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Experimental Test on the Stable End Points and Least-squares Methods to Find the Direction of Remanent Magnetization.

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Abstract

Specimens for paleomagnetic study have usually multi- components. To find the primary magnetization during the course of demagnetization, many techniques have been proposed. Two popular methods of the stable end points and least squares are compared experimentally. Both methods have small variations respectively.

The stable end points method tested in this paper is carried out using the alternating demagnetization data of two pilot specimens in one sampling site. A line passing through the origin on the Zijderveld plot is seeked referring the movement of the direction on the Schmidt net and the change of intensity. The stable end point step or step interval on the line being common between two pilot specimens is determined and all of specimens demagnetized at this demagnetization step.

The principal component analysis (PCA) is one of variations of the least squares method. Fitting line which is parallel to the maximum eigenvector gives the direction of remanent magnetization. As a precision factor, the maximum angular deviation (MAD) is calculated.

The deviation in direction of two methods in the volcanic rock regions is too small and less than 0.5° almost. The precision factors are similar each other. That means that efficiency of both methods for the volcanic rocks is identical.

Introduction

After the requirement of primary remanent magnetization, for example thermal remanent magnetization on cooling process, a rock is subjected to remagnetization through geologic time. The new magnetization has a component parallel to the local geomagnetic field of that time, and superimposes the primary remanence which the rock has obtained. It is important to find out the direction of the primary remanence at the specimen level in general case. The alternating field, thermal, or chemical demagnetization methods are used to separate the multiple remanent components. There are many techniques to separate the remanent components. The analyses of two popular methods, stable end points and least squares, for rock samples from volcanic areas are experimentally examined. The analytical results and comparison of two methods are described in this paper.

Here only the analytical nature is treated, and the archeomagnetic feature of these historic lava flows will appear soon in another paper.

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Practical Analysis

Technical methods to separate magnetic components during the course of demagnetization have been proposed by many researchers. Those are the vector substraction method (Roy and Park, 1974) and stable end points method (Irving, 1964). The Zijderveld diagram used most frequently is a plot of vector on two orthogonal planes (Zijderveld, 1967), and its usage was extended to multi-component magnetization (Dunlop, 1979). The great circle methods were developed by Halls (1978) and McFadden and McElhinny (1988). Stupavsky and Symons (1974) have used the least squares method.

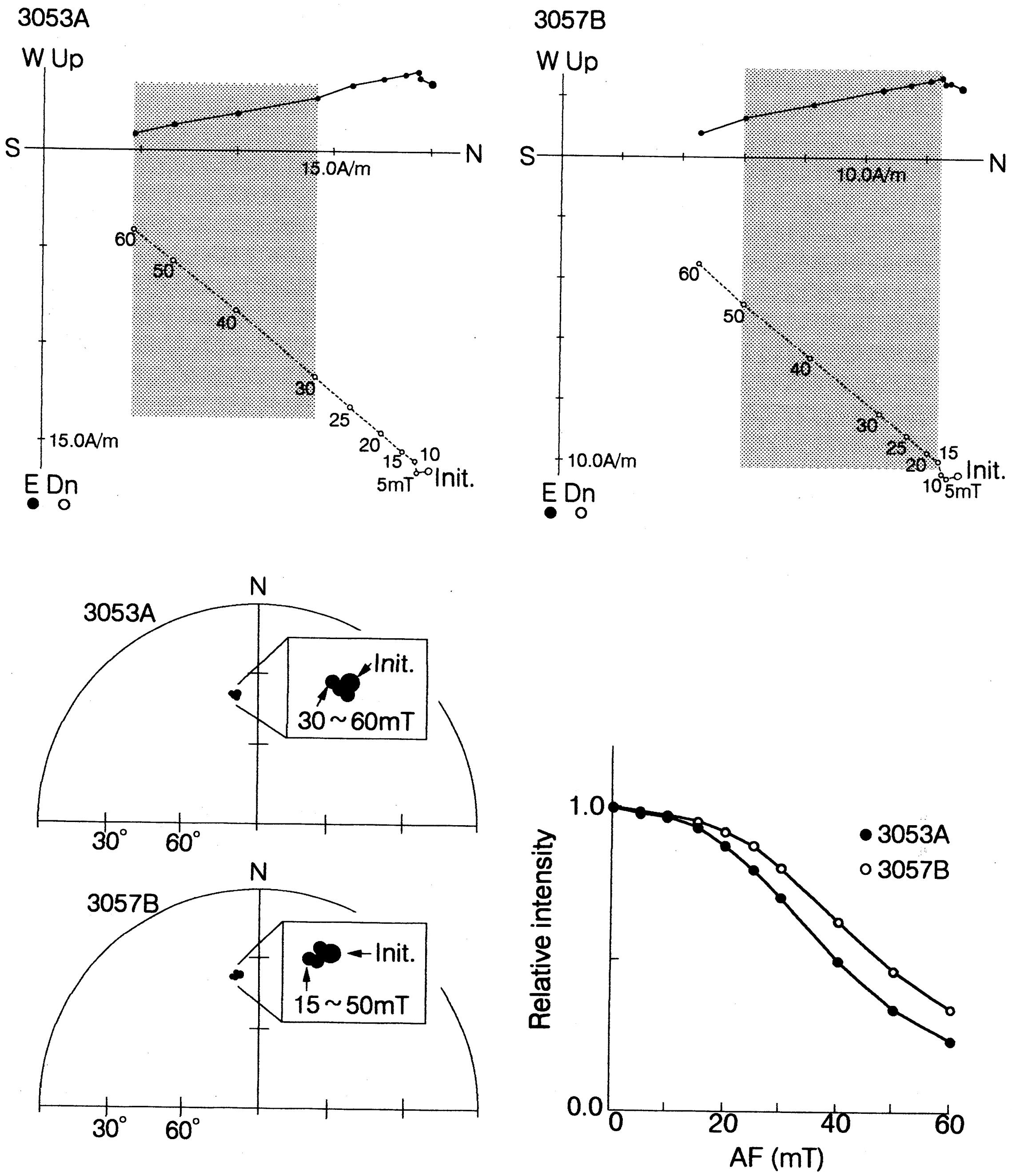

Fig. 1. Determining process of stable end points.
Upper: the Zijderveld plots. Lower left: the Schmidt net plot of direction. Lower right: changes in intensity.

Kirschvink (1980) introduced the least-squares line or plane analysis method.

There are two empirical procedures in the stable end points methods (Irving, 1964). McElhinny and Gough (1963) use the criterion that the stable end component changes only in intensity not in direction after the soft component is erased. Another criterion is based on the dispersion of several specimens from the same site. The minimum dispersion of pilot specimens after each demagnetization step is selected, and all specimens of the site are demagnetized at this demagnetization step (Irving et al., 1961; Ueno et al., 1975). In this study, the procedure which is similar to that of McElhinny and Gough (1963) is employed, and the alternating field demagnetization is carried out as a cleaning treatment . Two pilot specimens among ten or more specimens from one sampling site are selected. The demagnetization of pilot specimens at each step of 5, 10, 15, 20, 25, 30, 40, 50 and 60mT was done. On the Zijderveld diagram, the line fitting to pass through the origin of the diagram is tried. Referring the movement of the direction on the Schmidt net and the change of intensity, the stable end point step or step interval on the fitting line is decided for each pilot specimen. The common stable end point step of two pilot specimens is determined, and all of specimens of the site are demagnetized at this demagnetization field. The typical examples of the procedure to find the stable end points are shown in Figure 1. Specimen 3035A has a fitting line on which plots of 30, 40 , 50 and 60 mT lie, and specimen 3057B has a line including plots of 15, 20, 25, 30, 40 and 50mT. In the case that it is difficult to determine exactly the stable end step of sampling site, all of specimens of the site are demagnetized at two or three steps and the minimum dispersion step is employed.

The principal component analysis (Kirschvink, 1980) is one of the least squares methods. Here, the line not plane analysis of best least squares fit is applied to find the characteristic remanence. Remanent magnetization directions of each specimen from one sampling site is decided by this analysis of the data from progressive alternating field

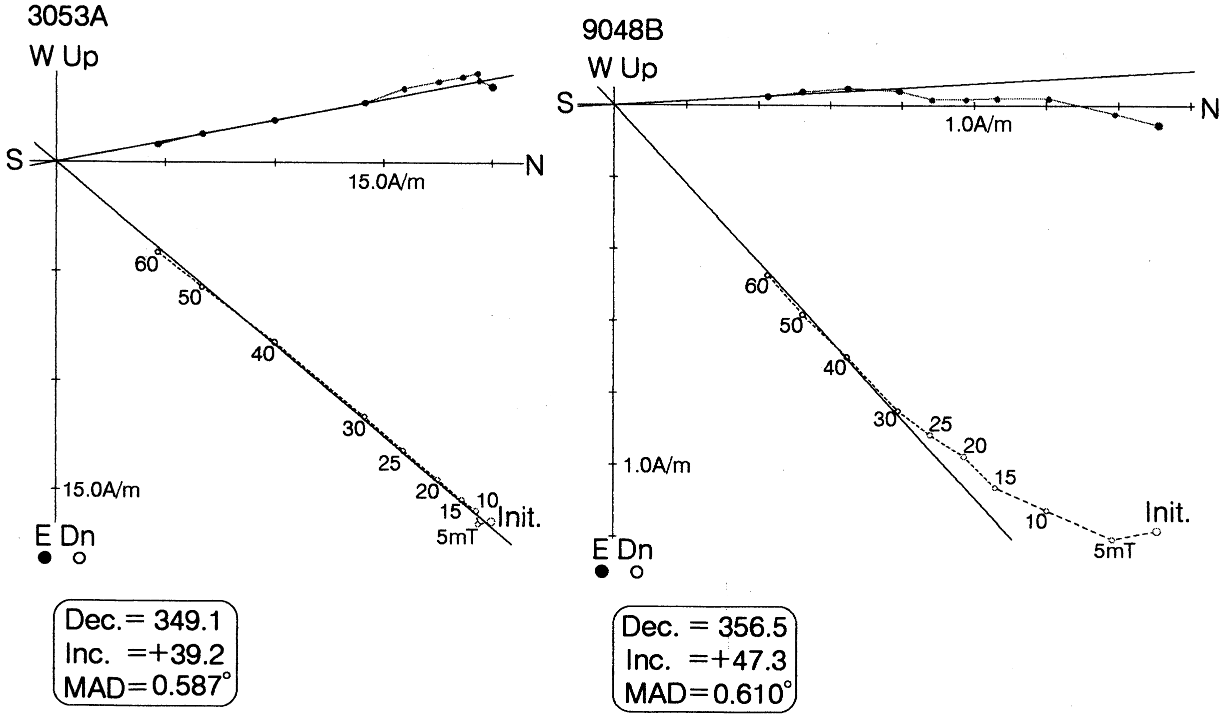

Fig. 2. Line fittig procedure using the Zijderveld plot of the principal component analysis of the least squares method.

demagnetization of each specimen. The angle of the fitting line that passes through the origin corresponds to the direction of remanent magnetization of the specimen. The line is parallel to the maximum eigen vector of the matrix from data set (Tanaka, et al., 1986). A maximum angular deviation (MAD) is calculated to provide the quantitative precision of the measurement with which the best fit line is determined. In case on specimen 3057A, the line passing the origin on the Zijderveld diagram and including plots of 30, 40, 50 and 60mT is selected (Fig. 2). The line of specimen 9048 B pass the origin and points of 30, 40, 50 and 60mT (Fig. 2). The least squares calculations are done using the those data sets.

The smooth decreasing of the alternating field is performed by the System Alternating Power Supply P-station Type-Ⅲ controlled by a microcomputer through GP-IB. Then there is no trouble during the course of the alternating field demagnetization after using this system. Moreover, it is possible to use the alternating field up to 80mT with 3 axes tumbling and up to 200mT in uniaxial-three position use.

Results

As test samples, lava and pyroclastic flows from Kirishima volcano, southern Kyushu and Kuchinoerabu island are examined. The location of sampling sites are given in Appendix. Volcanic rocks consist mainly of two pyroxene andesite. Mean initial intensities of remanent magnetization are 6 to 16 A/m. Volume magnetic susceptibilities range from 0.1 to 0.3 (SI unit), and Q-values are 8 to 17.

Results are shown in Tables 1 and 2. The precision parameters of α, k and R obtained by both analytical methods are very similar each other. In last column in Tables 1 and 2, the deviation in direction of both methods is indicated. A maximum angle is 0.9°. Most of them are within 0.5°. That means the results of both methods are identical, and any of two methods is sufficient for district use of directions such as archeomagnetism. The MAD of the principal components analysis is very small (Tables 1 and 2).

From the stand points of labors and times for experiment, the stable end points method has advantages. Numbers of times of demagnetization for each sampling site are 9 (steps) × 2 (specimens) + 8 (specimens) = 26 on the stable end points method, and 9 (steps) × 10 (specimens) = 90 on the least squares methods. The time of the stable end points method is less one third than those of the least squares method.

Table 1. Analytical results of the stable end points and least squares methods in the Kirishima area

Site	N	M(A/m)	analysis	Dr°	I r °	α°	k	R	AF(mT)	δ°	Δ° (PCA-SEP)
Kirishimajingu Lava ,Katazoe											
3031-3039	12	7.5	SEP	350.9	+43.2	1.70	652	11.98	30		0.56
			PCA	351.7	+43.3	1.80	585	11.98		0.85	
3040-3049	10	24.0	SEP	345.6	+47.2	1.92	635	9.986	40		0.10
			PCA	345.6	+47.3	1.69	821	9.989		0.31	
3050-3059	10	22.4	SEP	350.7	+37.1	1.09	1970	9.995	30		0.18
			PCA	351.0	+37.1	1.18	1680	9.994		0.47	
3060-3067	11	20.2	SEP	351.9	+47.3	1.55	874	10.99	30		0.52
			PCA	352.6	+47.2	1.72	706	10.99		0.38	
3095-3102	11	8.6	SEP	354.9	+42.8	2.23	419	10.98	30		0.10
			PCA	354.9	+42.9	2.12	466	10.98		0.23	
Kirishimajingu Lava ,Takaharu											
3076-3083	12	9.6	SEP	002.3	+54.3	1.05	1700	11.99	50		0.34
			PCA	002.5	+54.0	0.92	2240	12.00		0.29	
3084-3094	11	10.3	SEP	006.1	+50.0	1.70	719	10.99	50		0.51
			PCA	006.0	+49.5	1.72	709	10.99		0.78	
3103-3110	10	4.4	SEP	004.4	+46.3	1.75	766	9.988	25		0.00
			PCA	004.4	+46.3	1.75	766	9.988		0.39	
3111-3118	11	6.1	SEP	006.4	+44.4	1.57	851	10.99	40		0.07
			PCA	006.3	+44.4	1.43	1020	10.99		0.49	
Sano Lava											
4024-4031	11	6.5	SEP	357.6	+42.1	1.94	554	10.98	40		0.24
			PCA	357.8	+42.3	1.85	608	10.98		0.18	
4032-4041	9	9.8	SEP	358.4	+46.5	1.45	1270	8.994	30		0.18
			PCA	358.6	+46.6	1.44	1330	8.994		0.15	
4042-4054	12	4.8	SEP	357.5	+44.5	1.63	709	11.98	20		0.14
			PCA	357.7	+44.5	1.58	758	11.99		0.41	
Ohachi Scoria Flow											
5018-5030	12	9.4	SEP	003.4	+52.5	1.53	809	11.99	30		0.20
			PCA	003.4	+52.7	1.54	792	11.99		0.50	
5031-5044	12	6.9	SEP	001.2	+51.5	1.73	631	11.98	50		0.25
			PCA	001.0	+51.7	1.70	655	11.98		0.29	
5045-5058	14	9.4	SEP	005.4	+53.1	1.64	587	13.98	40		0.08
			PCA	005.3	+53.1	1.58	633	13.98		0.29	
5059-5071	13	14.4	SEP	002.0	+51.0	1.81	523	12.98	30		0.33
			PCA	001.6	+51.1	1.88	532	12.98		0.12	
Takachihogawara Lava											
6028-6039	10	13.9	SEP	000.6	+51.2	2.09	525	9.983	20		0.13
			PCA	000.7	+51.3	2.21	478	9.981		0.37	
6049-6057	9	11.6	SEP	001.7	+51.1	1.88	752	8.989	20		0.10
			PCA	001.7	+51.2	1.92	719	8.989		0.23	

N is the number of specimens. M is the mean initial intensity. SEP is the stable end point method. PCA is the principal component analysis method. Dr and Ir are the declination and inclination of remanence magnetization. α is the half angle of the cone of confidence at $p=0.95$ and k is the Fisher's best estimation of precision(Fisher,1953). R is the resultant of vector sum. AF is the peak alternation field. δ is the mean maximum angular diviation(MAD) (Kirschvink,1980). Δ is the difference angle between the paleomagnetic direction of two analytical methods.

Table 2. Analytical results of the stable end points and least squares methods in Kuchinoerabu island

Site	N	M(A/m)	analysis	Dr°	I r °	α°	k	R	AF(mT)	δ°	Δ° (PCA-SEP)
Shindake Lava											
9001-9006	12	2.0	SEP	358.1	+48.9	1.24	1220	11.99	40		0.31
			PCA	358.0	+49.2	1.28	1150	11.99		0.79	
9007-9013	13	1.5	SEP	000.0	+52.2	1.60	669	12.98	25		0.00
			PCA	000.0	+52.2	1.42	848	12.99		1.36	
9014-9019	12	1.5	SEP	355.0	+48.6	1.40	962	11.99	15		0.46
			PCA	355.3	+49.0	1.42	931	11.99		0.76	
9020-9025	10	2.0	SEP	356.1	+47.9	1.19	1640	9.995	50		0.82
			PCA	357.2	+47.8	1.29	1390	9.994		0.47	
9037-9044	10	1.5	SEP	356.9	+48.9	2.05	555	9.984	40		0.90
			PCA	357.8	+48.3	2.02	574	9.984		1.60	
9045-9048	10	1.9	SEP	000.7	+48.0	1.46	1090	9.992	40		0.12
			PCA	000.8	+48.1	1.48	1060	9.992		0.77	
9049-9055	10	5.0	SEP	351.9	+46.1	0.66	5430	9.998	30		0.24
			PCA	351.6	+46.0	0.70	4750	9.998		0.41	
9056-9064	11	3.8	SEP	358.8	+49.5	0.70	4210	11.00	30		0.13
			PCA	358.9	+49.4	0.68	4520	11.00		0.38	
Furudake Lava											
9065-9071	11	2.4	SEP	359.1	+41.8	1.36	1130	10.99	15		0.21
			PCA	359.2	+42.0	1.47	962	10.99		0.51	
9072-9078	13	9.4	SEP	000.4	+42.9	0.76	2940	13.00	25		0.07
			PCA	000.3	+42.9	0.78	2820	13.00		0.26	
9079-9086	12	12.8	SEP	356.2	+44.9	1.17	1380	11.99	40		0.20
			PCA	356.2	+44.7	1.19	1340	11.99		0.19	

Abbreviation is the same as in Table 1.

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Appendix Locations of sampling sites

[Kirishima area] Kirishimajingu Lava, Katazoe (31° 51.7′ N, 130° 53.0′ E); Kirishimajingu Lava, Takaharu (31° 51.7′ N, 130° 53.0′ E); Sano Lava (31° 54.0′ N, 130° 57.3′ E); Ohachi Scoria Flow (31° 52.9′ N, 130° 53.9′ E); Takachihogawara Lava (31° 52.5′ N, 130° 53.9′ E).

[Kuchinoerabu island] Shindake Lava (30° 27.1′ N, 130° 11.8′ E); Furudake Lava (30° 25.5′ N, 130° 12.8′ E).