−20°	59°S	178°E	0.81	

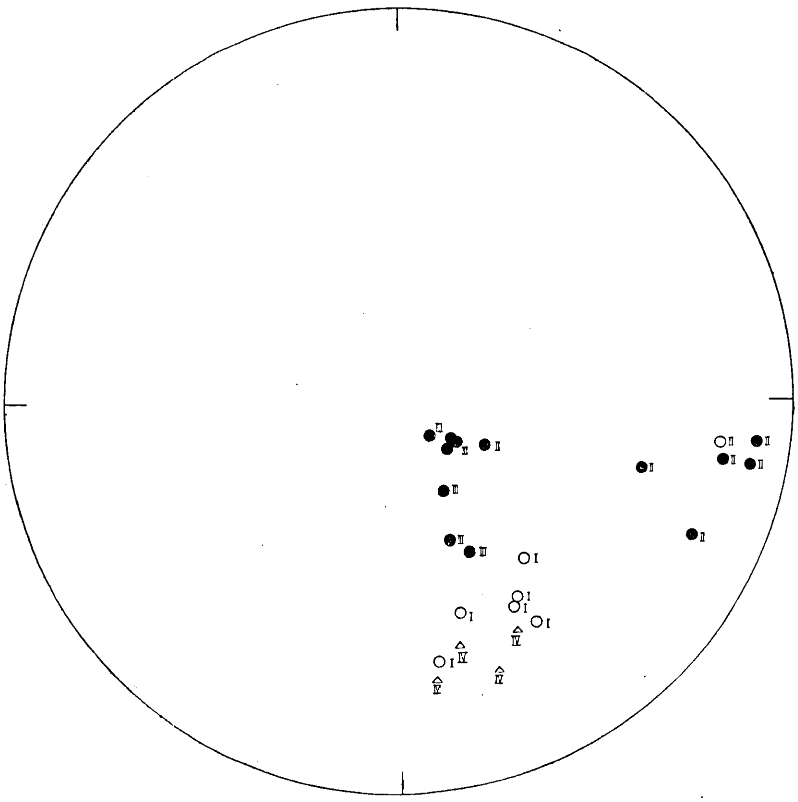

Fig. 11. Magnetic directions of the samples collected from Mt. Utsukushi-ga-hara. (*R.N.R.M.*).

Observed magnetic directions of the samples are shown in Table 5 and in Fig. 11. The directions indicate a good concentration and they are directed eastward. Fig. 3 F shows the results in the applications of *AC*-demagnetization to the samples from Ut I. The directions of artificially made *T.R.M.* also proved to be in parallel with the present geomagnetic field. Considering the distribution of observed direction, it seems likely that the obtained *R.N.R.M.* may be thought as stable.

6. *Magnetism of the samples collected in the environs of Suwa.*

Table 6. Magnetic directions and calculated directions of the centred dipoles of various samples in the environs of Suwa.

A) Suwa Kanko-doro group

Localities	Samples No.	Rock Names	Directions		Directions of the Centred Dipole	
Su VII	K 7	Ho.-2-Py. And.	177°E	−54°	86°S	140°W
Su VI	K22-25	2-Py.-And.	168°E	−40°	73°S	78°W
Su V	K29-34	(Ol.)-2-Py. And.	147°W	2°	34°S	87°E
Su II	K 1-6	2-Py.-And.	150°W	−25°	55°S	75°E
Su III	K 7-10	2-Py.-And.	132°W	−42°	46°S	45°E
Su IV	K11-16	2-Py.-And.	177°W	−25°	67°S	127°E
Su I	K 9-12	2-Py.-And.	121°E	35°	12°S	168°W

B) Fukuzawa-yama group

Localities	Samples No.	Rock Names	Directions		Directions of the Centred Dipole	
Ks II	Y 20-23	Ol.-2Py.-And.	142°E	−56°	59°S	120°W
Fu V	Y 17-19	Ol.-2Py.-And.	137°E	−45°	52°S	137°W
Fu IV	Y 15	Ol.-2Py.-And.	144°E	13°	37°S	178°E
Ks I	KK 12-19	Ol.-2Py.-And.	127°E	−44°	44°S	127°W
Fu III	531281-6 544101-5	Ol.-2Py.-And.	128°E	−72°	49°S	90°W
Fu II	Y 8-9	Ol.-2Py.-And.	120°W	−51°	40°S	61°E

Detailed descriptions of the geology of Suwa district will be made in the following chapter. Several flows of andesite lavas mainly of *Tep-*

peiseki type are embeded in thick tuff-breccias. Samplings were made at several places on Fukuzawa-yama—a type-locality of andesite of *Teppeiseki* type (Loc. Fu Ks) and at several places (Loc. Su) along the so-called " Sight-seeing Road " (Kanko Doro).

These two groups of localities have ascertained that they belong to the lower and middle members of the Enrei formation.

Observed directions and calculated pole positions of the samples are shown in Table 6. It was clearly indicated that the samples from the lower member of the Enrei formation were reversed and westward in direction whereas those from the middle member were reversed and eastward. The results of our tests made for the samples from Loc. Fu III at Fukuzawa-yama quarry (Fig. 18 a, b) will be mentioned in the following. The modes of thermal demagnetization applied to *Jn* and *Jtc* are alike as are illustrated in Fig. 4 B1 and 4 B2. Akimoto[20] measured the changes in *Js* in relation to changes in temperature, and the curves thus obtained are shown Fig. 5 B. The results also indicate that the curves through both process of heating and cooling are similar to each other and that the Curie point is estimated to be 490°C. The lattice constant of the magnetic minerals contained was calculated to be 8.382 Å for sample No. 4. This implies that the mineral belongs to Titano-spinel-Magnetite series.

Fig. 3 G shows the modes of *AC*-demagnetization of *Jn, JTc* and *I.R.M.*. The values of *Jn*/*JTc* of samples No. 4 and No. 3 were calculated respectively to be $1.29/2.45 = 0.52$ and $1.3/2.05 = 0.63$.

Summarizing all the experimental results, it may be said that the *N.R.M.* retained in all the samples from Loc. Fu III may be normal and very stable[21]. As all the samples from Loc. Fu-Ks group are lithologically quite similar to those from Loc. Fu III, the former is supposed to be consisted of the mineral stable in magnetic characters. Although the test considered may not always be sufficient to provide a decisive basis for our conclusions, the results above mentioned, will support, to some extent, the view that most of the *N.R.M.* of rock samples studied by the authors can be used for tracing the directions of the geomagnetic field in the past.

IV. Geological Settings

1. *General geology of the Enrei formation*

Various volcanic ejecta which consist chiefly of andesite lava-flows

20) S. AKIMOTO, *loc. cit.*, 18).
21) T. NAGATA, *loc. cit.*, 2a).

and tuff-breccias are distributed over a wide area around Lake Suwa. They extend northward to the vicinity of Utsukushi-ga-hara which is located east of Matsumoto City. The main part of these pyroclastic formations seems to have originated through a sort of volcanic depression accompanied by intensive volcanism, the thickness of the formation may attain to at least more than 400 m. Their wide distribution is shown in our geologic map. In some parts of the formation well stratified facies of sedimentary deposition are found, especially in the lowermost and the uppermost parts. Their depositional surfaces are fairly well-preserved as seen in an even summit-levels and shown in Figs. 20 and 21. These volcanic deposits were named the Enrei formation by one of the authors[22].

The oldest formations in our area are represented by the rocks of palaeozoic formation and those of metamorphics of the Sambagawa type; the former occupies small area in the south-western part of our geologic map, whereas the latter consisting of crystalline shists and phyllites of the Sambagawa type occur along the upper course of the Yokokawa-gawa.

The metamorphic groups of the Moriya and the Uchimura formations of the middle or early Miocene in age are exposed in some parts near Shimosuwa, Utsukushi-ga-hara and Hachibuse-yama. The metamorphics[23] called usually "Green-tuff" are intruded by quartz-diorite which is exposed in certain places near Omegura and Wada, and in another area very near to Lake Suwa.

The heights of the unconformity at which the Enrei formation overlies these basement rocks are at the level of 1,000 m. (above *M.S.L.*) in the north of Shimosuwa; 1,400 m. (the boundary between both formations is now in tectonic contact) in the east of Mt. Higashi-yama; 1,500 m. at the pass of Tobira-toge; 1,300～1,900 m. at Utsukushi-ga-hara, and 1,100 m. along the Yokokawa-gawa. The lowest level of exposure of the Enrei formation, on the other hand, is about 700m. above *M.S.L*, though the basement rocks are not found there.

The area where the basal unconformities are conceived to be located below the ground surface is interpreted to correspond with the sunken area introduced by volcanic depression.

2. *Stratigraphy and lithologic features of the Enrei formation*

The Enrei formation is generally characterized by large amounts of

22) Fossa-Magna Research Group, *Earth Science* (*Chikyukagaku*), **37** (1958), 46.

23) They consist mainly of altered volcanic pyroclastics with less sediments and altered porphyrite. The Tobira formations are similar to the Uchimura group lithologically, but the stratigraphic relation between the both, have not yet been sufficiently known.

tuff-breccias intercalating many sheets of lava-flows, much less conglomeratic and mud beds. Excepting local area of intense dislocation, the Enrei formation is represented by horizontal or gently inclined strata, although most parts of the formation do not show any remarkable stratification. Flat-lying and thin lava-flows are embedded at various horizons and show no crater-like landforms over there. Therefore it seems likely that very fluidal lava of lower-viscosity has extruded in many places from craters and flowed downwards over the gently-sloped surface of the tuff-breccias. The lava-flows are composed mainly of two-pyroxene andesite being accompanied by local occupation of liparite lava. Several intrusive bodies of hornblende andesite and basalt, though much less in amount, are also found locally. But they are undoubtedly of post-Enrei volcanic origin.

The liparitic bodies at the pass of Wada-toge have long been famous for the accompanying of glassy parts—obsidian and for that of large crystals of garnet. The obsidian has been used by our ancient ancestors for making stone implements since Palaeolithic times.

The basal part of the Enrei formation has not yet been ascertained but the area in the upper course of the Yosawa-gawa seems likely to represent the lower part. In this area conglomeratic beds are seen to underlie the main part of tuff-breccias suggesting that the bed might represent the pre-volcanic environments.

The name of *Teppeiseki* or *Hira*-ishi has been popularly used for the andesite which shows a remarkable appearance of well-developed jointing. The thickness of each flagstone separated by joint-planes is ranging from 1 to 3 cm. Flagstones, therefore, have been used for tiling over the roof of farm-houses in the environs of Suwa. The lavas of *Teppeiseki* are characterized by not only platy-joints but also by remakable lateral extension. The lavas which show the appearance of the *Teppeiseki*, comprise not only the special rock-type as seen at Fukuzawa-yama—a type-locality, but also several other rock-types being somehow varied in lithology as seen in many places of the Enrei formation.

Well-jointed feature of lavas dominates in the rocks of olivine-two-pyroxene-andesite which are quarried at several places now. The Fukuzawa-yama quarry is the largest and most famous one. Besides these, the quarries at Nyukai and Kakuma-shinden which are located north of the former are referrable to the same lava-flow. Making use of the perfect platy-joint and the vertical columnar-joints, large amounts of the flagstone are quarried at these places and sent to central cities for the buildingstone.

The quarries producing excellent plates are chiefly limited to these located at the exposures of olivine-two-pyroxene andesite distributed north of Kamisuwa. The thinner platy-joints are developed generally in the lower parts of lava-flow, whereas the upper part is less perfectly jointed and each flag is thicker. Sometimes intercrosses of joint-planes are observed in the uppermost part as shown in Fig. 19 a.

Tateishi quarry is located on the ridge opposite to Fukuzawa-yama quarry, and the altitudes of both quarries are almost equal to each other, although magnetic directions of both *Teppeiseki* lavas are different i.e. Tateishi andesite exhibits *Rw* but Fukuzawa-yama andesite is *Re*. That fact indicates that both lava-flows belong to different horizons respectively.

Another lava-flow of *Teppeiseki* type is found in the environs of Kawagishi and Tatsuno along the Tenryu-gawa. Its magnetic direction is *Rw* indicating that it represents the lowest member of the Enrei formation.

Well-jointed andesite lava of different rock-type is hornblende-bearing-two-pyroxene andesite of Nishimochiya. All of hornblende-bearing andesite are not invariably characterized by well-developed joints. For convenience of description, the area of the Enrei formation is to be divided into the following seven major units from geological and geographical stand points.

i) *Yosawa District*

A lithologic facies representing the basal members of the Enrei formation is found along the upper stream of the Yosawa-gawa in the western part of the map. In this district, the formation consists of the basal conglomerate, volcanic conglomerate and volcanic detritus, and they seem to cover uncomformably the older basement.[24]

The lower part of the conglomerate contains pebbles derived from the basal Miocene sandy and conglomeratic rocks that are highly silicified, whereas the upper part of the conglomerate comprises numerous cobbles and boulders consist of crystalline schists and phyllites of the Sambagawa type (Fig. 23). Overlying the conglomerate, are tuff-breccias which show in some parts the signes of water-deposition. It is designated the Yosawa conglomerate and the thickness is estimated to be more than 30 m. In the overlying tuffaceous beds fragmentary trunks of trees are found (Fig. 25). At Yuno-sawa, for instance, general strikes of the beds are variable from N 40°E to N 70°E and their dips

24) K. KOBAYASHI, *Rep. Geol. Survey. Nagano Pref.* (1955), 155.

are steep to the south, sometimes they are even vertical or partly reversal (Fig. 23). As a matter of course the steep dip of the bed is considered to have been caused by the transposition after the sedimentation. It seems that this transposition of strata might be affected by the faulting in the trend of NW-SE. The Yosawa conglomerate is accordingly, supposed to convert southwards to the tuff-breccia around Mt. Higashi-yama. A lava-flow is found in the lower part of tuff-breccias, but its magnetic direction has not been observed.

ii) *Yokokawa-gawa District*

Through the whole area of the Enrei formation, the Yokokawa-gawa and Utsukushi-ga-hara districts are characterized by the development of a thick assemblage of lava-flows.

Thick lava-flows of several kinds are exposed along both sides of the Yokokawa-gawa running down along the eastern foot of Mts. Higashi-yama and Takabotchi-yama. Although remarkably dislocated in many parts, a southward dip of about 60° has been observed in the lava-flow along the Yokokawa-gawa, and the magnetic directions of each of these lava-flows were measured. The obtained data of the magnetic direction of these lavas are satisfactory as compared with these of the equivalents in other places. But there is a little doubt as to whether we are able to make correct restorations of geologic displacements as we fear that too intense a displacement to be detected might have taken place.

The groups of lava-flows exposed along the Yokokawa-gawa are geologically referring to the lower and the middle members of the Enrei formation.

iii) *Shiojiri-toge District.*

The vicinity of the pass of Shiojiri-toge has been considered as the type-locality of the tuff-breccia facies of the Enrei formation. The thick tuff-breccia developed here overlies the above-noted part developed in the neighbourhood of the Yosawa. The exposures of lava-flows are found on the banks of a pond at Katturu and of Midoriko (a storage dam) in the southwestern part of the map. Both lava-flows show similar thin platy-joints to those developed in *Teppeiseki,* and are petrographically two-pyroxene andesite.

The sedimentary beddings in this region are much less inclined than those of Yosawa and Yokokawa-gawa districts, and in reality almost horizontal.

Blocks contained in the tuff-breccia which developed in the vicinity of the pass of Misawa-toge often carry hornblende and the member may therefore lithologically correspond to the upper member of the Enrei formation. At the top of the formation, conglomeratic facies and intercalated mud-seams are recognised at the pass of Misawa-toge. Such a sedimentary facies might undoubtedly have been water-deposited.

Two domes of Mt. Takao-san and east of Enrei park are necks of hornblende andesite[25] intruded into the Enrei formation in the later stage.

iv) *Kawagishi District*

In the east of Kawagishi, thick tuff-breccias which intercalated several lava-flows indicate also that they have been water-deposited as suggested by the occurrence of thin mud-seams at various horizons. Inclinations of the formation indicated by these intercalated sediments are averagely 10° toward the southwest.

A lava-flow of olivine-bearing-two-pyroxene andesite at Komazawa-shinden is found to be at the lowest level of the formation in the south of Kawagishi (Fig. 17 C). The lava-flow is not only characterized by remarkable platy-joints similar to *Teppeiseki* but also petrographically identical with that of the type-locality of Fukuzawa-yama and Kakuma-shinden quarries.

Three layers of lavas of two-pyroxene-hornblende andesite exposing at Doda and Karakasa-daira, are interbeded in the tuff-breccia which overlies the lava of *Teppeiseki*. Platy-joints are also developed in these lavas, whereas each joint-plane is more apart than that of *Teppeiseki*.

Magnetic directions of all lavas of Kawagishi district are observed to be *Rw* (reverse and westwards) as shown in Fig. 12. The fact may suggest, therefore, that tuff-breccias and lavas of this district represent the lower member of the Enrei formation. When we are to consider only the petrographic features, the *Teppeiseki* lavas at Komazawa-shinden may be correlated to those at the quarry of Fukuzawa-yama and the hornblende-bearing andesite lavas at Doda and Karakasa-daira are correlated to those at Kowashimizu and Mt. Kuruma-yama of Kirigamine district respectively[26].

v) *Wada-toge District.*

Another type-locality of the lower member of the Enrei formation

25) It is one of the volcanics showing the normal magnetization in the volcanic rocks developed around Lake Suwa and it seems to indicate the volcanic activity in the latest Pliocene or the earliest Pleistocene from the paleomagnetic points of view.

26) In the Suwa Sheet of Geological Survey (1/50,000), the tuff-breccia of the east of Kawagishi are named S 4 which was referred to the overlying members of the *Teppeiseki* lava in Suwa-Kirigamine district, the misunderstanding of this kind might be due to the correlation basing upon only the petrographic point of views.

is found in the district of Nishimochiya and Wada-toge along Nakasendo. At Nishimochiya, along the Nakasendo road olivine-bearing-two-pyroxene andesite which is demonstrated by the well-developed platy-joint as seen in the *Teppeiseki* lies unconformably above the altered porphyrites of the Tobira formation intruded by quartz-diorite.

In the west of Nishimochiya, a branched body of the well-known liparite main-mass which is typically exposed at the pass of Wada-toge, shows the relation in which the liparite intrudes into the lowest lava (Fig. 24). Up to the present day, most researchers[27),28),29)] understood that this outcrop indicated the fault relation between both rocks, and the liparite was the basement rock under the andesite lavas of this region. A block of the host rock (andesite lava) is caught in the liparite and the trend of flow-structure of the liparite is nearly vertical. The intrusive relation of liparite to andesite was also confirmed by means of geomagnetic consideration as already discussed (see p. 448). Hornblende-bearing-two-pyroxene andesite lava-flows overlying the olivine-bearing-two-pyroxene andesite lava, in the environ of Nishimochiya and the former exhibits as well-developed platy-joint as *Teppeiseki*-lava (Fig. 17 d).

The olivine-basalt exposes at one spot north of Nishimochiya and at higher altitude beside the Nakasendo road. The exposure of the rock is small but is traced vertically along the slope. It has often been discussed by the researchers who studied the geology of this district whether the basalt is dike or lava-flow. The authors have concluded on the geologic and geomagnetic evidence that the basalt is a dike which was injected in the later Pliocene age. A similar kind of basalt also outcrops at Horoku-zawa, beneath the ridge from Mt. Mitsu-mine to the pass of Wada-toge.

The uppermost flow of the andesite occupying the vicinity of the pass of Wada-toge is one of the biotite-bearing-hornblende-two-pyroxene andesite and it occurs along the ridge from Mt. Mitsu-mine to the pass of Wada-toge.

Intruding these andesite lavas, the liparite is exposed in the vicinity of Wada-toge indicating, however, certain varied facies in lithology. The liparite carries fine crystals of garnet. It can also be divided megascopically into several rock-types by the abundance and magnitude of the

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27) F. HOMMA, *loc. cit.*, 5).

28) S. KOZU, *et al.*, *Jour. Jap. Min. Petro. Econ. Geol.*, **24** (1940), 165.

29) K. SAWAMURA and E. OWA, *loc. cit.*, 6).

phenocrysts of quartz and feldspars and by amount of gas-pore, and sometimes it intercalates belts of black glass (obsidian) showing the appearance as if obsidian has injected in parallel with flow-structure of the liparite. Although the obsidian shows a much more intense remanent magnetism, the presence of the magnetic minerals is not recognized under the microscope.

The magnetic direction of the series from the andesite lava-flows of Nishimochiya to the liparite mass are all *Rw*, the facts suggest also that the volcanic complex of Nishimochiya～Wada-toge district represents the lower member of the Enrei formation.

In the east of Wada-toge, the lava of hornblende andesite is exposed around the summit of Mt. Washiga-mine covering unconformably the liparite. The hornblende andesite of Mt. Washiga-mine is scarcely accompanied by tuff-breccia. Natural remanent magnetism of the andesite lava seems to have been disturbed by thunderbolts. The geomagnetic field when the magnetism was acquired would, therefore, be impossible to determine. The petrographic characters of the lava, however, are identical with those of the lavas at Kowashimizu and also Mt. Kurumayama of Kiriga-mine volcano. The lava-flow at Mt. Washiga-mine may, accordingly, represent the upper member of the Enrei formation.

vi) *Mitsu-mine～Utsukushi-ga-hara District*

The andesite lava occurs in a rather limited area of the summit of Mt. Mitsu-mine. The lava indicated the *Re* (reverse and eastwards) magnetisation, and is petrographically identical with *Teppeiseki* (olivine-bearing-two-pyroxene andesite) of the Fukuzawa-yama quarry, and the lava is one of the representative types of the middle member of the Enrei formation. Though the lava of the summit of Mt. Mitsu-mine overlies directly biotite-bearing-hornblende-two-pyroxene andesite lava exposed along the ridge from Mt. Mitsu-mine to the pass of Wada-toge. A certain time-interval might be placed between the extrusions of both lava-flows, because it is concluded from the interpretation of the geomagnetic variation that the liparite of Wada-toge has intruded after the extrusion of the biotite-bearing-hornblende-two-pyroxene andesite and before the olivine-bearing-two-pyroxene andesite.

The similar type of andesite lava distributes in the environs of Mt. Utsukushi-ga-hara, north of the pass of Tobira-toge. As already stated, the Enrei formation here consists merely of thick andesite lava-flow covering directly the basement-rocks of the green-tuff, the sediments of the Hongo formation and quartz-diorite.

The thickness of the lava-flow attains in one place to at least 600

m. The surface of lava-flow as a whole forms a flat-topped summit of Mt. Utsukushi-ga-hara (Fig. 16).

Despite the striking thickness, the lava seems to show an uniform magnetic directions form bottom to top. There is a little doubt as to the magnetic direction of the lava of the highest part of Mt. Utsukushi-ga-hara, because the disturbances are markedly recorded in these rocks[30]. Excepting that the specimens obtained near the bottom carry a small amount of hornblende and their groundmass crystals are coarser-grained as compared with the specimens from the upper part, the andesite as a whole is very homogeneous in their petrographic characters, showing also the perfect platy-joints as seen in *Teppeiseki* (Fig. 17 a, b).

The same lava is distributed separately in the vicinity of Mts. Monomi-ishi-yama and Mizunotatsusawa-no-atama, north-eastward of Utsukushi-ga-hara.

The facts suggest that the fluidal lava-flow extruded at the same time has filled up the hollow part of the surface of the basement-rocks as if the water had filled up a pond, and partly overflowed to the north-east and the other direction. The extensive platform of Mt. Utsukushi-ga-hara having an altitude of about 2,000 m. may indicate the surface of a pond of extruded magma.

vii) *Kamisuwa-Kirigamine District.*

In the Enrei formation of the Kamisuwa-Kirigamine district, the lava-flows at the same altitudes may not always correspond to each other between the west and the east sides of the valley of the Kakuma-gawa. The formation of the west side of the valley of the Kakuma-gawa, namely that exposed along Kanko-doro (the sight-seeing road) from Jizo-ji to Tadeno-umi is recognized to intercalate the five flows of lavas as shown in our geologic map. The lowest flow of these lava is two-pyroxene andesite exposed at Jizo-ji. Though it can hardly be thought that the lava has been displaced, its magnetic direction is rather peculiar in this district as already stated (see p. 454).

At higher levels than Tate-ishi along Kanko-doro thin mud-seams and volcanic conglomerate beds which recorded marked signs of water-deposition are commonly found in the tuff-breccia.

The inclinations of the strata indicated by these mud-seams are about 30° south-westwards. Accordingly, it is thought that the higher the level we go up, the lower the strata we meet with in the vicinity of Tate-ishi. All of these three lava-flows (altitudes of their exposures are

30) K. KOBAYASHI, *et al.*, *Science* (*Kagaku*), **19** (1949), 284.

1,020 m., 1,050 m. and 1,050 m. above *M.S.L.* respectively.) are the two-pyroxene andesite and show the perfect platy-joints of the *Teppeiseki* type.

The olivine-two-pyroxene andesite exposed in the vicinity of Tateno-umi overlies the groups of Tate-ishi lava-flows. Except for the lava at Jizo-ji, all of these andesite lava-flows show the magnetic direction of *Rw*, and may represent the lower member of the Enrei formation.

At the east side of the valley of the Kakuma-gawa, on the other hand, olivine-two-pyroxene andesite lava is exposed at the lower level ($h = 980$ m. above *M.S.L.*), and another lava-flow of the same kind is also found below the Fukuzawa-yama quarry ($h = 1075$ m). Both these flows of the andesite lava show the magnetic direction of *Rw*, and may therefore correspond to the lower member of the Enrei formation. Marked platy-joints develop also in these lavas, although the thickness of each flag is somewhat larger than that of the typical *Teppeiseki* (Fig. 19 b). From the standpoints concerning magnetic directions and petrographic characters, it may be concluded that the lava-flow located beneath the Fukuzawa-yama quarry is correlated to the lava at Tateno-umi.

Above these lower members, the famous *Teppeiseki* lava quarried at such various places as Fukuzawa-yama (1,130 m. above *M.S.L*, Fig. 18 a, b), Nyukai (1,260 m.) and Kakuma-shinden (1,230 m.) is developed in wide extension as shown in our map.

The lava as a whole is identified with olivine-bearing-two-pyroxene andesite and is more than 30 m. in maximal thickness. The lateral extension of the lava-flow is traced southwards for a long distance and forms an continuous cliff as can be viewed from the opposite bank of Lake Suwa (Fig. 13 a). The magnetic directions of the lavas are observed to be *Re* (reverse and eastwards) and seem to indicate that they represent the middle member of the Enrei formation as supposed from the consideration due to petrographic studies.

Two flows of two-pyroxene andesite lava are found at higher levels above that at Tateno-umi. Tough their magnetic directions have not yet been measured, the flows may be referred petrographically to the middle member including the *Teppeiseki* lava.

The upper member of the Enrei formation is Kiriga-mine volcano and consists mainly of hornblende andesite lavas and associating tuff-breccias exposed between the area from Kowashimizu to Mt. Kuruma-yama and overlies all the middle member stated before. The hornblende andesite lava is characterized by the features in which it carries only hornblende as phenocrystic minerals and exhibits fairly glassy groundmass and remarkable flow-structure (Fig. 22), hence they are easily distinguished from the other rock members. So, they are discriminated from the lower and middle member as shown in our map.

The magnetic directions of this member were determined only from the specimens obtained from Kowashimizu because the specimens collected from the localities around Mt. Kuruma-yama have shown a distrubance influenced by thunderbolts. The observed magnetic directions of the lava are all *Re* too.

It seems however that a significant time-interval is not expected to intervene between the hornblende andesite at Kowashimizu and the *Teppeiseki* lavas at the Fukuzawa-yama and Kakuma-shinden quarries basing upon our considerations on the magnetic variation as will later be stated. Hence, hornblende andesite lavas of Kirigamine might have extruded succesively after the *Teppeiseki* and allied lavas which are assigned to the middle member of the Enrei formation.

As already mentioned, both the hornblende andesite at Washiga-mine and that at Kiriga-mine might therefore have extruded at the same stage.

3. *Petrographic notes*

Late Pliocene～early Pleistocene rocks around Lake Suwa may be classified as follows;

(1) two-pyroxene andesites and some varieties carrying olivine, hornblende and the least amount of biotite.

(2) liparite with obsidian.

(3) glassy hornblende andesite (lava-flow).

(4) hornblende andesite (neck).

(5) olivine basalt (dike).

Their petrographic characters will be described one by one concerning the specimens collected from type-localities.

i) *Hornblende-bearing-two-pyroxene andesite* (*Nishimochiya, Wadatoge*)

They contain phenocrysts of plagioclase, hypersthene, augite, magnetite and opathitized hornblende.

Large tabular phenocryst of plagioclase (up to 3 mm., idiomorphic) shows honeycomb structure due to the presence of glass inclusions and oscillatory zonal-structure ranging from acidic labradorite to andesite. Turbid core crowding with many minute inclusions is often observed. Sometimes plagioclase flocks together with pyroxene and forms large glomeroporphyritic aggregates. Clear prismatic and weakly zoned plagioclase (up to 1.5 mm. in length) is also scattered.

Prismatic hypersthene (up to 2.5 mm., sometimes fragmental) is common, sometimes it includes minute rounded inclusions and parallel intergrowth in which a small ill-formed hypersthene core usually enveloped by a thick augite mantle is often observed. Augite is smaller and less idiomorphic than hypersthene. Twinning on (100) is common in augite. Many small fragments of augite are arranged in the same optic orientation in a certain area under the microscopic field. The latter fact suggests that the previous large augite crystal has been replaced by later plagioclase crystal (Fig. 26 a). Small rounded or sphenoid grains of opathitized hornblende are often found, the pleochroism is as follows; $X =$ pale brownish yellow, $Y =$ light brown, $Z =$ light blackish brown to reddish brown. Besides brownish hornblende, comparatively large crystal of greenish hornblende is rarely observed being surrounded by narrow opathite margin. Pleochroism is $X =$ pale green, $Y \doteqdot Z =$ pale brownish green.

Xenoliths of two-pyroxene andesite characterized by higher crystallinity, coarser-grained and more basic groundmass are rarely found under the microscope.

Groundmass consists essentially of plagioclase, hypersthene, augite, magnetite and a little amount of tridymite and glass. Crystallinity of groundmass is lower than that of olivine-bearing-two-pyroxene andesite (*Teppeiseki*), though magascopic characters are similar to *Teppeiseki* especially in respect of well-developed thin platy-joints. Texture of the rock is pilotaxitic. Brownish glass fills sometimes large cavity of groundmass.

Biotite-bearing variety occurs west of the pass of Wada-toge, biotite flake is found as both phenocryst- and groundmass-minerals. This rock-type is characterized by low-crystallinity of groundmass and the predominant presence of tabular plagioclase. Plagioclase phenocryst encloses rarely hornblende and pyroxene grains. No brownish hornblende is found.

ii) *Olivine-bearing-two-pyroxene andesite* (*Teppeiseki*) (*Fukuzawa-yama*)

They contain phenocrysts of tabular plagioclase, hypersthene, augite magnetite, and olivine. Large tabular plagioclase (3∼5 mm. long) is rarely found, groundmass is coarse-grained, sometimes the rock looks non-porphyritic under the microscope. Tabular plagioclase is dominant and usually oscillatory zoned from labradorite to andesine and its central part is often charged with glass inclusions. A smaller prismatic phenocryst of plagioclase is also found, but it is generally clearer and more acidic than tabular phenocrysts. Polysymmetrical and penetrating twins are common.

Prisms of hypersthene and augite are also dominant. Hypersthene is generally larger and better-formed than augite. Parallel intergrowth in which irregular hypersthene core is enveloped by augite mantle is often observed. Both sorts of pyroxenes flock together with plagioclase forming glomerophorphyry.

Skeleton crystals of magnetite are common, and sometimes include minute inclusions of anisotropic minerals.

Olivine is usually corroded, often crushed and rimmed by small augite grains, it is sometimes recognized only as serpentinous pseudomorph after olivine.

Groundmass consists mainly of acicular plagioclase, hypersthene, granular augite, magnetite and subordinate amount of anorthoclase with a small amount of glass, and is characterized by pilotaxitic texture. Crystallinity of groundmass is considerably high.

iii) *Liparite* (*Wada-toge*)

They are purplish grey or white colored rocks and often spotted by iron rusts showing a frosty pattern. A striped pattern due to the repeat of dark and light colored bands may be a sign of flow-structure.

They contain rounded phenocrysts of quartz, oligoclase, alkali-feldspar and flaky biotite. The voluminal proportion of these phenocrysts to groundmass is less than 5 % of the bulk of rock.

Corroded quartz (sometimes fragmental and up to 2 mm. in diameter) occupies one half of the total amount of phenocrysts, is often remarkably cracked and has usually many minute inclusions. Plagioclase crystal exhibits rounded form due to corrosion, zonal structure is not recognized, and it often shows honeycomb structure due to the presence of glass inclusions. Alkali-feldspar is rarely found.

Sometimes biotite is found as slender flakes (up to 2 mm. in length). Judging from its form, it seems to be pseudomorph after hornblende. Pleochroism is $X=$ pale yellow, $Y \doteqdot Z=$ dark yellowish brown.

Groundmass is microfelsitic due to devitrification, often spherulitic and by minute grains of magnetite is scattered universally.

Obsidian. Black or brownish belts of obsidian sandwiched between light-colored liparite with $1 \sim 0.1$ m. in width are often observed, and they show dike- or vein-like appearances as if obsidian might intrude into liparite in parallel with their flow-structure. In black belts of obsidian, small, purplish grey and opaque spherulites are scattered. Sometimes they are in directional arrangement producing bands of spherulites.

Phenocryst is usually not found. Groundmass consists mainly of small anisotropic crystals (possibly quartz) and glass (colorless in thin section) enclosing minute hair-like crystallites. These trichites are in remarkable parallel arrangement.

Spherulites mentioned above are radial aggregates of devitrified glass and are brownish in color under the microscope.

iv) *Glassy hornblende-two-pyroxene andesite* (*Kowashimizu*)

They contain phenocrysts of plagioclase, hornblende, hypersthene, augite and magnetite, and characterized by marked flow-structure and vitric appearances. Idiomorphic prisms of plagioclase (up to 3 mm. in diameter) are common and oscilatory zoned from sodic labradorite to calcic andesine. The central part of such crystal is often charged with glass inclusions.

Hornblende is commonly small and prismatic crystals (1$\sim$3 mm. in length). Most of the hornblende is either rimmed by opathite-margin or replaced wholly by opathitic aggregates, the central part of which consists of augite grains and is surrounded by magnetite grains. Pleochroism is $X=$ pale yellow to light brown, $Y=$ brownish yellow, $Z=$ brown to reddish brown.

In pyroxenes, monoclinic pyroxene is subordinate to orthorhombic pyroxene in amount. Sometimes both kinds of pyroxenes flock together and form glomeroporphyry. Large poikilitic phenocryst of hypersthene is common. Corroded hypersthene crystal is rarely enveloped by hornblende crystals.

Groundmass is hypohyalline and rarely pilotaxitic, and exhibits remarkable flow-structure. It consists of plagioclase, hornblende, biotite, hypersthene, magnetite, alkali-feldspar and tridymite with considerably devitrified glass. Sometimes the groundmass is porous, and fine crystals of tridymite and other minerals are found in these druses.

In some varieties, biotite is found as a small anhedral phenocryst.

v) *Hornblende andesite* (*intrusive neck*) (*Takao-san*)

They contain phenocrysts of plagioclase, hornblende, magnetite, hypersthene and augite.

Plagioclase is as large as 3 mm. in length, hypidiomorphic and tabular andesine, and is often crushed. Usually it exhibits oscilatory zoning, and its core is charged with glass inclusions.

Hornblende is hypidiomorphic prism in form and encloses often augite grains poikilitically. It has altered partially to biotite with or without narrow opathite-margin. Sometimes it flocks together with pyroxene grains, plagioclase and magnetite. Pleochroism is $X =$ light green, $Y =$ pale brownish green, $Z =$ brownish green.

Skeleton crystal of magnetite is common and often rimmed by biotite flakes.

Hypersthene and augite are found as phenocrysts but are less in amount.

Groundmass is very compact and hypohyalline and consists of plagioclase, hypersthene, biotite and tridymite. Glass fills the interspace.

vi) *Olivine-two-pyroxene basalt* (*Nishimochiya*)

They contain phenocrysts of skeleton crystals of olivine, hypersthene, prismatic augite and labradorite. The amount of phenocrysts is less than only 10 % of the bulk. Often glomeroporphyritic aggregate of small augite with plagioclase is found. Sometimes plagioclase bears turbid and more calcic core (bytownite) and shows rarely oscillatory zoning. Parallel intergrowth of rhombic and monoclinic pyroxenes, zonal structure and hourglass structure or wave extinction of augite are commonly observed.

Groundmass exhibits hyalo-ophitic texture and consists of plagioclase, monoclinic pyroxene (pigionitic pyroxene), magnetite and subordinate amount of colorless glass.

4. *Correlation*

As the volcanic area is scarce of fossils, it is very difficult to establish the mutual relation between each separate volcanic mass and strata and search stratigraphically for the age of the explosion of the volcano.

However, the role of paleomagnetic research in our studies concerned with the geologic survey in Central Japan has propounded that the magnetic directions of rocks are very effective as a new type of fossil for stratigraphic work of the volcanic area. Based on geologic and paleomagnetic research, the volcanic rocks around Lake Suwa are divided into four units as follows.

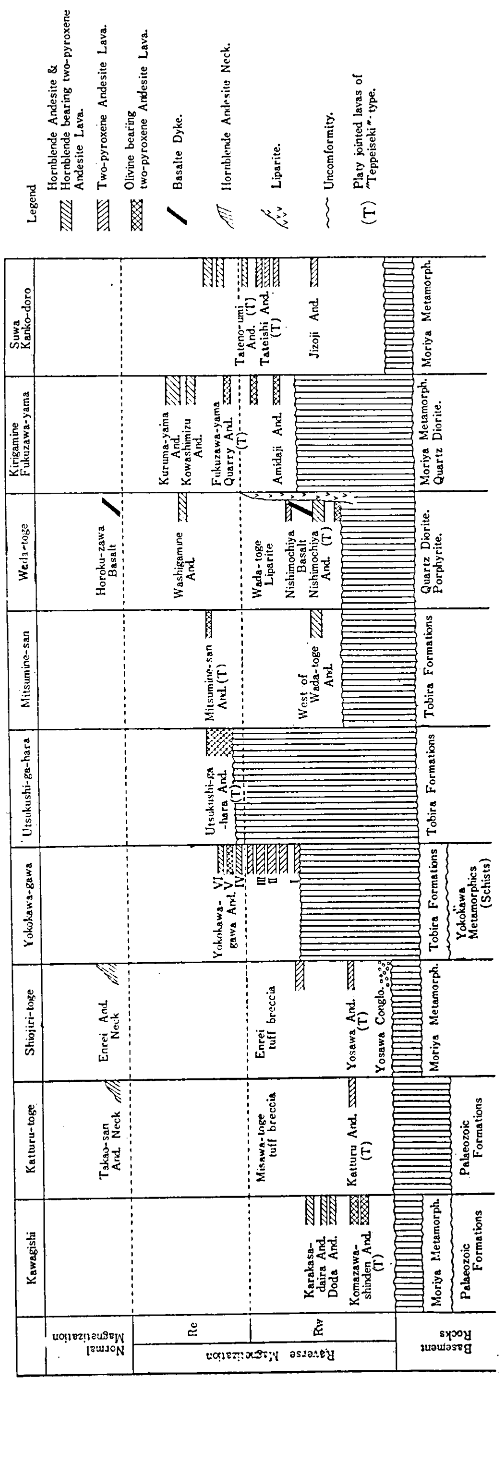

Fig. 12. Correlation chart basing upon geomagnetic and geologic studies of the Enrei formation.

Pleistocene or the latest Pliocene volcanics ………………… consists of the hornblende andesite necks of Takao-san and that east of Enrei Park, the basalt dykes of Nishimochiya and Horoku-zawa. Magnetic directions are *Ne*.

Enrei Formation (Late Pliocene)

- the upper member … consists mainly of the hornblende andesite lavas and associated pyroclastics. Magnetic direction is *Re* so far as the magnetic direction of the specimens collected from the lower part of this member are determined.
- the middle member… consists of two-pyroxene andesite lavas with or without olivine (*Teppeiseki*) and associated pyroclastics. Magnetic directions are *Re*.
- the lower member … consists of lava-flows of two-pyroxene andesite, olivine-two-pyroxene andesite and hornblende-two-pyroxene andesite and of pyroclastics associated with them, and liparite intrusive. Magnetic directions are *Rw*.

The stratigraphic succession of the Enrei formation that have been described individually from seven districts are summarized and correlated as shown in Fig. 12[31]. It is hard to find without geomagnetic criteria that both *Teppeiseki* lava-flows exposed at Komazawa-shinden and Fukuzawa-yama refer to two different horizons respectively. Similarly, the ages of such volcanic intrusives as liparite, basalt and hornblende andesite are not determined. The data of liparite intrusion of Wada-toge in relation to other rocks has been confidently determined by its magnetic direction which is shown on the variation curve to situate just near to

31) In Fig. 12, Kamisuwa-Kirigamine district is divided into two column, i.e. the eastern and western sides of the valley of the Kakuma-gawa.

the critical point at which magnetic direction have turned from *Rw* to *Re* as will later be demonstrated in Fig. 13. Because such a type of lava as the *Teppeiseki* of Fukuzawa-yama and Mt. Mitsu-mine is absent around the liparite body, the relation of liparite to the *Teppeiseki* lava can not be clarified in such a traditional method as has been used in geology.

Correlations by means of paleomagnetic researches for various Pliocene volcanics of the Fossa-magna region in Central Japan was already supplied by the senior author[32]. A remarkable coincidence with geologic data has been accepted to stand in all of the Shigarami, Komoro and the Enrei formations.

5. Discussion

1. *Summarized results of observed magnetic directions of samples collected from various localities.*

Geologic surveys made by us have supplied many conclusions concerning the geologic structures of the Enrei formation. In the light of the magnetic studies hitherto made, the change of geomagnetic field during late Pliocene times is supposed to be that which will be discussed in the following:

The observed magnetic directions of samples from the Enrei formation are all assigned to *R.N.R.M.* and it moreover is said that those in the lower part are westward and those in the upper part are eastward in direction.

All the lava-flows distributed over a wide area are accordingly conceived to be roughly contemporaneous with one another from the standpoints of geology and rock magnetism.

According to our measurements, only two examples which are represented by the andesite from Mt. Takao-san and the basalt from Horoku indicate their directions are normal. Both bodies are recognized as the postdated intrusives into the Enrei formation.

The fact will not provide a decisive evidence for considering that the whole range of the Enrei formation might be characterized by only geomagnetic reversal. We can suspect within the range of the Enrei formation that there has intervened a time when the geomagnetic field was normal. If such is the case, it is likely that we ought to have made a finding of *N.N.R.M.* in some of the samples collected from the Enrei formation.

The observed *N.N.R.M.* of the samples from Takao-san and Horoku,

32) K. MOMOSE, *loc. cit.*, 1).

therefore, seems to indicate their age of intrusion to be close to the Plio-Pleistocene boundary.

2. *Late Pliocene variations of geomagnetic dipole suggested by the obtained results.*

Pole positions calculated from the average magnetic directions with

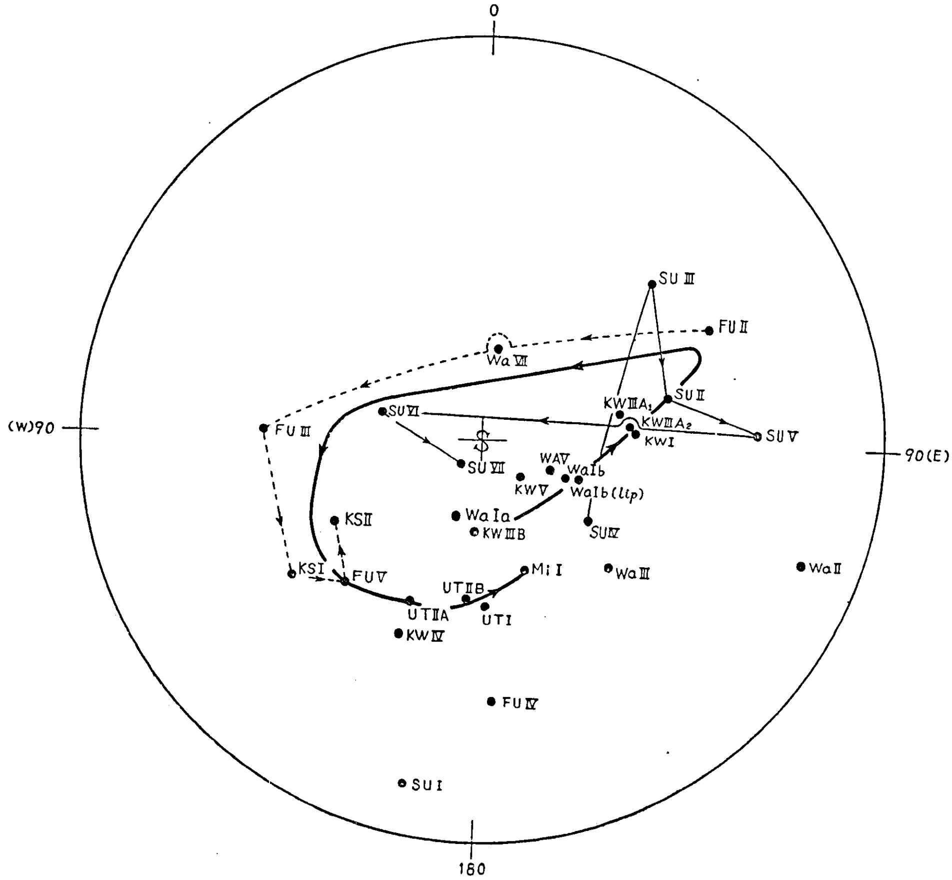

Fig. 13. Modes of the variation of pole positions which might have taken place during the time range of the Enrei formation. Pole positions calculated from measured magnetic directions of the samples taken from every locality are all plotted in this figure. Pole positions can be considered to have shifted along two slender lines with arrow signs basing upon stratigraphic succession in two areas. Taking advantages of other data obtained from the samples of the Enrei formation, we can conceive that pole positions might have shifted along the thick line drawned in the figure during the whole range of the Enrei formation.

respect to every locality are projected in Fig. 13 in relation to their stratigraphic situations. The shifting of pole position through late Pliocene times have thus been established by us.

The continuous and broken lines in Fig. 13 indicate respectively the shiftings of pole position inferred from the results obtained from the samples from Loc. Fu (called Fu group) and from Loc. Su (Su group) respectively. The mass of Su group marks in some parts certain dislocations influenced by faulting. As regards such dislocated beds, original values obtained, therefore, were corrected by making restoration for actual geologic dip of the bed. Although both modes of shifting of pole positions with regard to above-mentioned groups, do not show a complete coincidence with one another, they can be comparable as to the tendency in which pole positions might have shifted from east to west.

In addition to these, numerous instances have supplied a basis for considering that pole position might have shifted from east encircling the present position of the rotation axis westward through the whole time range of the Enrei formation (Fig. 13).

It can not easily be estimated how long the time range of polar variation of this sort lasted, it can, however, easily be inferred that the mode cited above does signify a continuous feature of polar variation during the late Pliocene.

3. *Pliocene chronology inferred by means of geomagnetic variation.*

As seen in the correlation chart which the senior author previously published[33], the whole range of Pliocene is thought to be represented by Shigarami, Komoro and Enrei formations, and he propounded in the paper his opinion that the geomagnetic polarization might have reversed in a continuous way through the span of middle Pliocene times. During the late Pliocene which is represented mainly by the Enrei formation, the pole position might be located close to the rotation axis of the earth.

According to publications hitherto made, many instances of inferred pole positions during the geologic past, even if they were those of either *N.N.R.M.* or *R.N.R.M.*, have been known to be located close to the rotation axis.

The senior author would like to believe that such affairs might be due to the actual existence of the fact that the time range when pole positions were close to the rotation axis might have lasted long.

He would also like to infer that the pole position might rather be

33) K. MOMOSE, *loc. cit.*, 1).

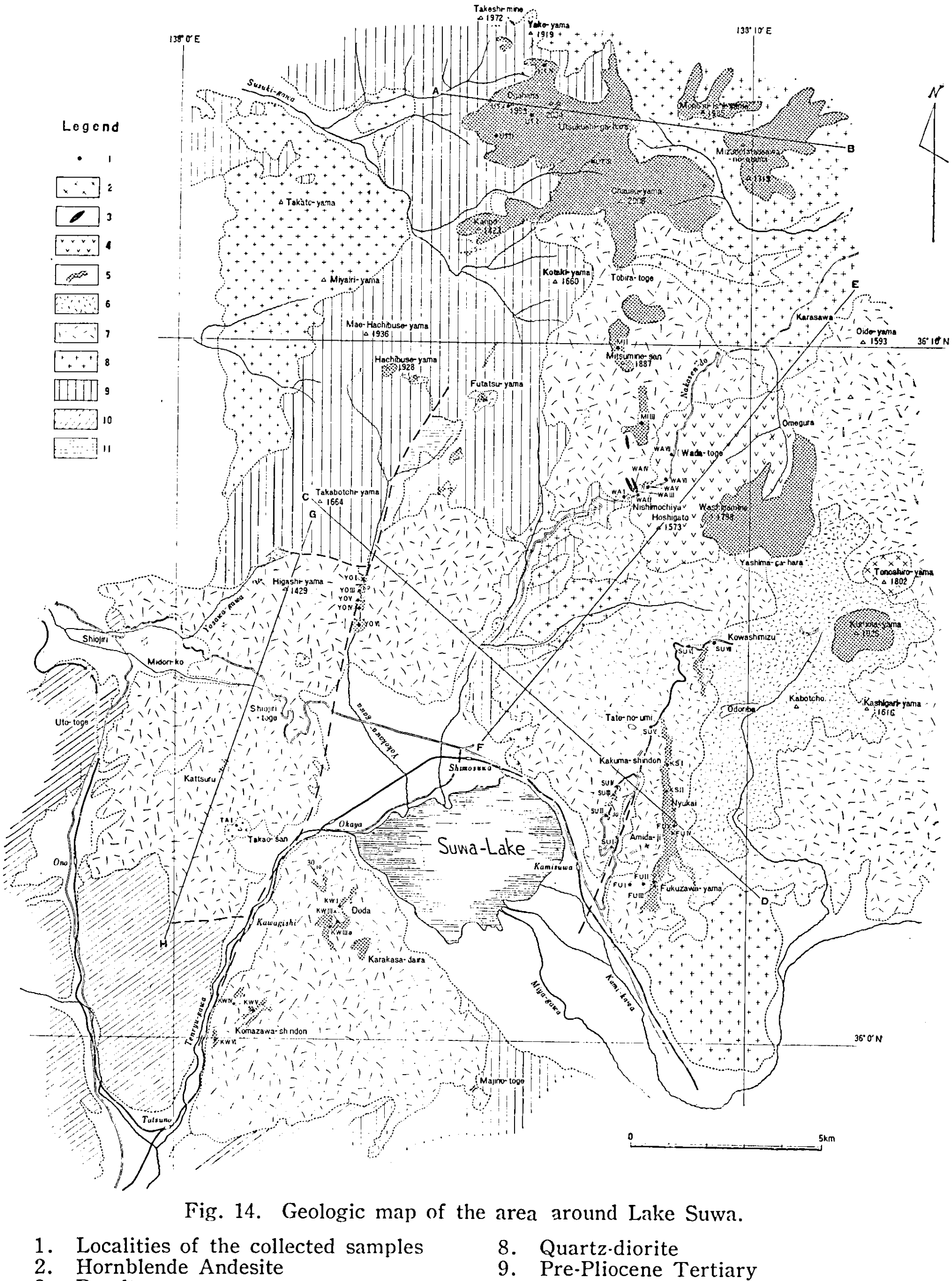

Fig. 14. Geologic map of the area around Lake Suwa.

1. Localities of the collected samples
2. Hornblende Andesite
3. Basalt
4. Liparite................ } Enrei formation
5. Lava-flow .... } Enrei formation
6. Upper part of tuff-brecia } Enrei formation
7. Lower part of tuff-brecia } Enrei formation
8. Quartz-diorite
9. Pre-Pliocene Tertiary
10. Palaeozoic
11. Yokokawa Metamorphics

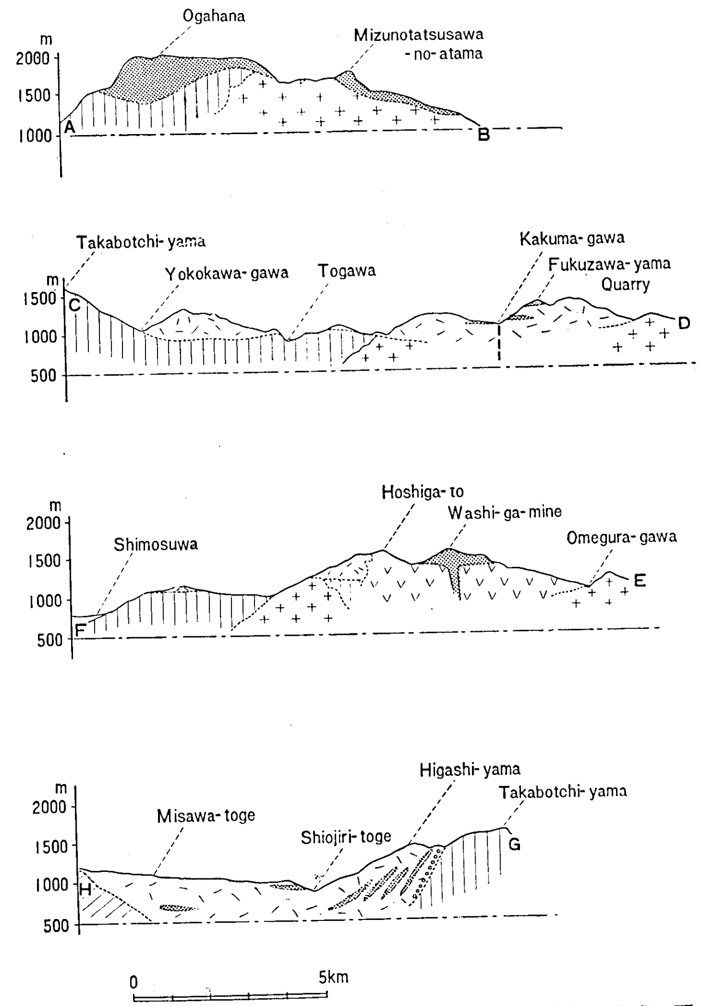

Fig. 15. Geologic profiles along lines $A-B, C-D, E-F$, and $G-H$ on map in Fig. 14.

stable only in the case when the dipole axis was close to the rotation axis, and the geomagnetic reversal might have taken place in a way unconnected with the rotation axis through the span of time when geomagnetic unstableness was introduced by some unknown causes.

Basing upon our evaluation of polar variation in Pliocene times, it can be said that the feature of polar variation in which the pole position has swing around the present South Pole seems to demonstrate the existence of polar swinging immediately after the middle Pliocene reversal of dipole axis.

It is hoped that the measurement of absolute time length of the Pliocene might become possible in the nearest future.

4. *Implications of geomagnetic researches to geology.*

The pyroclastic formations in the environs of Lake Suwa, the Enrei formations have long been studied and supplied many publications as to their geology. The analysis for the structures of the Enrei formations, however, have been done by recognizing that the similar facies in lithology might signify the contemporaneity of their formation.

But such a way of correlation has of course never warranted its adequacy. Based upon the data obtained from their field studies, the authors have established the sequence of volcanisms that have taken place in the areas as shown in Fig. 12.

According to the author's researches for geology and rock magnetism, certain revisions will be made for several opinions hitherto published.

Two lava-flows of the *Teppeiseki* type collected from both localities at Fukuzawa-yama and Komazawa-shinden show a complete resemblance with one another, and both of these are overlain by hornblende andesites of Kirigamine and of Doda respectively. The facts have made various authors to consider both the lavas of the *Teppeiseki* type to be at the same horizon.

The lava-flows at Komazawa-shinden, however, should be referred from the geomagnetic points of views to those of the lower part of the Enrei formation and those of Fukuzawa-yama should as well be referred to those of the middle.

The fact will imply that the extrusion of the similar kind of olivine-bearing-two-pyroxene andesite has twice taken place. The lava of olivine-bearing-two-pyroxene andesites at Mt. Utsukushi-ga-hara and Mt. Mitsumine (*Teppeiseki*-type) each of which locates apart, have been confirmed to be at the similar horizon to that of Fukuzawa-yama. Although a slight difference in the lithologic characters is recognized between the upper and the lower lavas of Utsukushi-ga-hara, they suggest in particular that they might have accumulated locally up to a considerable thickness in a basin or valley perhaps during a rather short period.

The horizon of the *Teppeiseki* lava is undoubtedly situated below the lava forming Mt. Kuruma-yama—the highest summit of Kirigamine Volcano and also below the lava of Mt. Washigamine. Seeing that the latters are markedly vitreous type of andesite and characterized by the occurrence of phenocrysts of hornblende, most authors have hitherto dealt with the lavas of the summit region of Kirigamine Volcano separately from those of the Enrei formation being characterized by the accompanying of the lava of the *Teppeiseki* type.

Such an interpretation has of course introduced the conception in which they recognized the upper part of our Enrei formation as one of the peculiar type of volcanoes—a shield volcano different from the Enrei formation.

So far as our field observations and magnetic measurements have been made in the neighbourhood of Kowashimizu, no significant hiatus can be expected to exist between the both lithologic facies. The authors are accordingly to believe that the extrusion of the *Teppeiseki* lava might surely be followed successively by that of the hornblende andesite lavas of Mt. Kuruma-yama and Mt. Washiga-mine, which are considered to represent the final volcanism of the Enrei formation. It is quite noticeable that the hornblende andesite lava of the similar kind is also found in the lower member of the formation in the environs of Doda.

It is not always easy to know the age of the intrusion of dike and volcanic neck. The age of the liparitic intrusion in the environs of the pass of Wada-toge is known from palaeomagnetic researches to have happened after the deposition of the lower member and before that of the middle member.

Both times of intrusion, on the other hand, of basaltic dike at Nishimochiya and volcanic neck at Mt. Takaosan have been clarified in the sense that they might have intruded a certain while after the final deposition of the Enrei formation.

Our estimation of the ages of intrusions of these special rock-types located in the area mainly of two-pyroxene andesite will surely be significant. It will also be useful for the considerations of the volcanism within the periods from the late Pliocene to the early Pleistocene.

5. *Implications to Geomorphology*

(i) *Mt. Utsukushi-ga-hara—a volcanic mesa.*

Mt. Utsukushi-ga-hara has long been discussed by various authors[34),35),36)] among whom were several authors who considered the mountain as a lava plateau. It exhibits a peculiar appearance in which a rather wide and level summit of more than 4 km^2 stands at a level of about 1,900m above the sea-level. On the southern slope of the upland where a good exposure of rocks as high as 500 m is displayed, there is found no pyroclastic materials interbedded with lavas. These facts are likely to have introduced an opinion that Mt. Utsukushi-ga-hara is sure to be a lava plateau. If the present geomorphic feature of the upland might be due to the primary volcanic froms, the origination of the steep cliff above-mentioned can hardly be explained. The level surface of Mt. Utsukushi-ga-hara is composed of lava and in parts of basement of quartz-diorite, marine sediments of middle Miocene times.

In the summit region, there can not be detected any marked discontinuity in topographical relief between the lava and the basement rocks. In the summit region consisting of lava-flows, the even surface dipping imperceptively eastward seems to represent the primary surface of lava-flows. On the marginal part of the main area of lava-flows, the lavas occupy in many places the upper part of mountain ridges and the basement rocks therefore are exposed up to the higher part of the valley sides. These facts will imply that Mt. Utsukushi-ga-hara which was built up during late Pliocene times would have been moderately dissected and its topographic feature should therefore be referred to "volcanic mesa".

(ii) *Geological age of the highest erosion surface.*

Two remarkable erosion surfaces are recognized along the western border of the Enrei formation, each of which is at the level of 1,900 m and at that of 1,500 m respectively. The erosion surface which truncates the basal rocks just at the level of the even summit of Mt. Utsukushi-ga-hara and the even crest of Mt. Hachibuse altitude 1,928 m consisting of middle Miocene sedimentary rocks are at the some level indicating the past development of the former erosion surfaces at the highest level in our district.

As was previously mentioned, the altitudes of surface of the basement over which the Enrei formation lies are variously at the lowest level of 1,300 m. and at the highest level of 1,900 m. or more. The

34) F. HOMMA, *loc. cit*,. 5).
35) T. YAGI, *Jour. Geol. Soc. Jap.*, **27** (1920), 125.
36) K. KOBAYASHI, *Geogr. Rev. Jap.*, **26** (1953), 291.

lavas might flood filling the tract of former valley or basin-like lower part introducing perhaps no distinguished volcanic inversion of relief, because the lavas are not exhibited so thickly on the highest erosion surfaces. The extruded lavas of Mt. Utsukushi-ga-hara might have piled up to the level of about 1,900 m filling up the former valleys whose bottoms are now at the level of about 1,300 m.

The highest erosion surface might therefore be formed before the time of deposition of the Enrei formation and after that of the middle Miocene formations. It is usually difficult in any district to know the time of origination of erosion surfaces at higher altitudes. The present studies have made without fail a contribution to a problem of geomorphological significances.

(iii) *Kirigamine Volcano—a shield volcano.*

The so-called Kirigamine whose summit region exhibits a low relief topography with rather flat cones here and there, has been referred to a shield volcano. However, no remarkable hiatus is considered to be placed between the middle part of the Enrei formation and the lava-flows forming the summit region of Kirigamine volcano. Although lithologic features of both members are discriminated, both members can not be discriminated perfectly by means of palaeomagnetic considerations. This is the reason why the authors have dealt with the hornblende andesite in the summit region as the upper member of the Enrei formation.

The lava flows of the *Teppeiseki* type as well as many flows of other types of andesite are generally less than 30 m in thickness and indicate a nature in which remarbable lateral extensions of lavas took place covering the even surface of tuff-breccia which in many places shows more or less signs of water-deposition.

It is easily understood that the striking platy-jointed structures might be originated from the striking lateral extension of lava-flows. The lava-flows in the summit region also suggest the fluidal nature of extruded lavas being indicated by dominant existence of flow structures of glassy groundmass.

Even the highest summit Peak Kuruma altitude 1,925 m. is only 300 m. higher above the middle horizon of the Enrei formation.

The so-called Kirigamine volcano as a whole is composed mainly of the pyroclastic material with interbedded lava-flows, but a sort of volcanic depression took place in the early stage of volcanism and several flat cones were formed in the later stage. These facts seem likely to have produced a volcanic form with the appearance of volcanic upland.

It may be said that Kirigamine volcano would be a shield volcano, but the necessary conditions in which such a peculiar type of landform might be resulted, should be explained in the way as mentioned above.

Acknowledgements

It was in 1940 when one of the authors made a finding that the andesite of Mt. Utsukushi-ga-hara indicated anomalously strong magnetism. Our palaeomagnetic researches that were commenced at that time have long been developed in order to decipher the geomagnetic chronology of late Cenozoic times. The present paper has discussed the palaeomagnetic and geologic problems concerning the volcanic area around Lake Suwa.

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29. 諏訪湖周辺の火山岩類の古地磁気学的および地質学的研究
— 中部地方における鮮新世火山岩の古地磁気学的研究（2）—

地震研究所 百瀬寛一

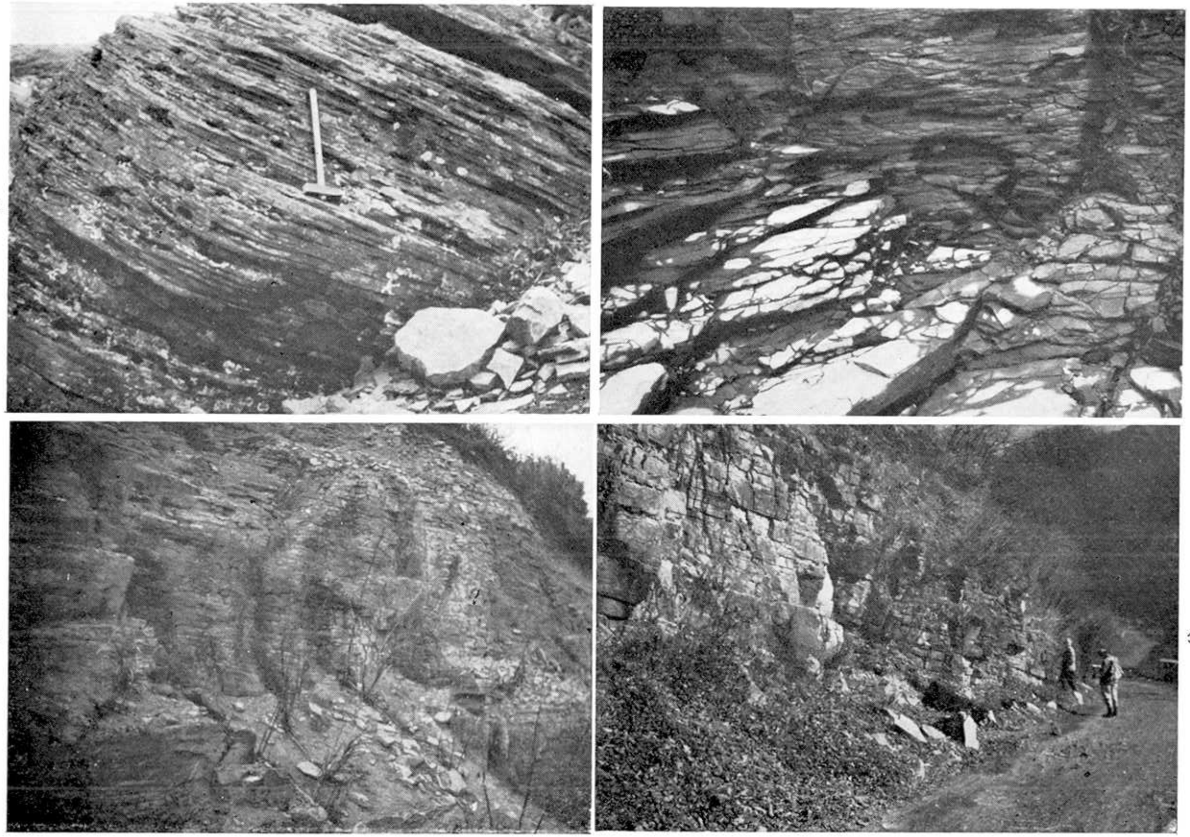
信州大学文理学部地学教室 {小林国夫, 山田哲雄}

（1） 諏訪湖周辺には，鉄平石とよばれる板状節理のよく発達した安山岩やそれに類似する安山岩の熔岩が何枚もある．全体的にこれらの熔岩は塩嶺累層とよばれる凝灰角礫岩を主とする火砕質岩層のなかに含まれている．

塩嶺累層中の火山岩のしめす磁化方位を利用して，地質時代における地球磁場の変動の模様，火山岩相互の時代の対比，地質年代，いわゆる霧ケ峯火山の地質学および地形学的意義，さらにすすんで地形面の形成時代などについて研究した．

（2） 塩嶺累層の火山岩のうち，次の各グループ和田峠，川岸，三峯，美ガ原，諏訪地方より岩石を採取し，磁化方位の測定および安定性のテストを行つた．塩嶺累層の下部層の岩石の磁化方位は Reverse の西偏，上部層の岩石は Reverse 東偏をしめした．また，この累層のすべての岩石の磁化方位は Reverse N.R.M. であつた．高雄山安山岩は塩嶺累層を貫く岩頸であることと，磁化方

Fig. 16. Flat-topped summit of Mt. Utsukushi-ga-hara — a volcanic mesa, as seen from the south-west. The summit level is averagely at the height of approximately 2,000 m.



a b c d

Fig. 17. Jointed andesite (Teppeiseki) at Loc. UT III (a) [Hyaku-magari on the southern part of Mt. Utsukushi-ga-hara], at Loc. UT IV (b) [north of Peak Ogahana], at Loc. Kw V (c) [Komazawa-shinden near Kawagishi]; and at Loc. Wa III (d) [Nishimochiya near the pass of Wada-toge] (hornblende-bearing-two-pyroxene andesite).

a

b

Fig. 18. Jointed andesite at Fukuzawa-yama quarry (a) and the whole view of the locality Fu III (b).

a

b

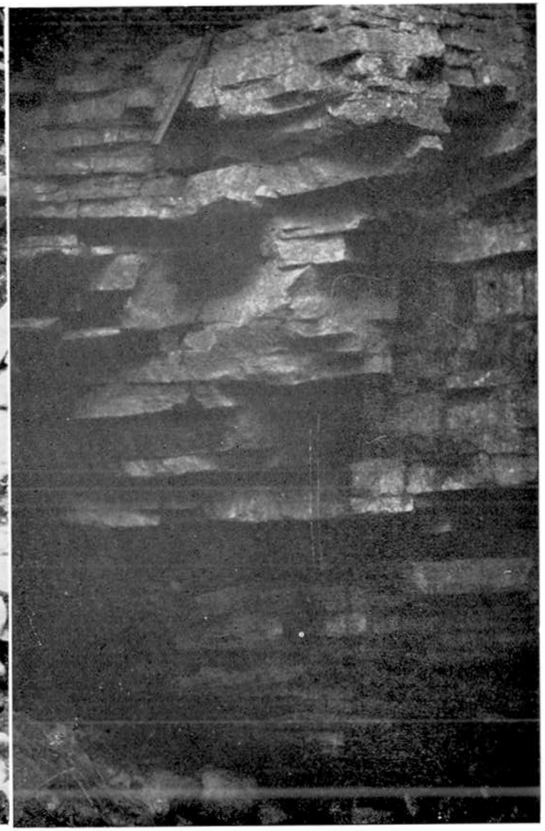


Fig. 19. Jointed andesite at Loc. Fu IV (a) below Nyukai showing the intercrossed joints of the upper part of the flow, and that (Oliv.-bearing-two-pyroxene andesite) at Loc. Fu II (b) below the Fukuzawa-yama quarry.

Fig. 20.

Fig. 21.

Fig. 22.

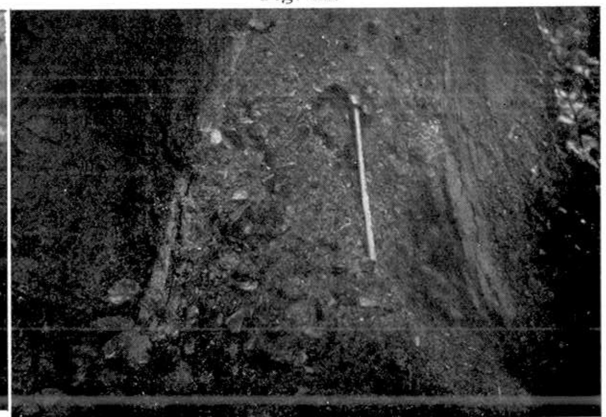


Fig. 23.

Fig. 20. View from south-west showing quarrys at Fukuzawa-yama and the summit level of the Enrei formation.

Fig. 21. The summit region of Mt. Kirigamine showing hilly but rather monotonous landscape of low relief.

Fig. 22. The upper lava exposed near Peak Kurumayama of Kirigamine Volcano showing its remarkable flow structure.

Fig. 23. Basal conglomerate of the Enrei formation at the uppermost part of the Yosawa.

Fig. 24.

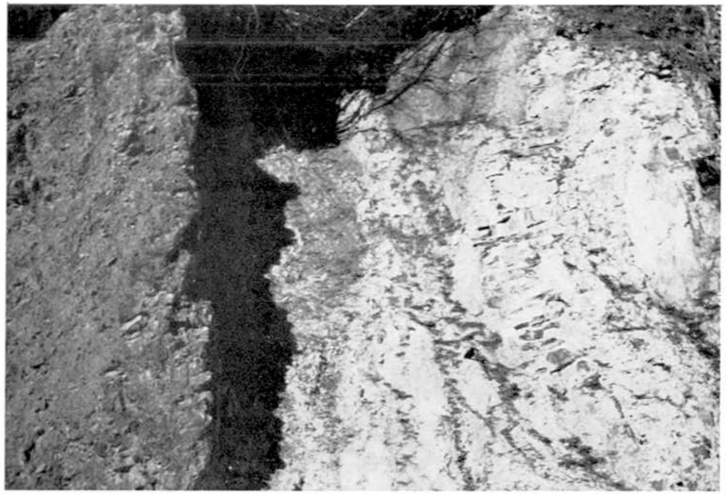


Fig. 26 a

Fig. 25.

Fig. 26 b

Fig. 24. Wada-toge liparite on the right in contact with andesite mass on the left.
Fig. 25. Tree fragments enclosed in the lower part of tuff-breccia at the uppermost part of the Yosawa.
Fig. 26. Microscopic photos of andesite of the Teppeiseki type at Nishimochiya (hornblende-bearing-two-pyroxene andesite a), and at Komazawa-shinden (olivine-bearing-two-pyroxene andesite b).

位が Normal N.R.M. を示す事実からみて，Plio.—Pleistocene にちかい Normal N.R.M. であろうと思われる.

（3） 各グループの磁化方位よりもとめた Dipole の位置を投影したのが Fig. 13 である. そこに示されるように Dipole の変動は累層の下部より上部になるにしたがつて，東から西へ変化している. すなわち，あたかも地球の回転軸を中心にして，一回転したようにみられる. この間の時間の長さを知ることはできないが，しかしうえにのべた変動形式は一種の極移動の連続的変化といつたものではないかと推察する.

（4） 百瀬 (J.G.G. Vol. 10, No. 1, 1958) はさきに柵累層および小諸層群と塩嶺累層との対比表で，この三層をつみかさねたものは，鮮新世全般にわたること，このうち鮮新世の中間にあたる部分の Dipole の軌跡は，地球磁場が連続的に比較的短時間のうちに極性を変えたごとくであることを報告した.

塩嶺累層の岩石より求めた Dipole の位置は，現在の地球回転軸の近傍にある. このことはまた柵累層上部や小諸層群上部（これらは塩嶺累層の下部にあたる）についても同様である. 多くの研究者によつて従来発見された資料の大部分のものは，Normal N.R.M. と Reverse N.R.M. とをとわずそれらの Dipole が地球回転軸の近傍にあつたことを示している. このことはつぎのような事実が存在したことによるものではないであろうか? すなわち，地質時代において Dipole が回転軸近傍に存在した時間は，それが連続的に極性をかえるために要した時間にくらべてはるかに長いものであること，さらに前者は地球磁場の比較的安定していた時代—たとえば現在の地球磁場のような安定度のものではなかつたかと臆測する. 地球磁場の逆転について漠然とした考えではあるが，地球磁場は Dipole の軸方向が回転軸の方向にある場合には安定しているが，何らかの理由によつて磁場に不安定な状態がおこると，比較的短時間に連続的に極性を変えるのではないかと考える.