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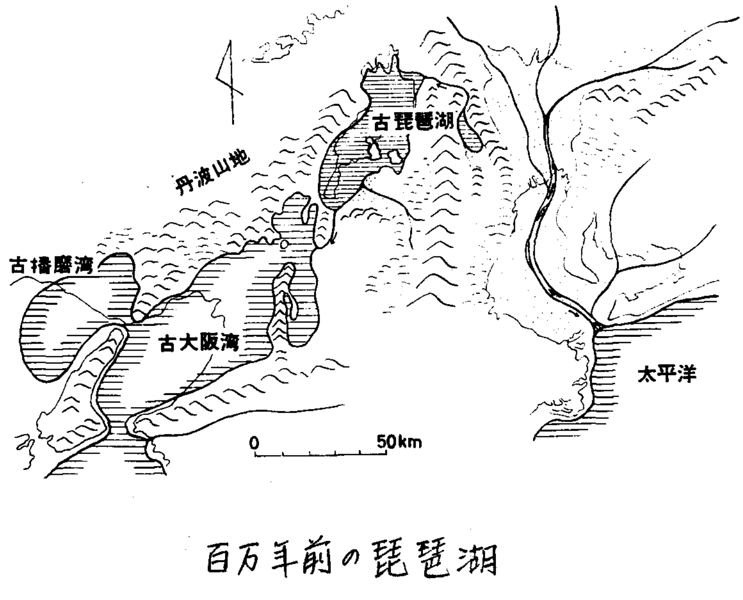
Secular Variation of Geomagnetic Field in the Quaternary

Tadashi NAKAJIMA



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This paper consists of two PARTs which have respective Figures, Tables and References. In PART 1 was described an oscillating geomagnetic field reduced from the measurement of the entire core of Lake Biwa approximately 200 m in length. Whereas, in PART 2 were represented the detailed results of measurements at the upper part of the same core about 22 m in depth.

CONTENTS

PART 1

Oscillating Geomagnetic Field with a Recurring Reversal

A project to acquire a boring core column from below Lake Biwa has long been proposed by Horie of Kyoto University. It was only recently that the aim, supported by a grant fortunately, became achieved satisfactorily. The lowermost portion of the column was finally dug out in 1971 from the depth 198 m below the lake bottom, and a long core composed of green clay particles became entirely revealed under the sun. The location from which the core was taken is shown in Fig. 1.

(Fig. 1, here)

Since the beginning of the Tertiary period in which the lake started to exist, an enormous amount of clay particles has been gathered from her vast drainage basin. They all were falling ceaselessly in water to form a thick ooze at the bottom. As it became gradually consolidated under increasing load with increasing over-lying particles, an undisturbed basin with no gap of deposition began slowly to develop till its thickness exceeded over more than 1000 m.

The core, when examined under the microscope, contains fine spherical ferromagnetic particles resembling conspicuously to the cosmic dust collected from ocean bottom. On further observation under the magnetometer, the whole column was found to possess a weak but stable remanent magnetism. Each sphere made a damped oscillation, whilst it was descending in water, till its polarity became parallel to that of the geomagnetic field and subsequently fossilized within the clay matrix.

Consequently, one could trace the geomagnetic field backward in time by measuring the magnetism from the uppermost part of the core to the lowermost successively.

In Fig. 2 is shown the geomagnetic inclination change with increasing depth.

(Fig. 2, here)

In the above measurements 40 sampling horizons were so chosen that they may spread over the entire column uniformly with a nearly equal separation of 5 m. Then, from each horizon three specimens were cut off successively along the core axis, and measured after the magnetic cleaning using alternating field.

Although most of the inclinations we observed have positive values and fluctuate smoothly from point to point in the diagram in Fig. 2, there appear at least five regions A, B, C, D and E in which one positive value jumps suddenly to a negative one. When more specimens were taken and examined carefully at each region, many transient inclinations as shown by the square dots were discovered.

The geomagnetic field itself seems to have changed the sign so frequently in the geologic time. If so, similar pattern must be seen in the change of declination to be measured, too. Unfortunately, however, no orientation in situ was marked in the core before it was removed from the basin. Nor a vertical column longer than 2 m was obtainable due to the technical restriction in the present boring. The entire column was broken up into pieces more than 200 in number.

It, nevertheless, is possible to join them together, if the lowermost part of one piece of column and that at the uppermost part of the underlying column were assumed to possess the same direction of magnetization. One piece is to be rotated relative to the other around the core axis so that two directions measured at each joint may become parallel to each other as shown in Fig. 3. The error arising from this method of restoring the column must be small in the regions B, C and D, where only two or three pieces were dealt with.

When this joint piece was examined, continuously changing declination with depth was found in each of the regions as shown in Fig. 4. The three varying directions of magnetization are plotted on a Schmidt's projection in the diagram.

(Figs. 3 and 4, here)

An important question remains as to whether or not the intensity of magnetization decreased in the great polarity change. Despite of our careful test, however, no significant evidence has been confirmed in the transition zone as yet.

The free fall velocity of very fine particles in water is in general slow as the Stokes' law indicates. An extremely sluggish rate of deposition, therefore, is characteristic of the sediments in Lake Biwa. HORIE (1971), estimated the rate from both the thickness of the present lake deposits and the three ages of young strata lying at different horizons, giving 0.4 mm/year as the most plausible value. The ages were determined by the C^{14} method of analysis in which were used many organic relics embedded in each stratum.

The rate, being available only within 20 m or so below the bottom, can not be extrapolated to such a great depth of the core. YASKAWA (1972) proposed, therefore, the following equation in order to date a deep seated stratum in general sedimentary basin:

$$h = A (t - t_o) + B [1- \exp C (t - t_o)]$$

Where h and t are the depth (cm) and age (yr) of the stratum at a horizon respectively. When Horie's results shown in Table 1 are taken into account, and each coefficient in the equation becomes determined, i.e. A=0.0426 , B=561.8 , C=-0.000365 and t_o=1,090 , age of any horizon in this particular basin can be obtained quantitatively.

Thus, the three events represented by the observed reverse fields were dated as shown in Table 2. The second reverse field appeared in 104 thousand yrBP and disappeared 117 thousand yrBP.

All through the three events one reverse field is separated from the next by a nearly identical interval of time. The duration T_1 in which one normal field is existing is about 85 thousand years. The duration T_2 in which one field is being switched from the opposite one is so short as 4 thousand years. On the other hand, the duration T_3 in which one reverse field is approximately 10 thousand years.

(Tables 1 and 2, here)

The data obtained so far seem to support the present author who believes that a regular oscillation of the geomagnetic field with such a recurring reversal is an intrinsic chracteristics of the self-exciting dynamo in the earth's core during the past 500,000 yrs. A period of relatively stable field with the normal polarity persisted for approximately 100,000 years and became unstable at its end. Then the field switched to a new field with the opposite polarity. The transition was completed within a time-interval of 4,000 years. The opposite field, however, had a relatively short duration and within the subsequent 10,000 years the normal field reappeared to make up one cycle.

Since the Brunhes geomagnetic epoch began 0.69 m.y. ago, no reverse geomagnetic field was said to have come to existence up to the present time. When the continuous sediments with no gap of deposition in Lake Biwa were studied in detail, it was clarified that the apparently monotonous Brunhes normal epoch involved several occassions at which the field became instable and gave away to the field whose polarity was opposite to the main field. The Brunhes geomagnetic field has such an oscillating characteristic. Independently from our study and quite recently several authors discovered sporadic distribution of short period geomagnetic anomalous directions at the Puy de Laschamp in France, Gothenburg in Sweden and the Blake outer ridge in the North Atlantic, respectively called the Laschamp, Gothenburg and Blake event (BONHONNET and ZÄRINGER, 1969; MÖRNER et al., 1971; SMITH and FOSTER, 1968). Similar anomaly was reported by STACY (1969) who claimed that it began 350,000 yrBP and came to the end 330,000 yrBP.

In Table 3 the anomalies so far found from various part of the world were compared with the events of instability confirmed within the Lake Biwa deposits. Agreement of the occurrences implies that the instability of geomagnetic field as well as the oscillation is a world-wide phenomenon.

(Table 3, here)

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Table 1

Depth (m)	Age (yrBP)
0.8 ± 0.05	1430 ± 95
4.5 ± 0.15	3650 ± 105
11.5 ± 0.20	14980 ± 460

Table 2

	Depth (m)	Age ($X10^3$ yrBP)	T_1	T_2 ($X10^3$ yrs)	T_3
			99	6	
B. Second Reversal	50.5	104			13
	55.0	117			
				4	
			51	4	
C. Third Reversal	80.5	176			10
	85.0	186			
			104	2	
D. Fourth Reversal	130.0	292			
	132.5	298			6
		Mean	85	4	10

Table 3

Name of event	Location	Age (yrBP)	Reference	Corresponding reversal field region from Lake Biwa
Gothenburg	Gothenburg, Sweden	12,400- ?	MÖRNEN, 1971	A
Laschamp	Puy de Laschamp, France	8,730 20,000 - ?	BONHOMMET, 1969	
Blake	Blake outer ridge, North Atlantic	108,000-114,000	SMITH, 1969	B
Biwa I		176,000-186,000	present study	C
Biwa II		292,000-298,000	present study	D

Figure captions

Fig. 1 Map of Lake Biwa.

Dot shows the location from which the core was taken

Fig. 2 Inclination of remanent magnetism versus depth.

Square shows the inclination of transient magnetization. Hollow circle shows each inclination of the reverse fields of which the polarity was confirmed also from the declination check. The mean value is shown with rhombus.

Fig. 3 Method of restoring broken core to the original orientation.

Fig. 4 Change of the direction of magnetization.

(a) Region B

(b) Region C

(c) Region D

(Depth increases with increasing number of suffix).

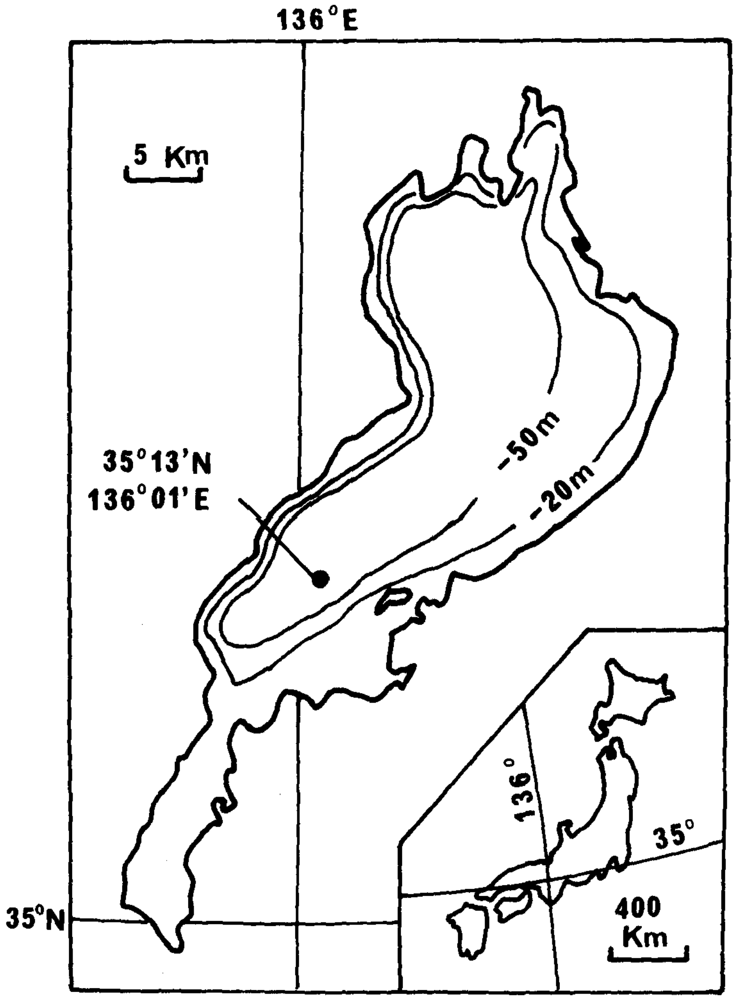

Fig. I

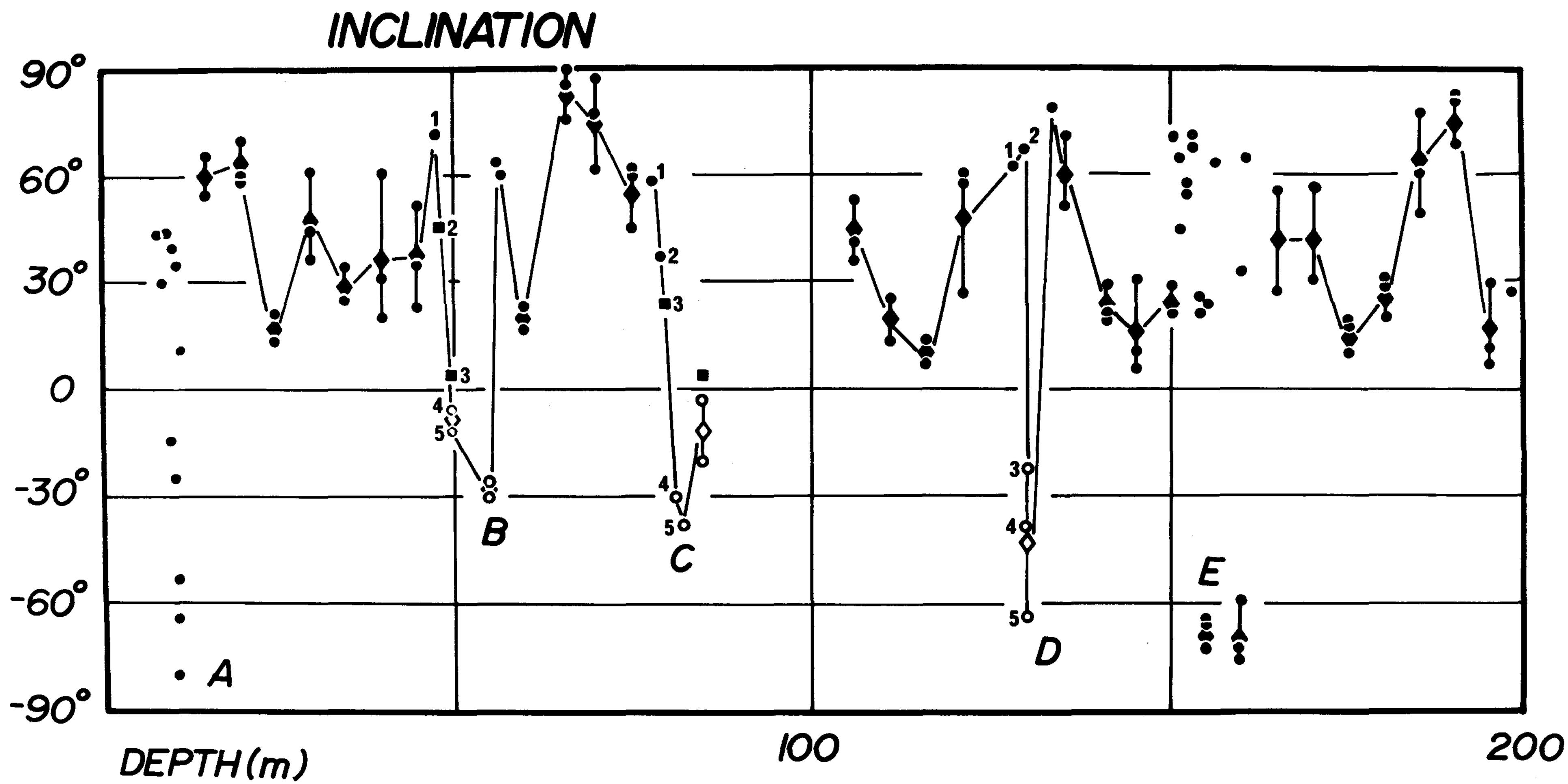

Fig.2

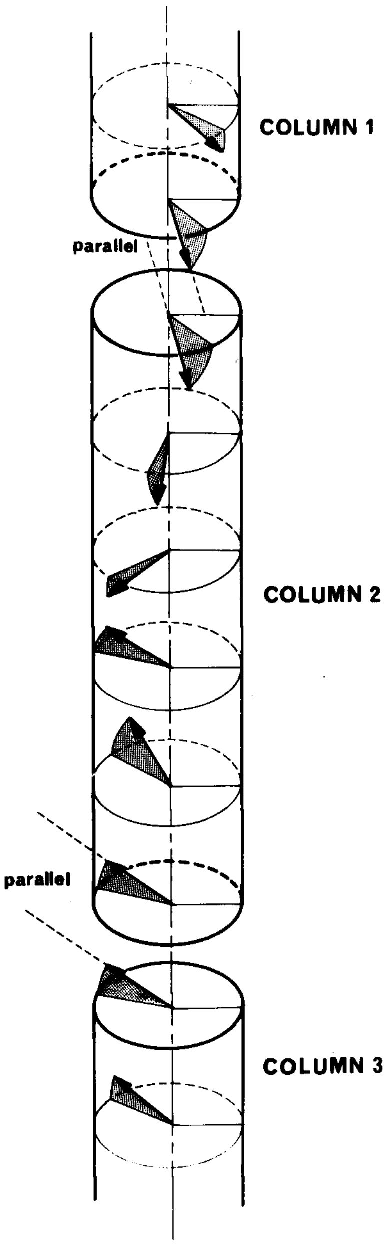

Fig.3

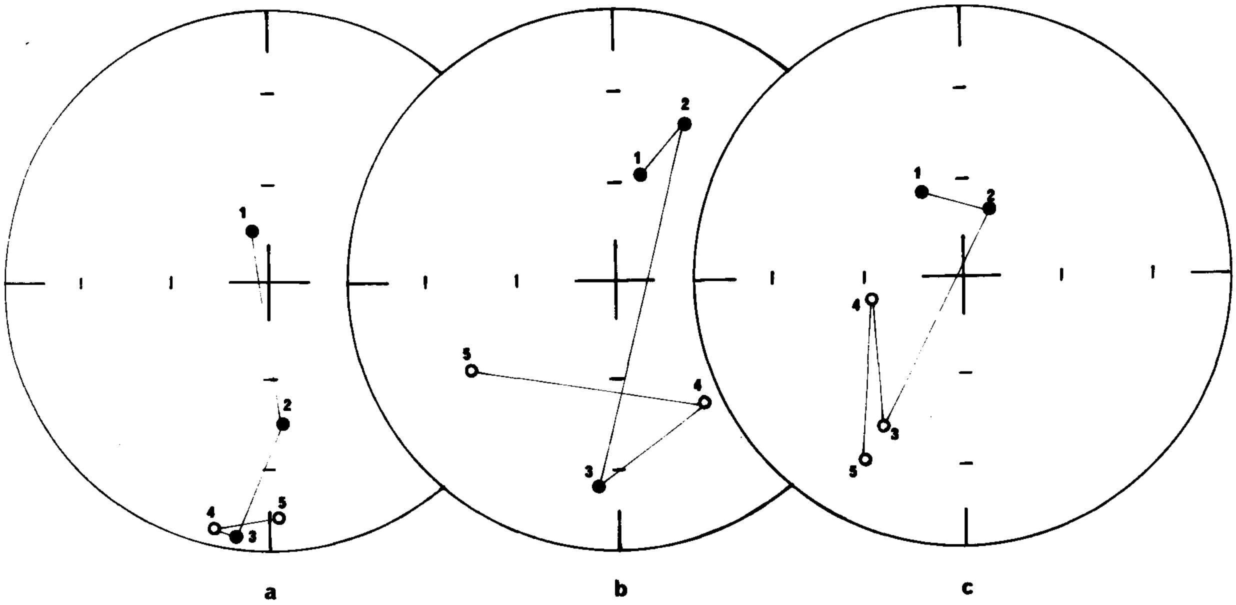

Fig. 4

PART 2

Secular Variation of the Geomagnetic Field during the Past 38,000 yrs

Introduction

To obtain secular variation of the past geomagnetic field modern sediments called varved clay were studied by several investigators in the early stage of the study (JOHNSON et al., 1948; CLEGG et al.,1954; KING, 1955; GRIFFITHS et al., 1960 etc.). It is possible to count directly the number of the varves and estimate ages of the clays quite accurately back to say 100,000 yrs or so. However, inclination of NRM has a special tendency to become slightly smaller in case the deposition occurred at places away from pole and equator of the earth. Ferromagnetic particles are nonspherical in shape. While they are descending in water, the direction become smaller than the angle of actual inclination, or otherwise the plurality of the particles link together to form a needle whose axis tends also to lie on the horizontal plan. Even after the deposition the dip angle decreases while the sediment was being compacted.

It is also possible to follow the secular variation when ocean deposit is taken and its NRM is to be measured. But the rate of deposition is generally too slow to subdivide the deposit. Measurable thickness of the deposit by means of the astatic magnetometer or spinner magnetometer is about

2 cm, covering laps of time more than 500 yrs or so. On the other hand, in case the rate of deposition is too rapid as in the case of ordinary sedimentation in most geosynclines, the ferromagnetic particles are so diluted that intensity of magnetization becomes too weak to be measured.

Quite fortunately, the rate in the case of the Lake Biwa deposit is about 0.4 mm/yr, being neither too slow nor too rapid. 2 cm core sample is sufficiently measurable under our astatic magnetometer without sacrificing the accuracy. Time required for the sedimentation is about 50 yrs. It, therefore, is possible to follow the variation twice a century back to the desired past.

The study of secular variation using the Lake Biwa boring core was started last year 1972. The results are shown in the following sections.

Sampling and Measurements

571 samples of 2 cm cube were taken from the top of the core successively downward till to the depth 22 m whose age is 38,000 yrBP.

The core unfortunately broken up into four pieces of column. Three gaps of measurements were unavoidable, each occurring at about 6,000, 17,000 and 28,000 yrBP respectively. Uppermost part of the bottom is not only oozy but also too soft to be taken out of the lake surface. During the boring this oozy part recording the very recent secular field was gone away with the water. The gaps are shown in the diagram showing ages vs. depth relation (Fig. 1).

(Fig. 1 here)

The intensity and direction of the remanent magnetization of each sample was measured under a very sensitively astatic magnetometer.

Progressive demagnetization using AC field up to 600 Oe was applied to each cube sample. Change of direction of the remanent magnetization and that of the intensity are shown in Figs. 2 and 3. As shown in the former diagram there exist two typical types of the remanent magnetization, one yielding no significant change even from the initial AC field, and the other turning out to be stable when the AC field was elevated in excess of 100 Oe. Stability of the remanence is in general very high. Even after the demagnetization using 400 Oe half a original value remains as shown in the latter diagram.

(Figs. 2 and 3 , here)

Results

In Table 1 are shown the results obtained after cleaning in 100 Oe peak alternating field.

(Table 1 , here)

The changes of intensity and inclination with depth, hence, with age are shown in Fig. 4. Scatter in the observed values of inclination is slightly larger than that in the intensity. It certainly arose from our sampling and measuring error. The scatter, however, can be minimized when a simple seven-point moving average was taken into account. The data of intensity were also averaged in the same way.

(Fig. 4 , here)

The mean value of the inclination in the entire Lake Biwa core is 42.4°, with a standard deviation 14.9° (Fig. 5). The mean value approximately coinsides with that of the present geomagnetic field (47°).

(Fig. 5 , here)

Discussions and Conclusions

1) The intensity of NRM varies from 2×10^{-6} to 12×10^{-6} emu cm^{-3} (Fig. 4). Concentration of ferromagnetic particles responsible for the NRM is not always constant in the entire core column. It fluctuates significantly and, therefore, one needs a proper correction before we discuss the geomagnetic field variation from the data.

In order to make this correction, we first obtained the intensity of I_sRM after application of a direct field of 6,000 Oe. Then, the intensity values of NRM per unit I_sRM were calculated as shown in Fig. 6.

(Fig. 6 , here)

2) Although the change in the inclination revealed in the diagram appears relatively irregular, one can at least recognize three different oscillations coexisting, one having longest period of approximately 20,000 yrs, that having shortest period less than 500 yrs, while that with an intermediate period ranging from 1,500 to 5,000 yrs.

3) Since the unconsolidated part of the oozy core was lost, the age of the uppermost solid core column ranges from 2,800 to 6,000 yrBP. The measured changes of the intensity and inclination are shown in Fig. 7 together

with the results summarized by BUCHA (1971) and those obtained by HIROOKA (1972) from Japan. Intensity variation in the Lake Biwa deposits and those reduced from the baked earths show a striking resemblance. However, estimated age of the column is approximately 3,000 yrs older than the baked earths. The reason why the age difference occurred is that the particles were being held in suspension in water in the uppermost ozzy layer of the lake basin during these 3,000 yrs, all particles being remained free to rotate. They have become unmoved only recently and fixed within the clay matrix at the depth about 3 m. As confined water and porosity decreased due to the static compaction under the increasing load of the overline particles in the soft deposit, one solid particle began to make contact with the neighbouring particles to increase the mutual friction which prevented the further rotation of the magnetic particle under the geomagnetic field. This is occurring at about 3 m below the lake bottom. Namely, the acquisition of the remanent magnetism finished only recently within the past deposit about 3,000 yrs old in this particular deposit of the lake. Not only the intensity but also the inclination variation shows the same time difference. The latter variation resembles with those obtained from the recent baked earths, peak values of the inclination such as 1, 2, 3 and 4 correspond respectively with the peaks 1', 2', 3' and 4' in Fig. 7.

(Fig. 7 , here)

4) A short period fluctuation is found to exist in a range from 17,600 to 18,700 yrBP. A remarkable characteristic to this fluctuation is that it bears a negative value of the inclination appearing at 18,000 yrBP. In the very event, however, the direction deviated only 70° from the mean direction of the geomagnetic field for the duration only 1,100 yrs or so as shown in Figs. 8 and 9. The intensity of the NRM did not decrease so significantly as in the other events of the geomagnetic instability.

(Figs. 8 and 9 , here)

This corresponds to the latest reverse direction already found and reported in the previous part of this paper on the oscillating dipole field. Worth noticing is that this particular deviation of geomagnetic field has been confirmed from France and Sweden, being respectively called Laschamp and Gothenburg event. The Laschamp event ended in a period between 20,000 and 8,000 yrBP, whereas Gothenburg event in 12,400 yrBP (BONHOMMET and ZÄHRINGER, 1969; MÖRNER et al., 1971). But these durations are not known exactly as yet. Recently, BARBETTI and MCELHINNY (1972) also reported a short period oscillation with shallow negative inclinations occurring at about 30,000 yrBP. This was found from the aboriginal fireplaces in Australia. The path of the virtual pole movement of this event is similar to that of Lake Biwa as shown in Fig. 10 and Table 2.

(Fig. 10 and Table 2 , here)

Acknowledgements

The author would like to express his cordinal thanks first to Prof. Naoto Kawai of Osaka University, and also to Assistant Prof. Katsumi Yaskawa of the same university for the invaluable suggestions and the continuous encouragement throughout the study.

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Table 1. Data on magnetic measurements after cleaning in in 100 Oe peak alternating field

Depth (m)	Age (yr BP)	Sample	Inclination (°)	Intensity ($X10^{-6}$ emu cm^{-3})
	2,800	B1-5	44	3.7
		B1-6	33	6.9
		B1-7	35	5.4
		B1-8	32	5.5
		B1-9	35	6.1
		B1-10	41	5.4
	3,000	B1-11	43	5.2
		B1-12	43	4.6
		B1-13	32	5.7
		B1-14	37	7.0
		B1-15	33	5.5
		B1-16	42	4.2
		B1-17	28	2.3
		B1-18	29	5.3
4		B1-19	26	5.0
		B1-20	26	6.0
		B1-21	32	7.4
		B1-22	20	6.9
		B1-23	22	6.1
		B1-24	36	7.7
		B1-25	28	5.4
		B1-26	22	7.7
		B1-27	26	6.8
		B1-28	22	5.4
		B1-29	10	6.5
		B1-30	21	7.6
		B1-31	16	7.5
		B1-32	16	7.0
		B1-33	23	6.8
		B1-34	22	9.6
		B1-35	23	8.7
		B3-3	31	10.1
		B3-4	29	9.1

Depth (m)	Age (yr BP)	Sample	Inclination (°)	Intensity ($X10^{-6}$ emu cm^{-3})
		B3-5	24	8.0
		B3-6	35	8.7
		B3-7	38	11.0
		B3-8	37	9.6
		B3-9	35	9.8
		B3-10	45	7.3
		B3-11	52	8.0
		B3-12	52	11.1
		B3-13	41	12.6
		B3-14	42	11.1
		B3-15	49	9.6
		B3-16	54	10.5
	4,000	B3-17	48	11.2
		B3-18	48	12.2
5		B3-19	46	11.8
		B3-21	51	10.0
		B3-22	55	10.6
		B3-23	52	12.7
		B3-24	45	12.5
		B3-25	51	12.9
		B3-26	52	11.0
		B3-27	36	7.4
		B3-28	28	9.9
		B3-29	22	10.4
		B3-30	28	12.1
		B3-31	27	16.3
		B3-32	37	10.9
		B3-33	26	11.1
		B3-34	32	9.9
		B3-35	30	9.1
		B3-36	27	10.0
		B3-37	25	8.7
		B3-38	24	8.7
		B5-6	43	10.7
		B5-7	31	11.1
		B5-8	34	9.8
		B5-9	46	8.4
		B5-10	55	9.4

Depth (m)	Age (yr BP)	Sample	Inclination (°)	Intensity ($\times 10^{-6}$ emu cm^{-3})
		B5-11	40	8.6
		B5-12	44	7.5
		B5-13	37	9.2
		B5-14	39	9.8
		B5-15	40	10.6
		B5-16	34	7.5
		B5-17	44	9.7
		B5-18	39	10.5
		B5-19	34	10.1
		B5-20	39	12.2
		B5-21	36	10.2
6	5,000	B5-22	36	11.6
		B5-23	23	13.4
		B5-24	34	12.5
		B5-25	23	11.7
		B5-26	26	12.4
		B5-27	29	13.8
		B5-28	37	12.1
		B5-29	29	12.5
		B5-30	24	11.0
		B5-31	14	10.9
		B7-2	35	9.4
		B7-3	59	7.2
		B7-4	57	9.5
		B7-5	45	11.0
		B7-6	22	6.4
	6,000	B7-8	38	11.6
	6,600	B9-2	25	8.2
		B9-3	23	8.4
		B9-4	28	7.7
		B9-5	26	8.2
		B9-6	24	5.2
		B9-7	34	7.5
		B9-8	21	6.7
	7,000	B9-9	26	6.7
		B9-10	26	6.5
		B9-11	24	6.7

Depth (m)	Age (yr BP)	Sample	Inclination (°)	Intensity (X10^{-6} emu cm^{-3})
		B9-12	12	6.5
		B9-13	25	6.3
		B9-14	24	6.6
		B9-15	28	6.5
		B9-16	18	5.9
		B9-17	28	6.7
		B9-18	18	9.0
		B9-19	22	6.4
		B9-20	12	7.1
		B9-21	30	19.2
		B9-23	32	7.3
		B9-24	35	6.7
		B9-25	34	7.7
8		B9-26	27	7.9
		B9-27	20	8.3
		B9-28	27	9.5
		B9-29	16	9.6
		B9-30	24	7.1
	8,000	B9-31	18	6.1
		B9-32	27	7.2
		B9-33	26	9.3
		B9-34	27	9.7
		B9-35	27	9.9
		B9-36	24	9.7
		B9-37	38	9.6
		B9-38	32	8.6
		B9-39	42	9.6
		B9-40	46	8.0
		B11-1	30	9.7
		B11-2	25	9.2
		B11-3	32	9.5
		B11-4	36	12.1
		B11-5	50	13.2
		B11-6	38	11.8
		B11-7	45	11.3
		B11-8	44	10.6
		B11-9	57	12.1
		B11-10	58	11.4

Depth (m)	Age (yr BP)	Sample	Inclination (°)	Intensity ($X10^{-6}$ emu cm^{-3})
	9,000	B11-11	44	10.9
		B11-12	50	10.5
		B11-13	49	10.7
		B11-14	58	11.2
		B11-15	43	11.5
		B11-16	45	14.2
		B11-17	37	7.1
		B11-18	44	10.2
		B11-19	41	8.9
		B11-20	49	9.9
		B11-21	38	9.7
		B11-22	37	9.7
		B11-23	36	9.2
		B11-24	37	9.2
		B11-25	43	9.8
		B11-26	42	10.0
9		B11-27	35	10.3
		B11-28	37	10.0
		B11-29	32	10.9
		B11-30	32	9.0
	10,000	B11-31	36	9.6
		B11-32	40	10.6
		B11-33	35	8.7
		B11-34	32	5.4
		B11-35	38	7.1
		B11-36	34	7.0
		B11-37	43	5.4
		B11-38	53	5.9
		B11-39	33	7.4
		B11-40	33	9.0
		B11-41	36	10.3
		B11-42	43	2.6
		B13-1	77	4.3
		B13-2	69	2.3
		B13-3	52	3.6
		B13-4	35	3.1
		B13-5	32	2.9
		B13-6	54	2.2
		B13-7	64	3.4

Depth (m)	Age (yr BP)	Sample	Inclination (°)	Intensity ($\times 10^{-6}$ emu cm^{-3})
		B13-8	56	3.0
	11,000	B13-9	72	2.5
		B13-10	54	3.5
		B13-11	68	4.5
		B13-12	73	4.2
		B13-13	72	4.4
		B13-14	50	5.1
		B13-15	56	6.2
		B13-16	57	5.1
10		B13-17	47	4.1
		B13-18	53	3.4
		B13-19	58	2.6
		B13-20	33	2.5
		B13-21	57	2.9
		B13-24	32	3.6
		B13-25	44	4.6
		B13-26	47	5.0
		B13-27	51	4.9
		B13-28	53	3.3
		B13-29	52	6.4
		B13-30	40	4.4
	12,000	B13-31	45	1.3
		B13-32	69	1.3
		B13-33	60	2.4
		B13-34	38	2.0
		B13-35	35	2.3
		B13-36	37	2.9
		B13-37	52	3.3
		B13-38	35	1.9
		B13-39	53	2.1
		B13-40	57	2.3
		B15-2	43	4.8
		B15-3	47	6.0
		B15-4	53	8.3
		B15-5	49	5.2
		B15-6	40	6.6
	13,000	B15-7	53	5.2
		B15-8	53	6.1
		B15-9	42	5.5

Depth (m)	Age (yr BP)	Sample	Inclination (°)	Intensity ($X10^{-6}$ emu cm^{-3})
		B15-10	36	5.4
		B15-11	29	4.5
		B15-12	28	3.1
		B15-13	34	4.3
11		B15-14	38	5.1
		B15-15	43	6.1
		B15-16	45	6.1
		B15-18	54	1.5
		B15-19	46	1.3
		B15-20	61	1.5
		B15-21	56	1.6
	14,000	B15-22	72	1.6
		B17-4	61	3.1
		B17-6	77	2.5
		B17-8	76	1.5
		B17-9	62	2.3
		B17-10	57	2.1
		B17-11	77	2.9
		B17-12	64	2.6
		B17-13	74	3.1
		B17-14	69	2.7
		B17-15	69	2.8
		B17-16	68	4.0
	15,000	B17-17	64	2.6
		B17-18	60	2.6
		B17-19	61	4.2
		B17-20	62	3.1
		B17-21	58	2.0
		B17-22	67	2.2
		B17-23	45	3.7
		B17-24	37	3.4
		B17-25	40	3.8
		B17-26	43	4.0
		B17-27	44	1.9
12		B17-28	39	2.8
		B17-29	29	4.5
	16,000	B17-31	52	5.6
		B17-32	59	5.9
		B17-33	56	6.5

Depth (m)	Age (yr BP)	Sample	Inclination (°)	Intensity ($X10^{-6}$ emu cm^{-3})
		B17-34	48	7.3
		B17-35	48	6.8
		B17-36	64	4.6
		B19-1	41	6.0
		B19-2	47	7.1
		B19-3	45	6.2
		B19-4	25	4.6
		B19-5	32	4.6
		B19-6	66	2.9
		B19-7	53	3.5
	17,000	B19-8	51	2.8
	17,600	B21-3	46	4.7
		B21-4	48	5.1
		B21-5	62	4.1
		B21-6	42	5.8
		B21-7	42	5.1
		B21-8	59	4.1
13	18,000	B21-9	25	4.2
		B21-10	-6	5.2
		B21-11	28	5.2
		B21-12	25	9.2
		B21-13	73	7.9
		B21-14	73	9.1
		B21-15	62	8.8
		B21-16	64	7.4
		B21-17	30	7.4
		B21-18	37	7.3
		B21-19	44	7.4
		B21-20	42	8.1
	19,000	B21-21	41	7.9
		B21-22	38	7.1
		B21-23	31	5.7
		B21-24	36	7.6
		B21-25	34	8.6
		B21-26	29	8.0
		B21-27	46	10.6
		B21-28	37	10.5

Depth (m)	Age (yr BP)	Sample	Inclination (°)	Intensity ($X10^{-6}$ emu cm^{-3})
		B21-29	39	11.4
		B21-30	36	11.1
		B21-31	41	10.2
		B21-32	40	9.3
		B23-2	61	8.2
	20,000	B23-3	49	8.4
		B23-4	50	7.3
		B23-5	47	6.4
		B23-6	51	7.0
		B23-7	60	6.8
		B23-8	51	10.1
		B23-9	58	6.9
14		B23-10	62	6.9
		B23-11	60	6.6
		B23-13	63	8.2
		B23-14	43	6.6
		B23-15	50	6.8
		B23-16	38	4.8
		B23-17	50	4.2
	21,000	B23-18	51	4.2
		B23-19	48	4.7
		B23-20	56	3.7
		B23-21	46	5.0
		B23-22	44	2.9
		B23-23	42	2.9
		B23-24	53	3.0
		B23-25	45	3.3
		B23-26	52	6.4
		B23-27	48	5.9
		B23-28	37	5.3
		B23-29	52	4.3
		B23-30	61	1.5
		B23-31	50	1.7
	22,000	B23-32	81	1.9
		B23-33	66	1.3
		B23-34	66	1.6
		B23-35	58	2.1
		B23-36	57	2.5
		B23-37	49	3.5

Depth (m)	Age (yr BP)	Sample	Inclination (°)	Intensity ($X10^{-6}$emu cm^{-3})
		B23-38	53	2.7
		B23-39	53	2.4
		B25-1	28	4.4
		B25-2	25	3.1
		B25-3	17	4.5
		B25-4	10	2.4
15		B25-5	6	2.3
		B25-6	4	3.3
		B25-7	8	4.0
		B25-9	15	4.9
	23,000	B25-10	12	5.0
		B25-11	14	6.3
		B25-12	26	5.8
		B25-13	33	8.4
		B25-14	39	6.8
		B25-15	51	8.3
		B25-16	43	8.1
		B25-17	35	8.3
		B25-18	25	7.0
		B25-19	15	5.4
		B25-20	15	4.7
		B25-21	21	4.1
		B25-22	3	5.1
		B25-23	17	8.4
		B25-24	5	7.3
		B25-26	23	7.6
		B25-27	41	5.5
		B25-28	29	4.4
		B25-29	20	4.9
		B25-30	26	5.2
		B25-31	17	6.6
	24,000	B25-32	19	6.0
		B25-33	32	7.4
		B25-34	31	7.5
		B25-35	25	7.6
		B25-36	26	7.7
		B25-37	36	7.7
		B25-38	21	7.1
		B25-39	18	6.8

Depth (m)	Age (yr BP)	Sample	Inclination (°)	Intensity ($\times 10^{-6}$ emu cm^{-3})
		B25-40	20	7.1
		B25-41	32	6.5
		B25-42	14	5.9
		B25-43	19	5.8
		B27-1	44	6.0
		B27-2	38	8.5
		B27-3	42	9.6
		B27-4	43	8.4
		B27-5	42	4.9
		B27-6	45	6.6
		B27-7	44	6.0
	25,000	B27-8	41	8.8
		B27-9	60	10.0
		B27-10	44	10.6
16		B27-11	35	9.0
		B27-12	41	7.6
		B27-13	44	7.8
		B27-14	47	4.8
		B27-15	40	6.9
		B27-16	37	6.9
		B27-17	57	5.8
		B27-18	37	5.9
		B27-19	41	6.5
		B27-20	46	6.0
	26,000	B27-21	45	6.1
		B27-22	41	7.1
		B27-23	47	5.6
		B27-24	47	7.6
		B27-25	36	9.1
		B27-27	37	7.0
		B27-29	31	5.1
		B27-30	34	5.5
		B27-31	45	5.8
		B27-32	35	5.3
		B27-34	36	5.8
		B27-35	40	6.2
		B27-36	41	5.6
		B27-37	29	7.6

Depth (m)	Age (yr BP)	Sample	Inclination (°)	Intensity (X10^{-6} emu cm^{-3})
	27,000	B27-38	40	6.8
		B27-39	35	7.4
	28,500	B33-1	59	3.1
		B33-2	66	5.0
		B33-3	46	5.1
		B33-4	44	5.5
		B33-5	51	4.5
		B33-6	47	5.1
	29,000	B33-7	50	5.6
		B33-8	57	2.9
		B33-9	65	4.3
		B33-10	60	4.2
		B33-11	64	5.8
		B33-12	56	6.3
		B33-13	57	6.0
		B33-14	61	5.0
		B33-15	64	6.2
		B33-16	59	5.6
		B33-17	67	5.1
		B33-18	74	4.6
		B33-19	67	4.8
18	30,000	B33-20	86	5.4
		B33-21	85	5.0
		B33-22	82	5.0
		B33-23	85	4.4
		B33-24	73	5.9
		B33-25	58	5.7
		B33-26	55	5.6
		B33-27	67	6.2
		B33-28	71	6.2
		B33-29	71	8.0
		B33-30	59	6.5
		B33-31	55	6.7
		B33-32	56	8.4
	31,000	B33-33	52	10.0
		B33-34	58	7.8
		B33-35	72	6.8

Depth (m)	Age (yr BP)	Sample	Inclination (°)	Intensity ($X10^{-6}$ emu cm^{-3})
		B33-36	48	7.7
		B33-37	58	7.5
		B33-38	48	4.9
		B35-2	47	7.0
		B35-3	33	6.9
		B35-4	33	8.3
		B35-5	41	5.5
		B35-6	38	9.8
		B35-7	42	7.7
		B35-8	51	8.9
		B35-9	40	6.5
		B35-10	55	7.0
		B35-11	51	7.1
		B35-12	39	6.0
		B35-13	60	7.1
	32,000	B35-14	49	6.5
		B35-15	52	5.5
		B35-16	56	5.1
		B35-17	37	8.0
		B35-18	43	6.9
		B35-19	40	7.0
		B35-20	29	8.4
		B35-21	43	6.9
		B35-22	55	8.2
		B35-23	42	7.5
		B35-24	48	8.3
		B35-26	50	6.7
		B35-27	35	7.1
		B35-28	45	6.9
		B35-29	37	8.4
		B35-30	41	6.6
19		B35-31	52	7.2
		B35-32	41	7.2
		B35-33	34	7.1
		B35-34	39	6.6
	33,000	B35-35	43	5.3
		B35-36	29	7.6
		B35-37	29	7.8
		B35-38	28	8.4

Depth (m)	Age (yr BP)	Sample	Inclination (°)	Intensity ($\times 10^{-6}$ emu cm^{-3})
		B35-39	48	8.1
		B35-40	47	6.8
		B35-41	26	7.9
		B35-42	38	8.0
		B35-43	37	8.2
		B37-1	32	8.2
		B37-2	23	8.3
		B37-3	45	8.9
		B37-4	51	7.8
		B37-5	61	8.7
		B37-6	32	7.1
		B37-8	41	10.4
		B37-9	43	9.2
		B37-10	32	8.8
		B37-11	43	8.8
		B37-12	42	9.0
	34,000	B37-13	48	8.3
		B37-14	43	9.2
		B37-15	35	7.5
		B37-16	49	8.5
		B37-18	30	9.5
		B37-19	33	11.7
		B37-23	49	7.5
		B37-24	54	6.4
		B37-25	53	8.1
		B37-26	53	8.1
		B37-27	58	7.6
		B37-28	42	9.2
		B37-29	56	7.3
		B37-30	43	7.1
		B37-31	46	8.8
		B37-32	55	9.2
		B37-33	53	8.0
20		B37-34	40	8.4
		B37-35	62	10.8
	35,000	B37-36	67	7.3
		B37-37	68	8.0
		B37-38	52	7.7
		B37-39	48	8.7

Depth (m)	Age (yr BP)	Sample	Inclination (°)	Intensity ($X10^{-6}$ emu cm^{-3})
		B37-40	43	9.0
		B37-41	40	7.5
		B39-3	34	9.3
		B39-4	27	11.7
		B39-5	48	8.9
		B39-6	37	8.0
		B39-7	39	9.4
		B39-8	40	8.4
		B39-9	30	8.7
		B39-10	41	8.0
		B39-11	49	8.0
	36,000	B39-12	25	8.0
		B39-13	27	7.0
		B39-14	49	7.7
		B39-15	55	9.6
		B39-16	37	8.4
		B39-17	49	9.0
		B39-18	42	10.1
		B39-19	29	10.8
		B39-20	28	9.6
		B39-21	45	11.0
		B39-22	32	8.7
		B39-23	41	8.1
		B39-24	53	8.6
	37,000	B39-25	69	9.4
		B39-26	56	9.1
21		B39-27	42	10.9
		B39-28	50	11.6
		B39-29	33	9.2
		B39-30	36	7.9
		B39-31	43	8.2
		B39-32	34	8.1
		B39-33	47	11.0
		B39-34	43	9.2
		B39-35	46	8.6
		B39-36	48	9.0
		B39-37	74	8.4
		B39-38	66	6.8
	38,000	B39-39	57	7.5

Table 2 (A) Paleomagnetic results after cleaning in 100 Oe peak alternating field from Lake Biwa

Sample	D(°E)	I(°)	V.P.P. Lat.(°N)	V.P.P. Long.(°E)	
B21-32	5	40	Mean		
B21-31	3	41			
B21-30	1	36			
B21-29	8	39	D_m=0 (°E)		
B21-28	3	37	I_m=38 (°)		
B21-27	18	46	k=122.5		
B21-26	-4	29	α_{95}=3.3 (°)		
B21-25	-5	34	N=16		
B21-24	-6	36			
B21-23	-7	31	V.P.P.		
B21-22	8	38	Lat.=76 (°N)		
B21-21	-6	41	Long.=316 (°E)		(1)
B21-20	1	42			
B21-19	-4	44			
B21-18	-9	37			
B21-17	0	30			
B21-16	3	64	79	147	(2)
B21-15	-1	62	82	131	(3)
B21-14	10	73	66	149	(4)
B21-13	-2	73	67	133	(5)
B21-12	-65	25	28	43	(6)
B21-11	--61	28	32	42	(7)
B21-10	-76	-6	-10	215	(8)
B21- 9	-31	25	54	16	(9)
B21- 8	-35	59	62	66	(10)
B21- 7	-53	42	43	48	(11)
B21- 6	-37	42	56	37	(12)
B21- 5	-22	62	71	78	(13)
B21- 4	-15	48	76	24	(14)
B21- 3	-15	46	75	19	(15)

D; Declination I; Inclination

k; Fisher's precision parameter α_{95}; 95% confidence circle radius

N; Number of Samples V.P.P.; Position of virtual north pole

Table 2 (B) Position of virtual north pole from Lake Mungo in Australia

	Fireplace or sediment	V.P.P. Lat.(°N)	V.P.P. Long.(°E)
A	S1	77	308
B	S6	31	49
C	S7	5	50
D	F7	-28	34
E	F8	12	232
F	F6	3	237
G	S8	89	126

Figure Captions

Fig. 1 Age vs. depth of the Lake Biwa core.
A, B and C were dated by the C^{14} method (HORIE,1971)
Continuous curve was obtained by YASKAWA's equation (1972), the parts shown in dotted line show gaps of the core.

Fig. 2 Direction change of remanent magnetization of the typical sample by AC demagnetization.

Fig. 3 Change of the intensity with AC peak demagnetizing field.

Fig. 4 Changes of the intensity and inclination with age (depth). Solid lines show seven-point moving averages.

Fig. 5 Frequency distribution of inclinations.
I_m ; mean value
s.d. ; standard deviation

Fig. 6 Ratio of the intensity of NRM to that of I_sRM.
Lower curve shows the change of the intensity of NRM.

Fig. 7 Changes of the intensity and inclination with age during the past 6,000 yrs.
pp' ; Present study
AA', CC', JJ' ; Data summerized by BUCHA (1971) from America, Europe and Japan, respectively.
SJ-SJ' ; Data by HIROOKA (1972) from Southwest Japan.

Fig. 8 Change of the intensity and derection of the remanent magnetization with age from 20,000 to 17,500 yrBP. Declination are measured to an arbitary zero.

Fig. 9 Direction change in a range from 20,000 to 17,500 yrBP (plotted on a Schmidt's projection).

Fig. 10 Path of virtual pole position.

A) Short period fluctuation appearing at about 18,000 yrBP (found from Lake Biwa) Mean declination in a range from 20,000 to 18,700 yrBP was set to zero, then V.P.P. was calculated.

B) Similar fluctuation appearing at about 30,000 yrBP in Australia (BARBETTI and MCELHINNI, 1972) Each V.P.P. is tabulated in Table 2.

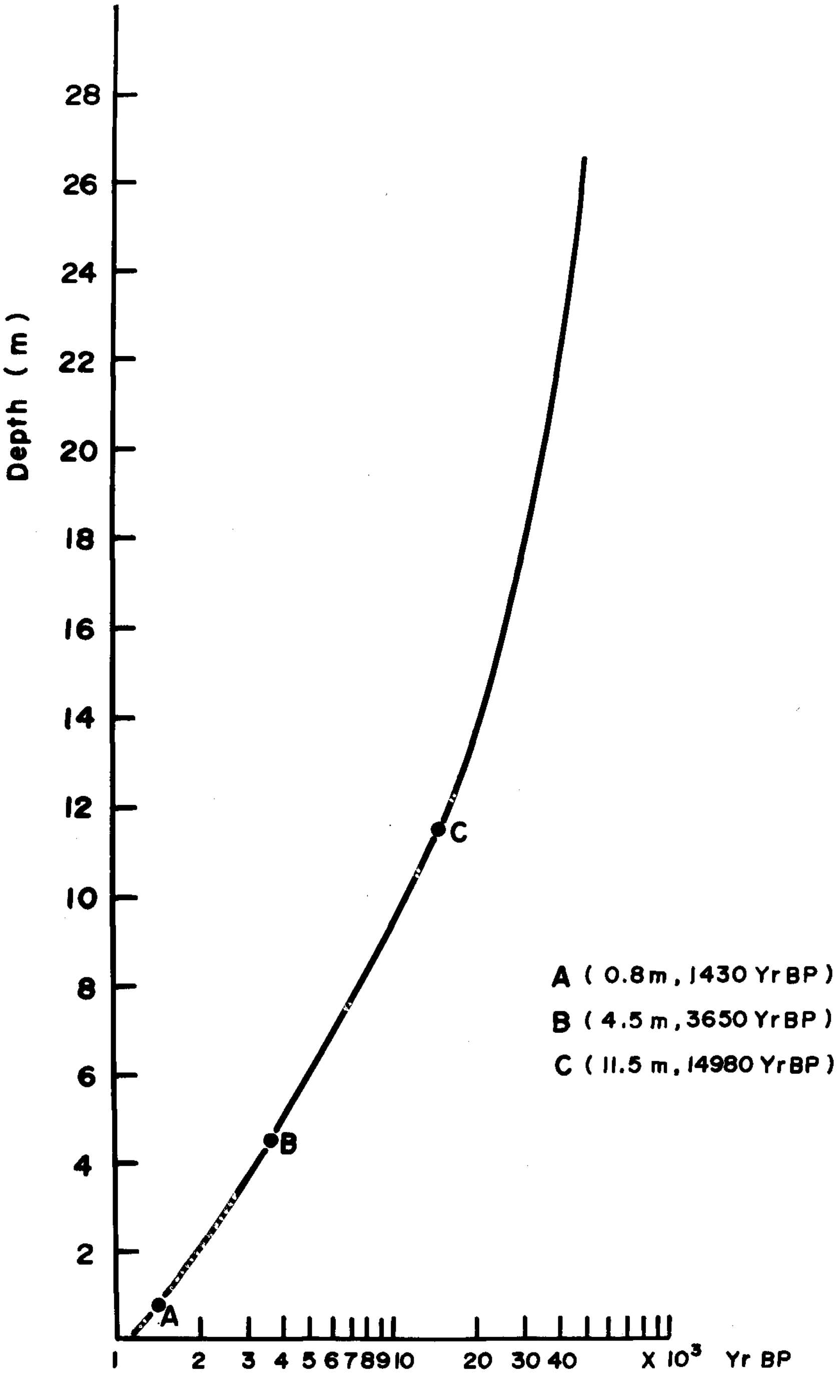

Depth (m)
28
26
24
22
20
18
16
14
12
10
8
6
4
2
A
B
C
A (0.8 m, 1430 Yr BP)
B (4.5 m, 3650 Yr BP)
C (11.5 m, 14980 Yr BP)
1
2
3
4
5
6
7
8
9
10
20
30
40
X 10³ Yr BP

Fig. 1

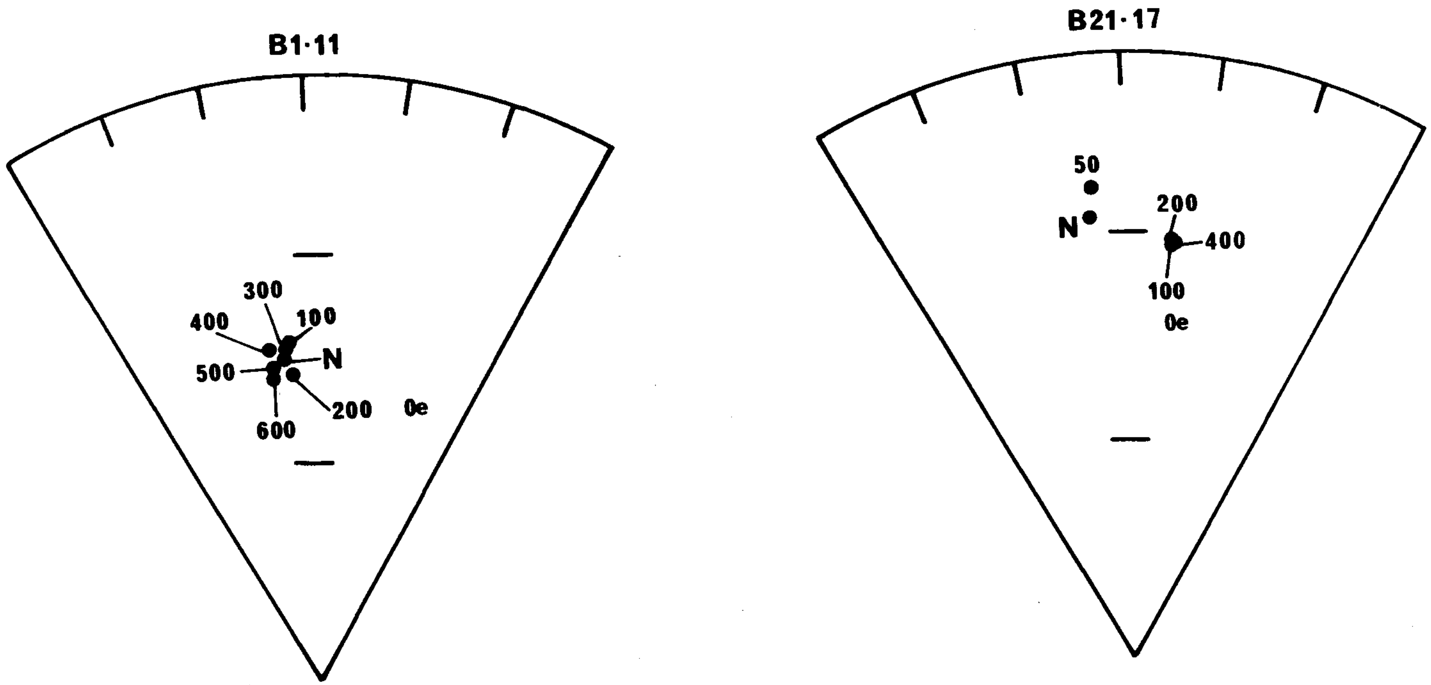


Fig.2

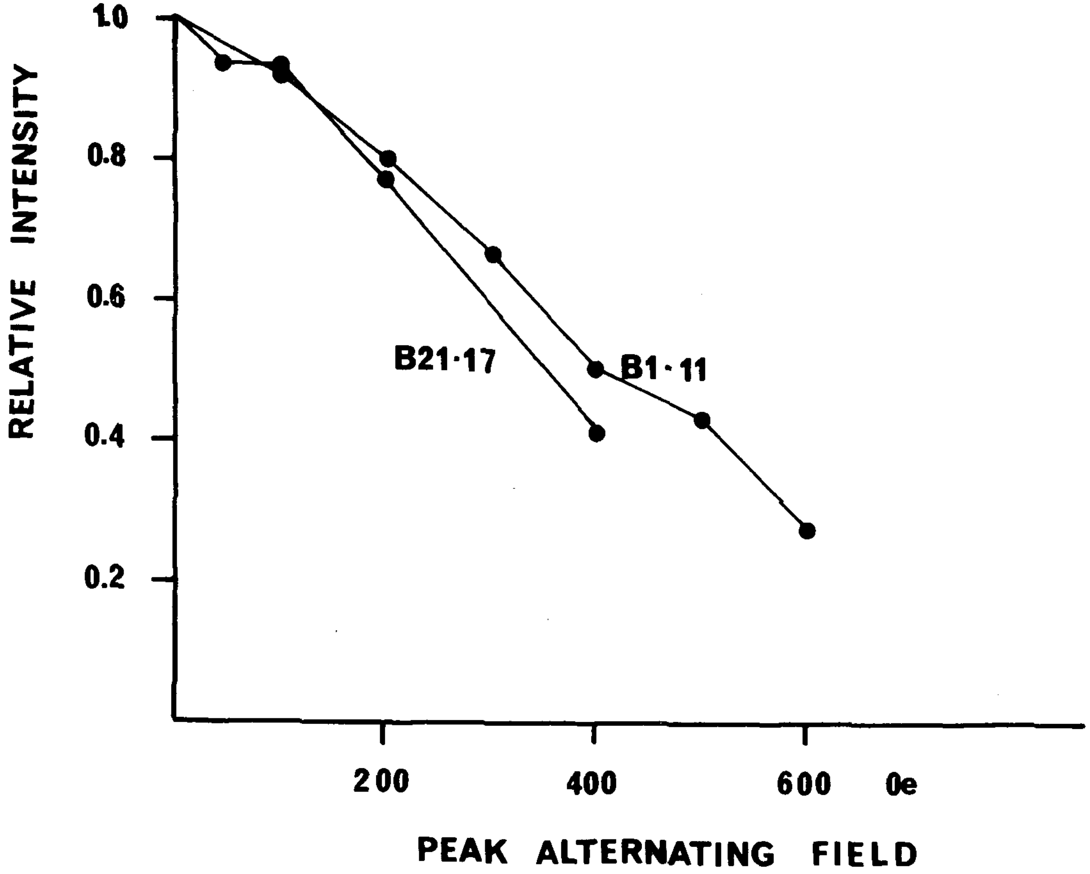

1.0
0.8
0.6
0.4
0.2
RELATIVE INTENSITY
B21·17
B1·11
200
400
600
0e
PEAK ALTERNATING FIELD

Fig.3

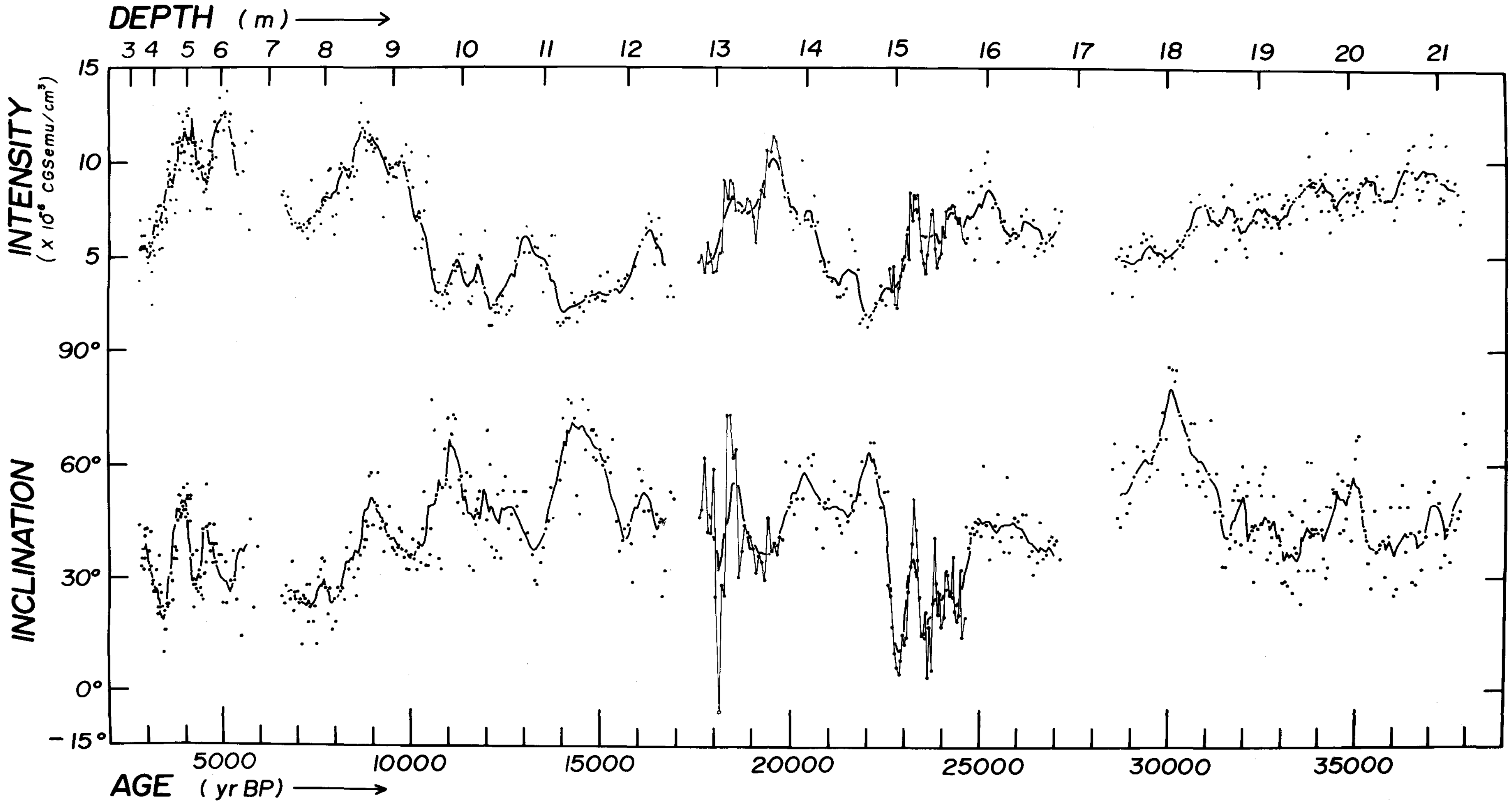

DEPTH (m)
3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
INTENSITY
(x 10⁻⁶ CGSemu/cm³)
15
10
5
90°
60°
30°
0°
−15°
INCLINATION
5000 10000 15000 20000 25000 30000 35000
AGE (yr BP)

Fig. 4

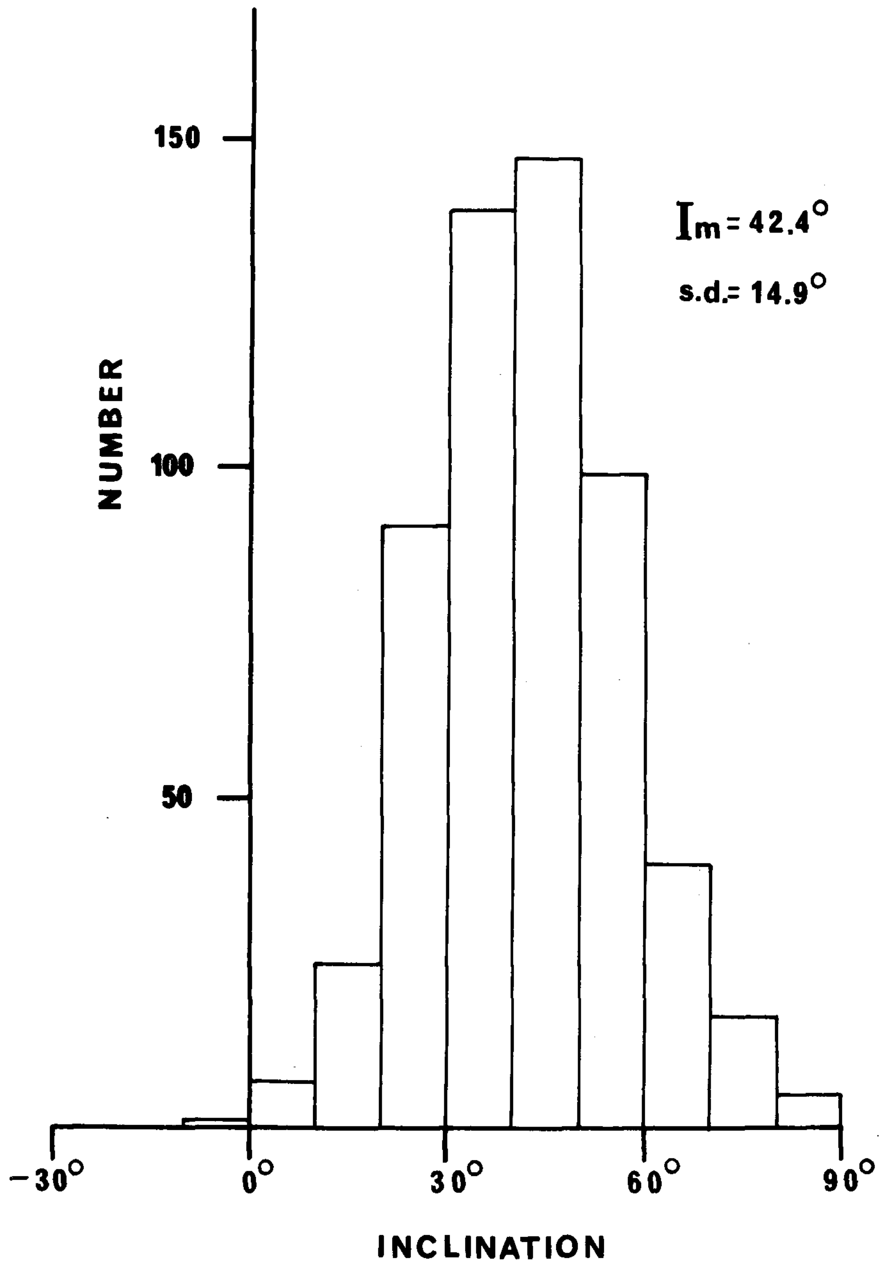
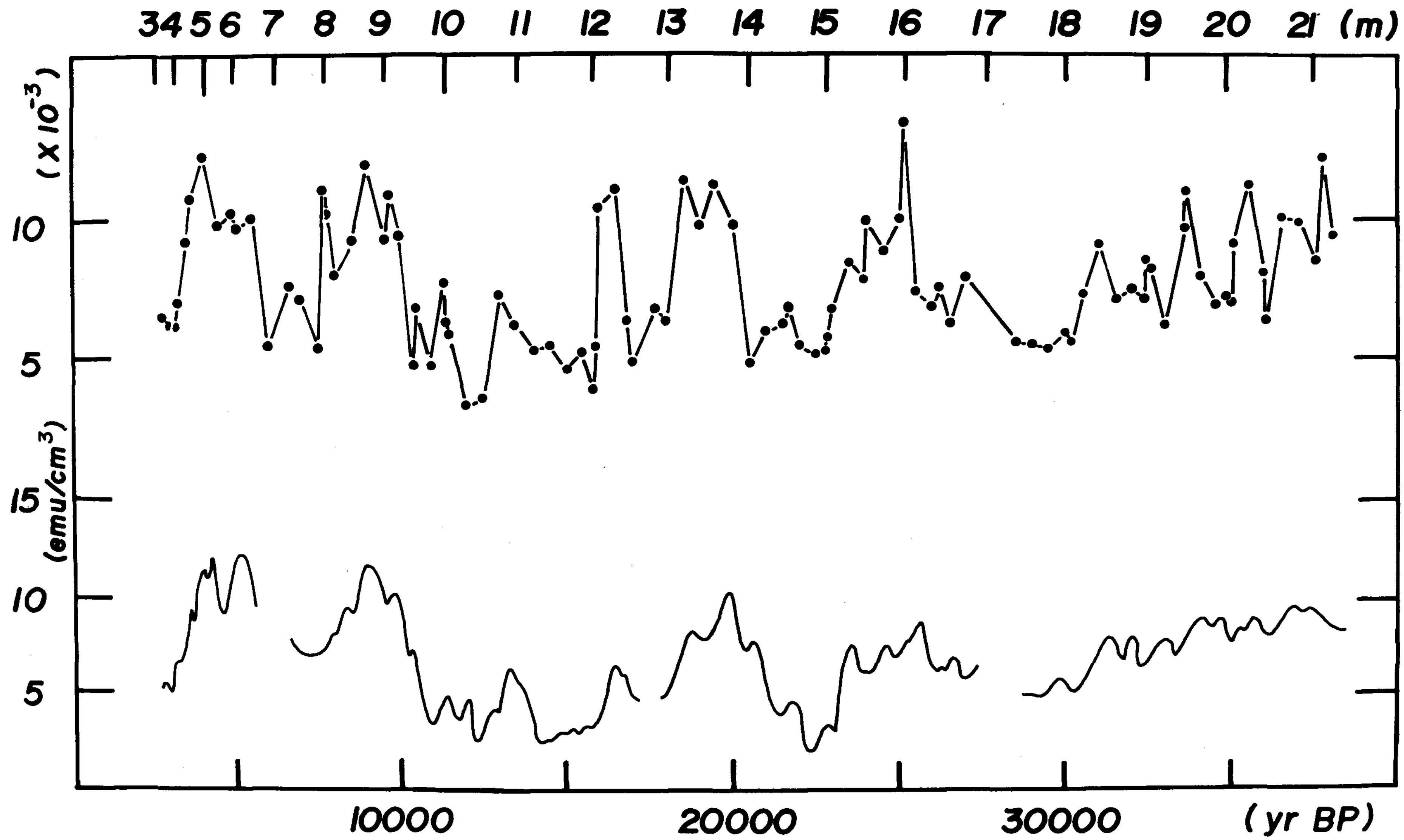
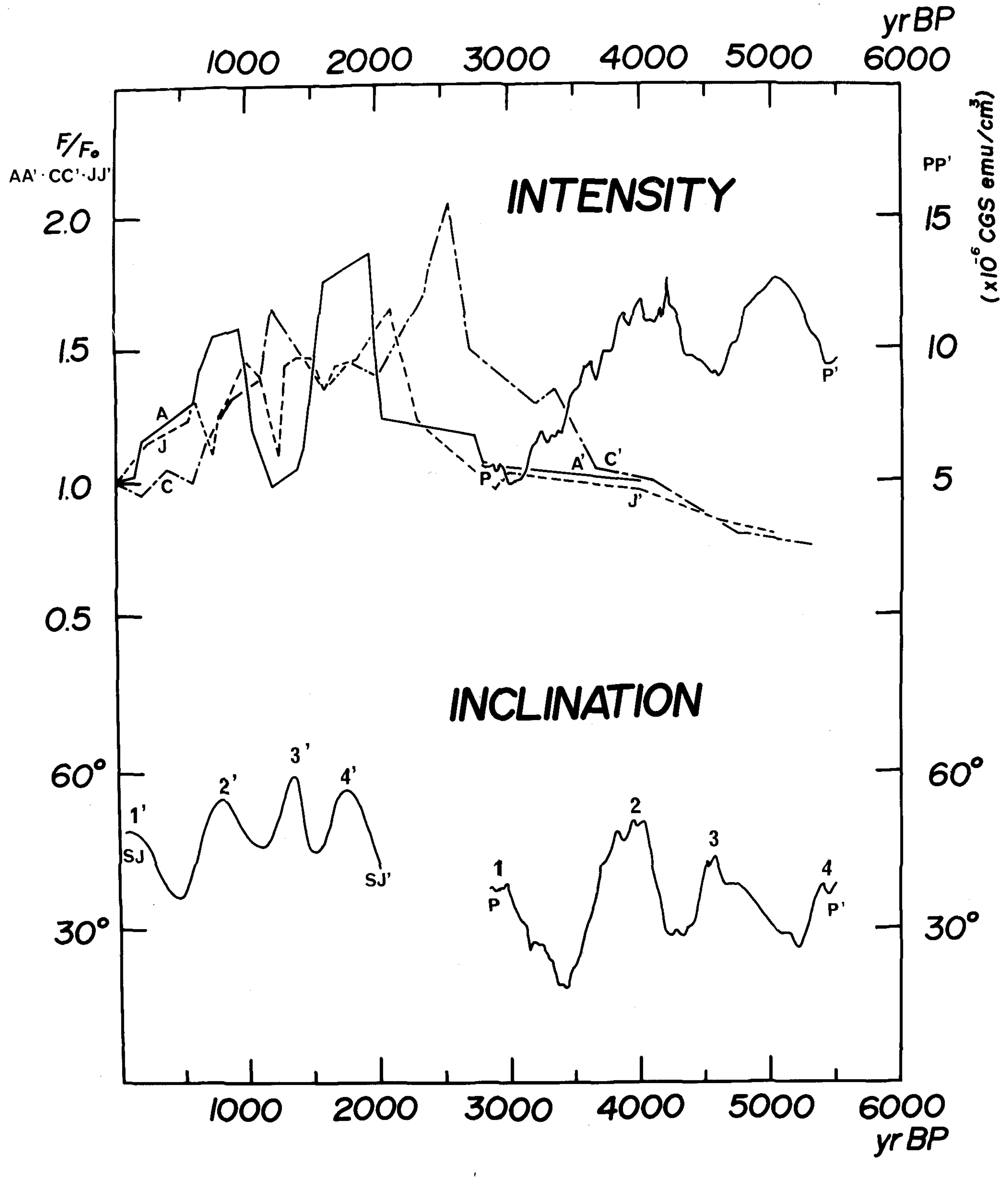


Fig.5



3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 (m)
(X 10-3)
(emu/cm3)
10
5
15
10
5
10000
20000
30000
(yr BP)

Fig.6



yr BP
1000
2000
3000
4000
5000
6000
F/Fo
AA'·CC'·JJ'
INTENSITY
PP'
(x10⁻⁶ CGS emu/cm³)
2.0
1.5
1.0
0.5
15
10
5
A
J
C
P
P'
A'
C'
J'
INCLINATION
60°
30°
1'
2'
3'
4'
SJ
SJ'
1
2
3
4

Fig.7

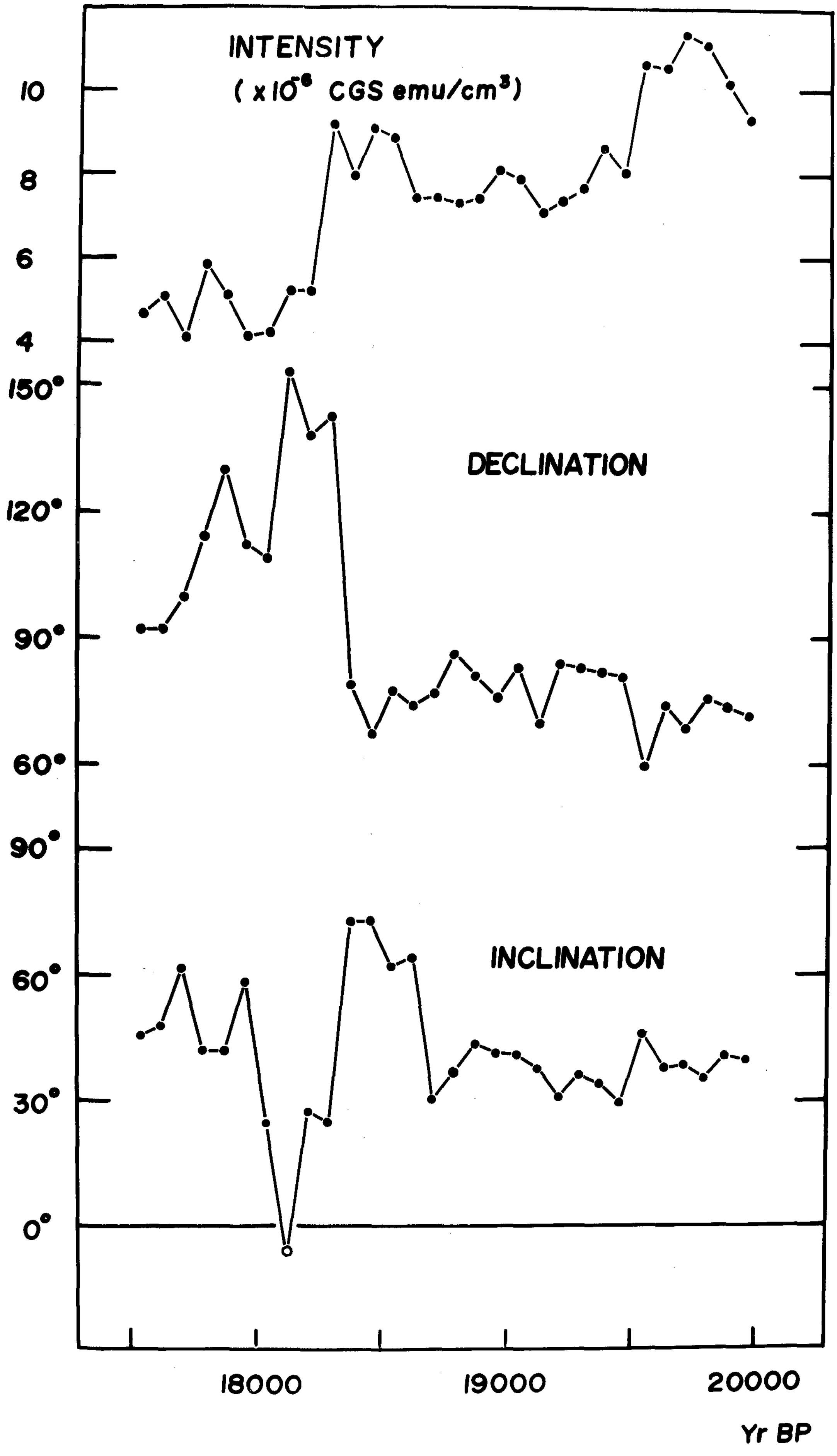

INTENSITY
(x10⁻⁶ CGS emu/cm³)
10
8
6
4
150°
120°
90°
60°
DECLINATION
90°
60°
30°
0°
INCLINATION
18000
19000
20000
Yr BP

Fig.8

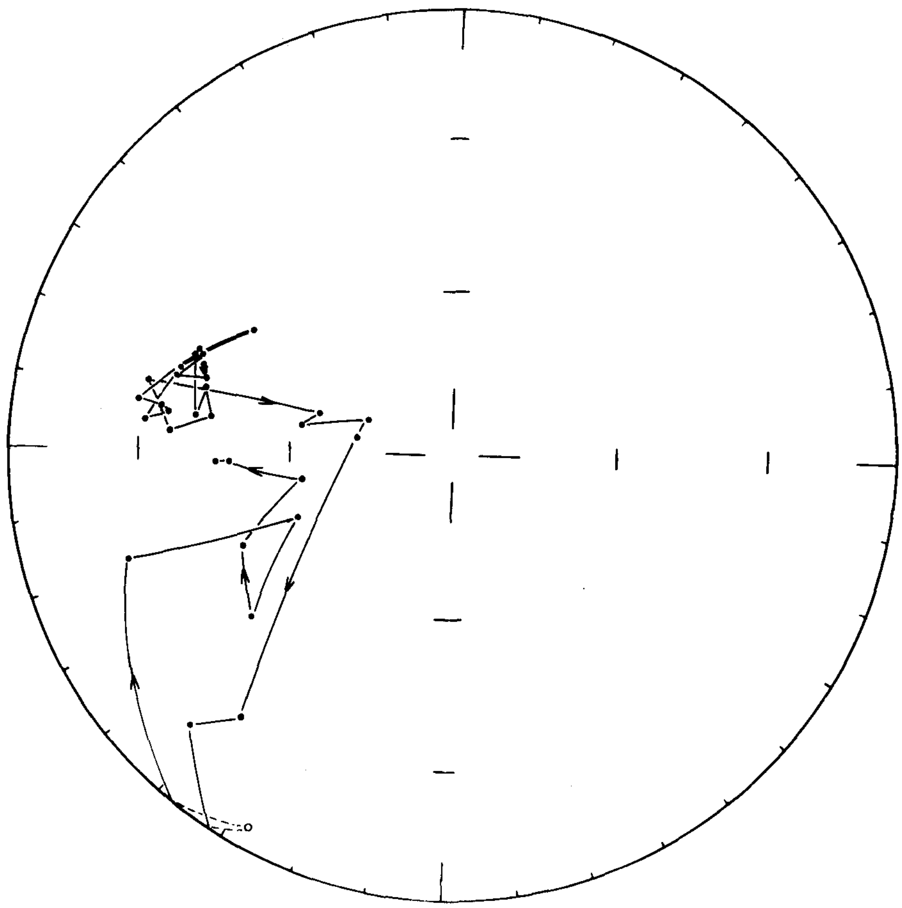


Fig.9

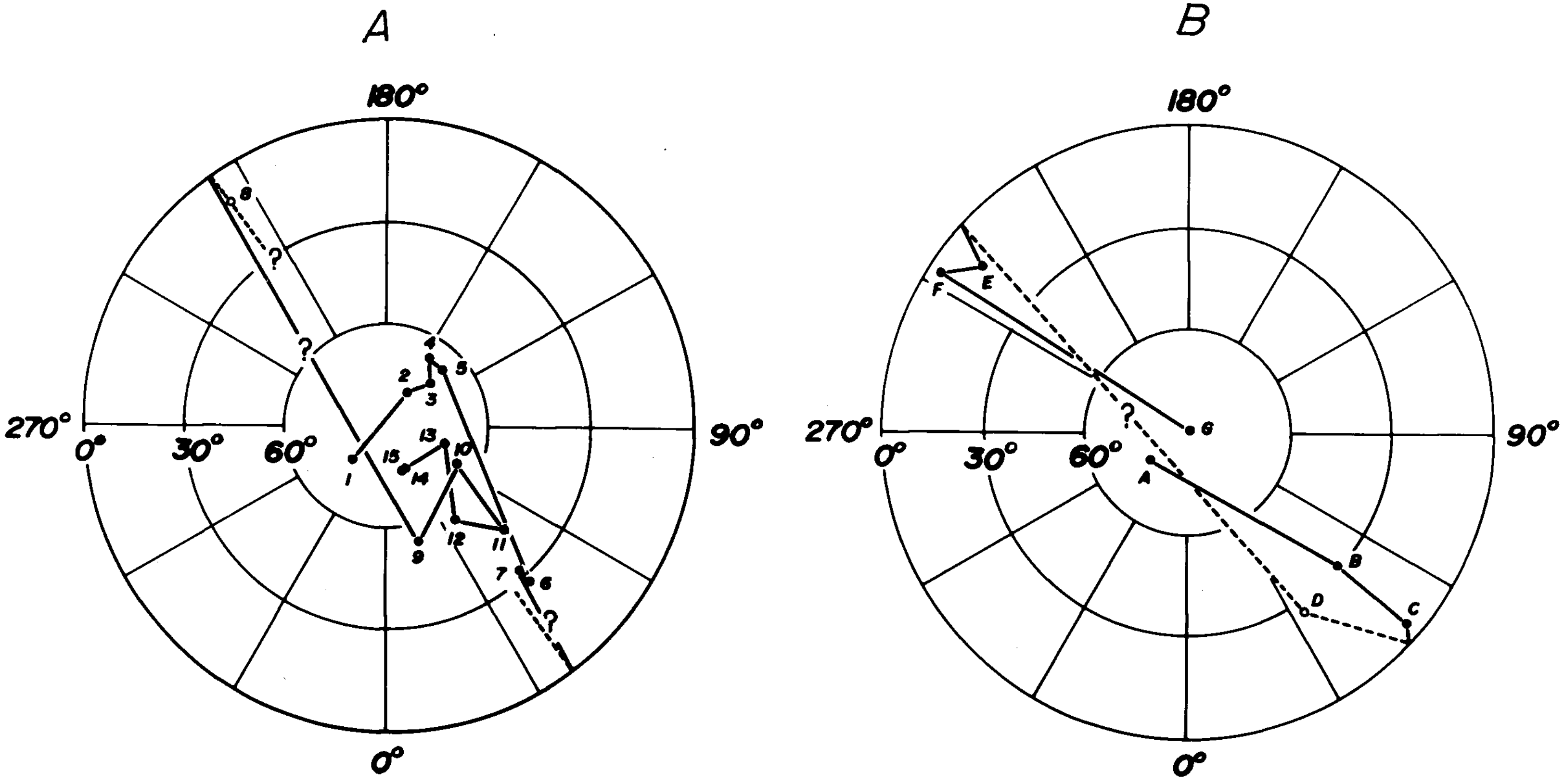

A
180°
270°
90°
0°
0°
30°
60°
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
?
B
180°
270°
90°
0°
0°
30°
60°
A
B
C
D
E
F
G
?

Fig.10

PRESENT AUTHOR'S PAPERS

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2) On a Possible Land Block Movement of Hokkaido Relative to the Main Island of Japan
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6) 陶邑古窯跡群の熱残留磁気測定結果について
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