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SEDIMENTARY PALEOMAGNETIC EVIDENCE FOR COUNTER-CLOCKWISE ROTATION OF THE FIJI PLATEAU

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN OCEANOGRAPHY

MAY 1971

By

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I. INTRODUCTION

This thesis reports the results of a detailed sedimentary paleomagnetic investigation of four closely spaced 7 to 11 meter piston cores collected on the Fiji Plateau in the Western Pacific in June, 1970. This plateau, which surrounds the Fiji Islands, has recently been proposed as an example of a crustal block which has undergone westward bending and counter-clockwise rotation of up to 180 degrees since the early Tertiary(Malahoff 1971). This interpretation is based on several lines of geophysical evidence that are summarized in figure 1. This figure is adapted from Malahoff(1971).

> In this figure dashed lines represent bathymetric lows; solid lines bathymetric highs; solid arrows indicate direction of crustal movement on the Fiji Plateau. Hollow arrows along the Tonga Trench suggest directions of oceanic crustal plate movement into the trench. Chequred arrows north and south of the Fiji Plateau indicate directions of oceanic crust movements deduced by . . . Malahoff. . . from sea floor spreading evidence. Dots indicate location of earthquake focii for shallow earthquakes(0-70 Km), from 1961 to 1969. . .

See Malahoff(1971) for a complete discussion of this figure and the geophysical evidence for rotation of the Fiji Plateau.

The four cores studied in this thesis were collected from the portion of the Fiji Plateau indicated by the large circle in figure 1. This area of the plateau has undergone a large amount of counter-

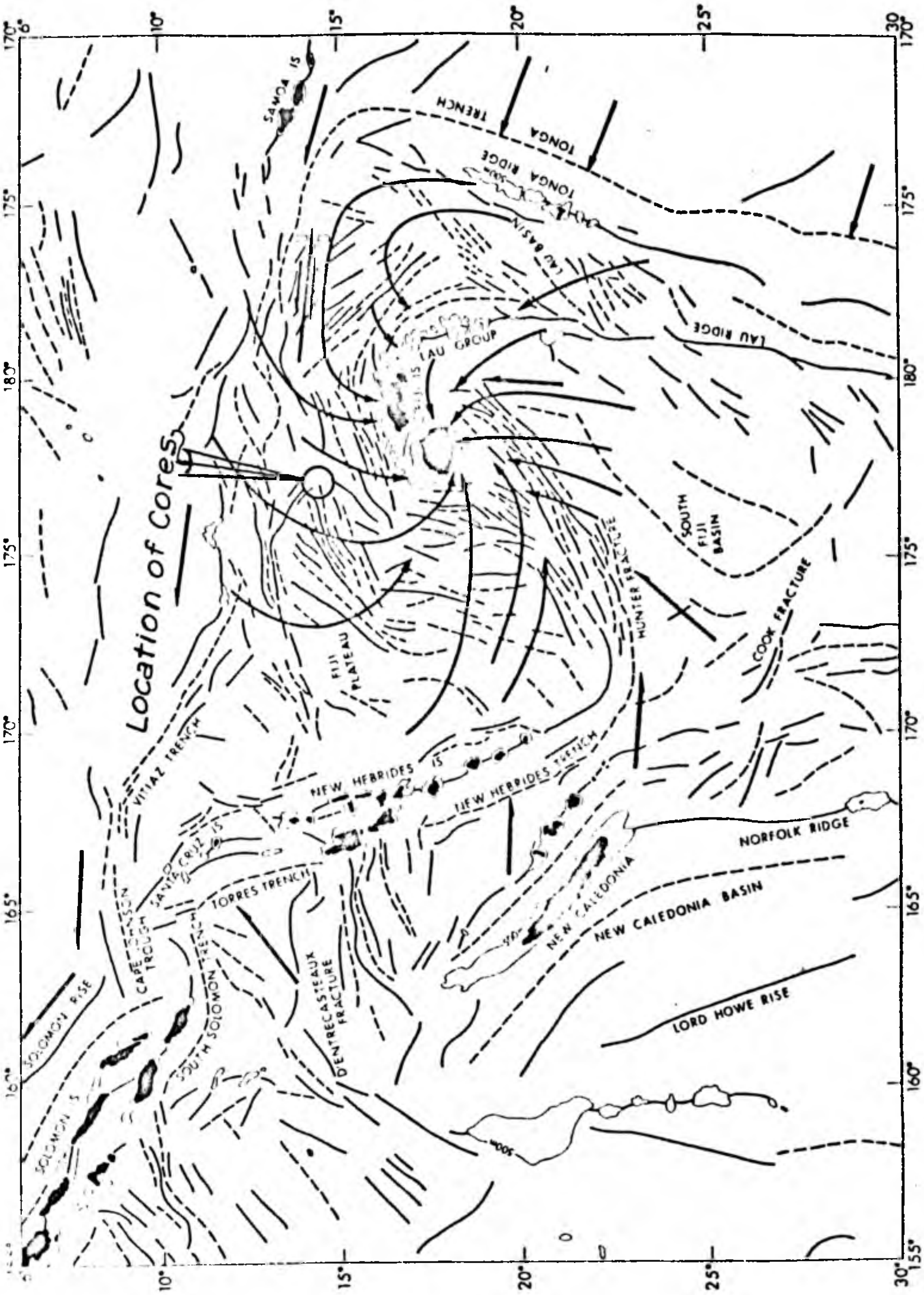

Location of Cores
TONGA TRENCH
TONGA RIDGE
LAU BASIN
LAU GROUP
LAU RIDGE
SAMOA IS
SOUTH FIJI BASIN
FIJI PLATEAU
HUNTER FRACTURE
COOK FRACTURE
VITIAZ TRENCH
NEW HEBRIDES IS
NEW HEBRIDES TRENCH
TORRES TRENCH
SOUTH SOLOMON TRENCH
D'ENTRECASTEAUX FRACTURE
NEW CALEDONIA
NEW CALEDONIA BASIN
NORFOLK RIDGE
LORD HOWE RISE
SOLOMON RISE

FIGURE 1

clockwise motion if Malahoff's interpretation is correct.

The sedimentary paleomagnetic measurements reported here are important for they provide an independent means with which to test this tectonic interpretation. It was expected that the proposed counter-clockwise rotation of the Fiji Plateau would be observable as a change in declination of the paleomagnetic vector with depth in the cores. Rates of observed rotation can be calculated from the depths at which reversals of inclination(due to reversals of the polarity of the earth's geomagnetic poles of known age) are encountered in the sediments.

This thesis is also important for it is one of the first times that variations in the declination vector of marine cores have been used to deliniate the tectonic history of an oceanic crustal plate. Recent studies of sedimentary paleomagnetism have concentrated mainly on the determination of depths of polarity reversals as an independent time stratigraphic tool for dating cores. Recent work in low latitudes has used changes in declination in internally oriented cores as a means of distinguishing these polarity changes(Hays and others 1969, Foster and Opdyke 1970).

The use of paleomagnetic methods in a study of this kind is only possible because of rapid developments in this field in the last decade. The deliniation of an accurate and generally accepted chronology for the reversals in polarity of the earth's magnetic pole from potassium argon dating of volcanic rocks(Cox 1969); the extension of this chronology by studies of the linear magnetic anomalies on the ocean floor(Pitman and Heirtzler 1966, Heirtzler and others 1968, Talwani and others 1971); and the applications of this chronology to sediments on the ocean floor(Opdyke and others 1966, Hays and others 1969, Foster and Opdyke 1970) have been some of the more important of these advances.

Development of a low speed spinner magnetometer using flux-gate probes(Foster 1966) made possible the routine measurement of the weak paleomagnetism of marine sediments. Prior to the introduction of these instruments, such an application of paleomagnetism was exceedingly difficult because of the cumbersome and delicate astatic magnetometers then in use (Blackett 1952).

The comparatively recent increase in the number and precision of paleomagnetic measurements from all areas of the world combined with the acceptance of the concepts of continental drift and plate tectonics have increased the confidence with which paleomagnetic results have been accepted.

The remainder of this thesis is divided into two main sections. The first section describes in detail the techniques and procedures followed in the analysis of the cores. The final section presents the experimental results and then discusses the conclusions and implications of these results. An appendix is included at the end which describes each of the four cores in greater detail.

II. TECHNIQUES AND PROCEDURES

COLLECTION OF CORES

Four piston cores were collected on the Fiji Plateau north-north west of the island of Viti Levu in June 1970. Pertinent data for the cores is listed in the Appendix. All of the cores were collected with a piston corer using six meter plastic core liners. These six meter plastic liners were pre-marked with two vertical lines 66^{o} apart which ran down the entire length of the liner. Junctions between liners were alligned by these marks prior to coring. These cores were not alligned with respect to the present magnetic field but internal allignment within a single six meter liner should be accurate to several degrees. Upon retrieval the liners were cut into 1.5 meter lengths, capped, and stored under refrigeration.

SAMPLING AND LOGGING

At the laboratory the liners were transferred from a portable refrigerated core locker and split into two equal halves along one of the vertical marks on the liner. The liner half without the remaining allignment mark was then sampled for paleomagnetics with 2 cm. cubic plastic boxes at 10 cm. intervals down the center of the split core. The other liner half was logged following standard procedures of the institute (Andrews 1970) and sealed in a plastic "D" tube. This sample is stored under refrigeration as an archive sample.

When analyzed, all four cores show an abrupt 66^{o} change in declination 4, 1.5 meter sections up from the bottom. This distance corresponds to the junction between plastic core liners in the piston coring equipment and is attributed to misallignment of core liners during shipboard operations. In the following discussions the top sections of core are recalculated to remove this offset.

Hays and others (1969) and Foster and Opdyke (1970) attribute changes they observed in the declinations of three Equatorial Pacific piston cores to twisting of the coring apparatus. They also encountered unexplained shifts in declination in the cores which they suggest are due to coring or handling operations. The cores they were examining were collected with unlined piston corers by Lamont-Doherty Geophysical Laboratories. The procedures used to allign the various sections of their cores are to cut a groove down the length of the unlined core as it is extruded on board ship and then to lay a string into this groove. The unlined core is later split along this string. In contrast, the procedures followed in this laboratory are based on premarked plastic liners 6 meters long. This system entails much less opportunity for gradual rotation to be artificially engendered by necessarily hurried operations aboard ship with soft marine sediments. The only possibility of an error in handling these sections occurs in the allignment between liners at 6 meter intervals.

ANALYSIS--5HZ SPINNER MAGNETOMETER

All of the paleomagnetic measurements were made within three days of sampling on Permali 5HZ Spinner Magnetometers using a pair of anti-parallel Schonstet flux-gate probes as sensors. This equipment has been described in detail by Hammond (1970).

Tests for Magnetic Stability

Prior to analysis, several random samples from each core were tested for magnetic stability by stepwise A. C. Demagnetization to 150 Oersteds on a Permali Axis A. C. Washer. Plots of the changes in declination and inclination of these samples are shown as stero-plots in figure 2. The intensity of magnetization for these samples are shown in figure 3. These figures reveal that the magnetic materials in these cores fall into two classes; in cores 20, 21, and 22, samples with an intensity of magnetization less than about 1×10^5 at 50 Oe A. C. demagnetization are much more unstable than samples with greater intensities. This instability is apparent in the much larger changes in declination and inclination which the lower intensity samples showed. The stronger class of samples show remarkably constant magnetic vectors, and are not destroyed at 150 Oe. On all four cores, 50 Oe was chosen as the optimum level at which to clean the samples of unstable magnetic components. Measurements that yielded intensities of magnetization less than

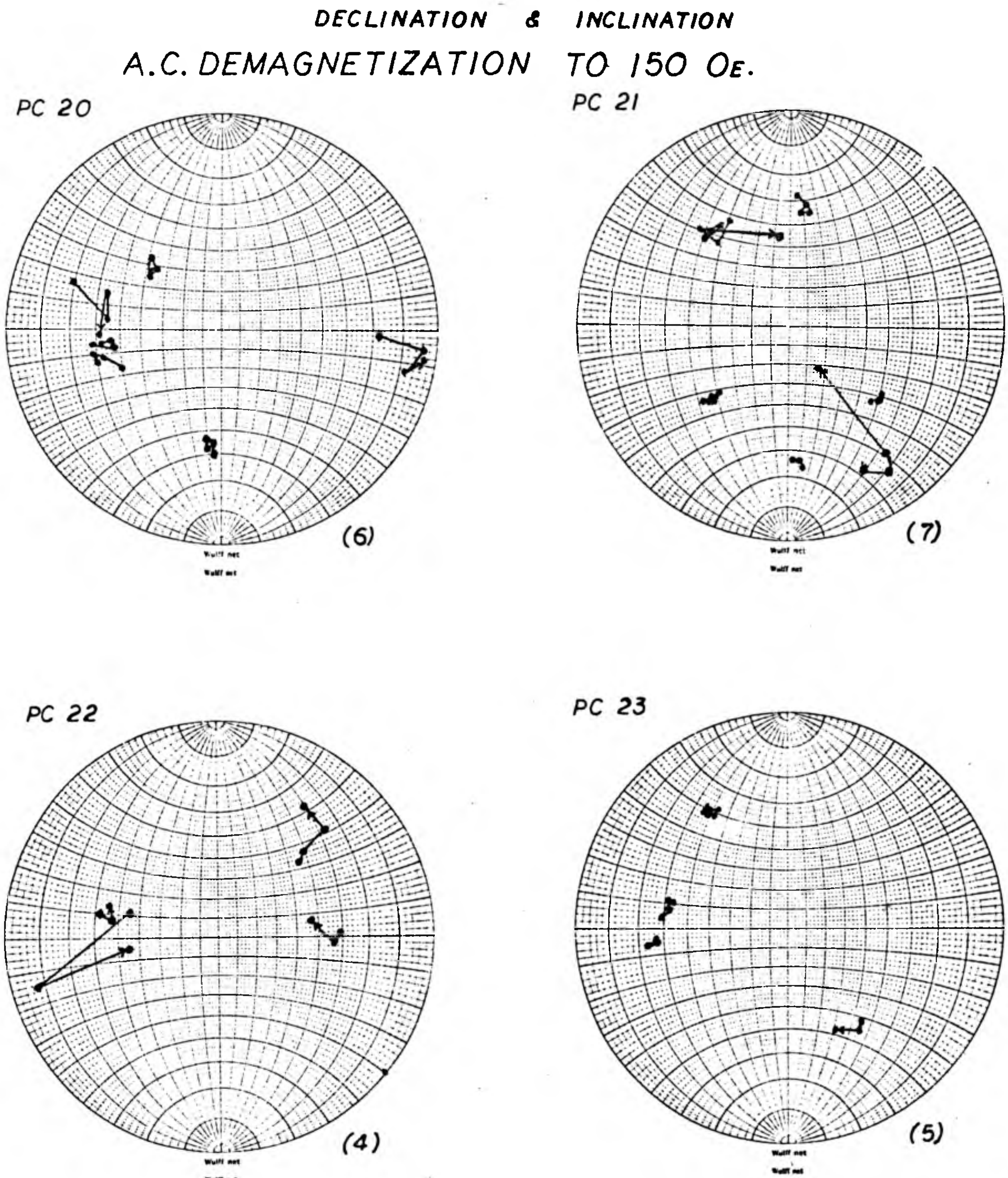

DECLINATION & INCLINATION
A.C. DEMAGNETIZATION TO 150 Oe.
PC 20
(6)
PC 21
(7)
PC 22
(4)
PC 23
(5)

FIGURE 2

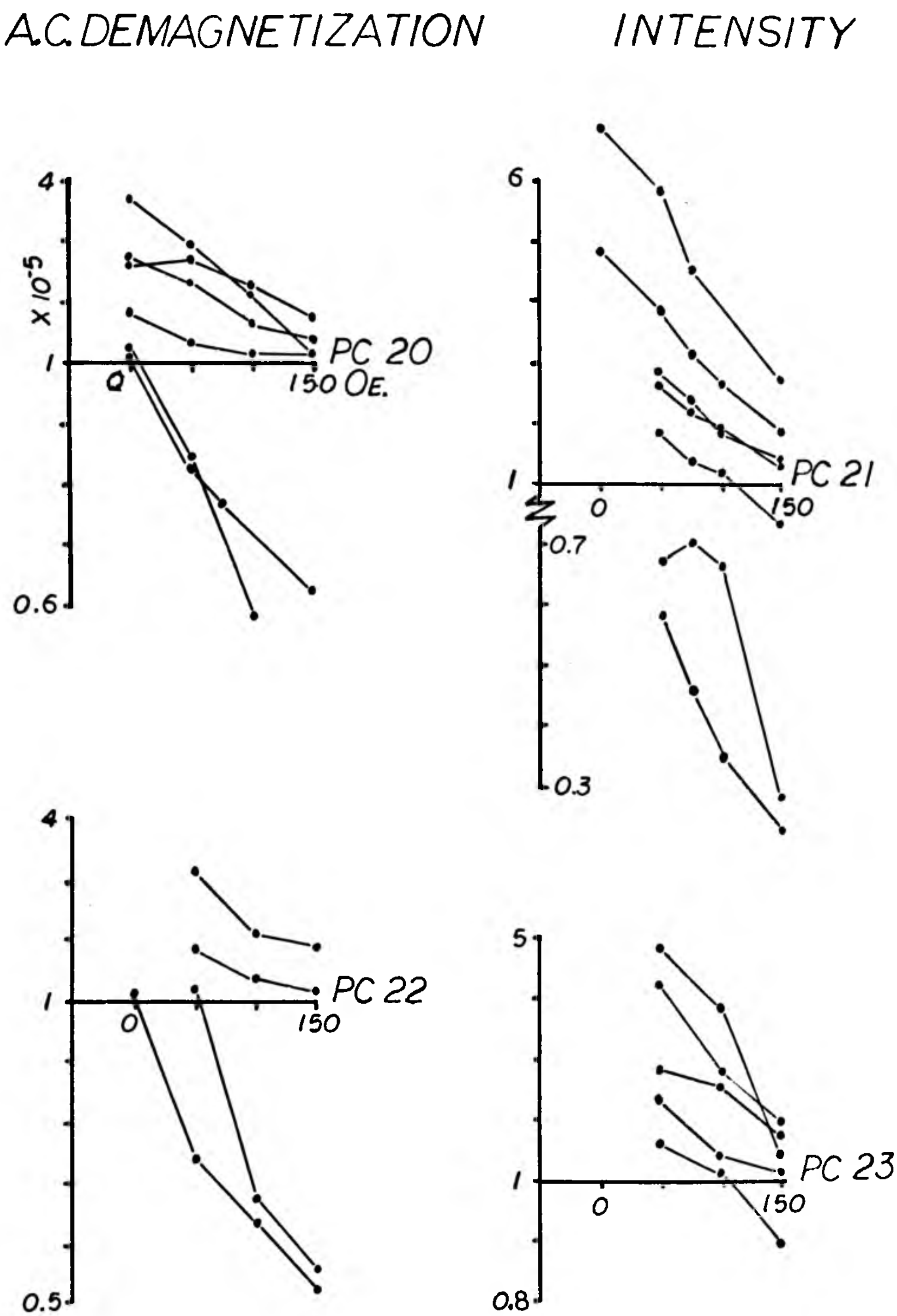

A.C. DEMAGNETIZATION
INTENSITY
X 10⁻⁵
4
1
0.6
0
150 Oe.
PC 20
6
1
0.7
0.3
0
150
PC 21
4
1
0.5
0
150
PC 22
5
1
0.8
0
150
PC 23

FIGURE 3

1×10^5 at 50 Oe demagnetization were discarded and not used in the analyses.

Analysis

After A. C. Demagnetization at 50 Oe, each sample was spun on three perpendicular axes and values were obtained for the X, Y, and Z axes. This procedure is described in detail by Hammond (1970) and is similar to the procedures used by other paleomagnetic laboratories. A standard sample of known declination, inclination, and intensity that had been checked with other laboratories was run daily on each instrument to check its performance. The values obtained were converted to declination, inclination, and intensity on a computer program developed by Hammond (1970).

III. RESULTS, DISCUSSION AND CONCLUSIONS

The values of Declination, Inclination, and Intensity for the four cores as a function of depth are shown in figures 4 and 5 below. Two of the cores, PC 21 and PC 22, penetrate through the reversal at .95 million years at the end of the Jaramillo Event. Cores PC 20 and PC 23 penetrate the reversal above this at .89 million years which marks the beginning of the Jaramillo Event.

SEDIMENTATION RATES FROM DEPTHS OF MAGNETIC REVERSALS

The depths at which reversals occurred are plotted as a function of age from the Geomagnetic Time Scale of Cox (1969) in figure 6.

In three of these cores (20, 21, 23) a straight line can be drawn through these points and the origin. A line drawn this way for core 22 however, intersects the depth axis in the vicinity of 130 to 160 cm. (dashed line in figure 5). It should be noted however, that core 22 was the only core which was disturbed badly. The liner was collapsed by the suction of the piston from 180 to 340 cm. and contained little sediment. Based on this information, it has been assumed that there is a 140 cm. break in this core starting at 180 cm. depth. This assumption allows the sedimentation curve in figure 6 to be shifted 140 cm. to the left as shown by the arrows. In the following discussion all samples from this core below 180 cm.

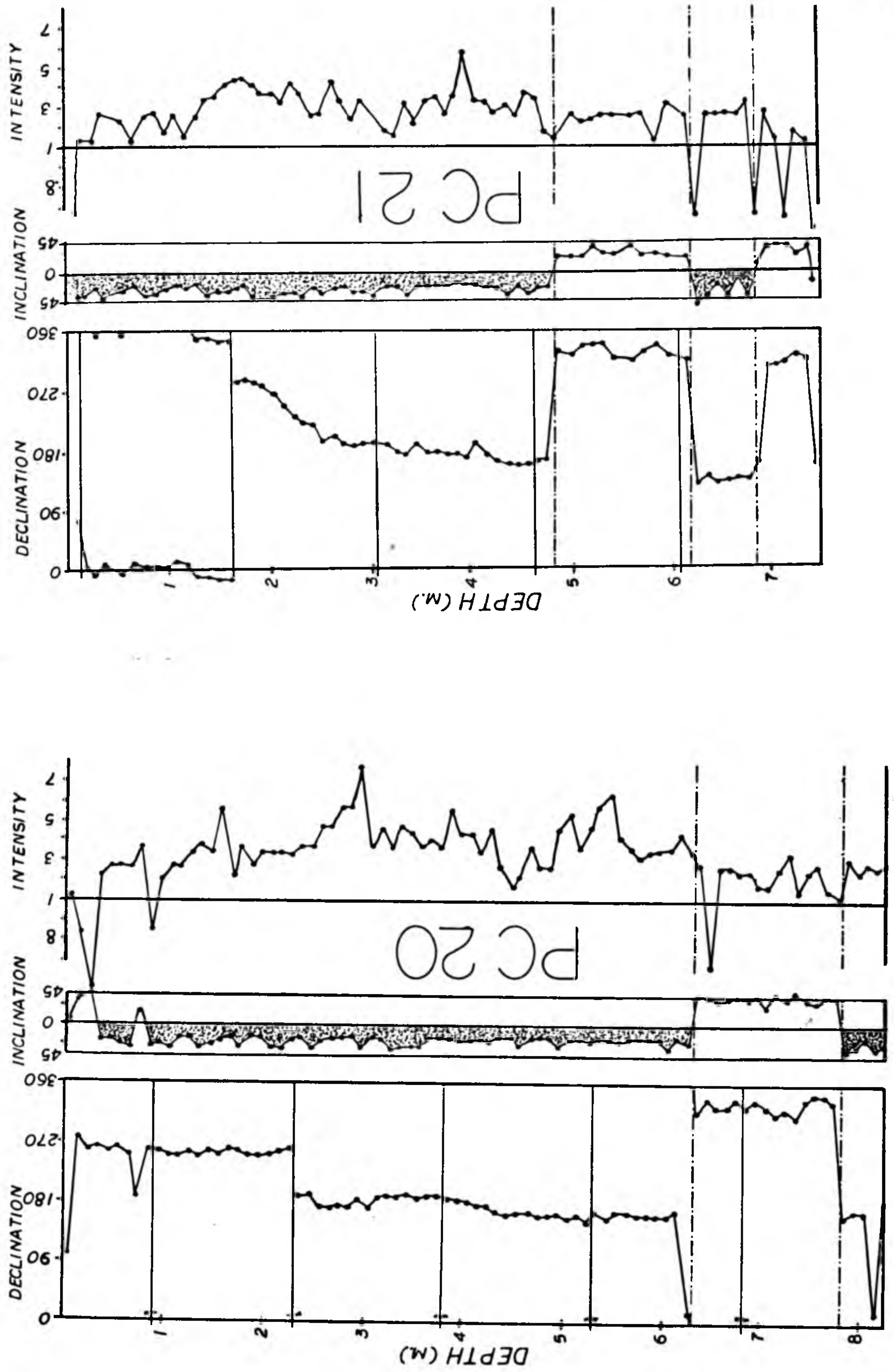

PC 21
INTENSITY
INCLINATION
DECLINATION
DEPTH (M.)
PC 20
INTENSITY
INCLINATION
DECLINATION
DEPTH (M.)

FIGURE 4

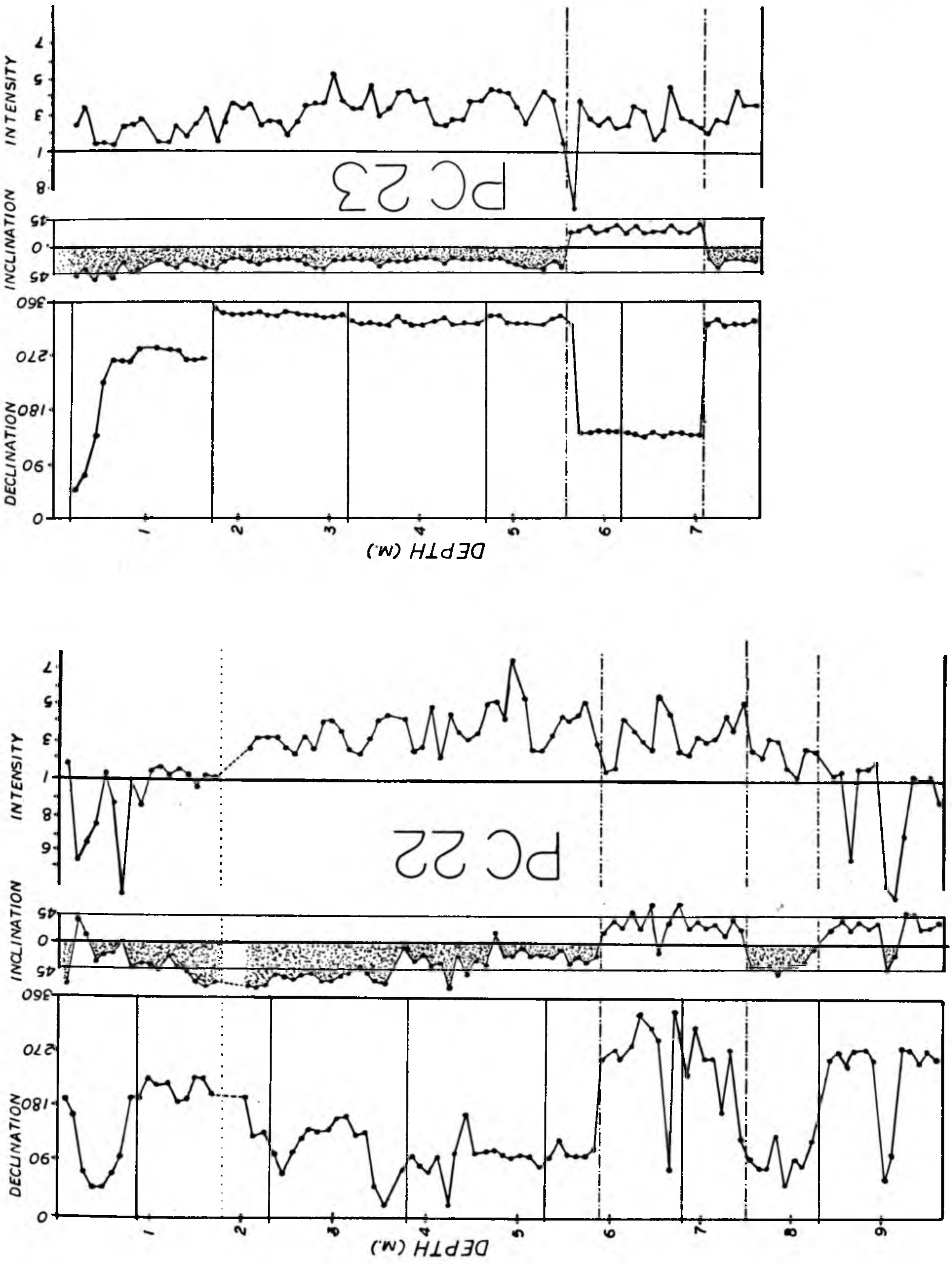
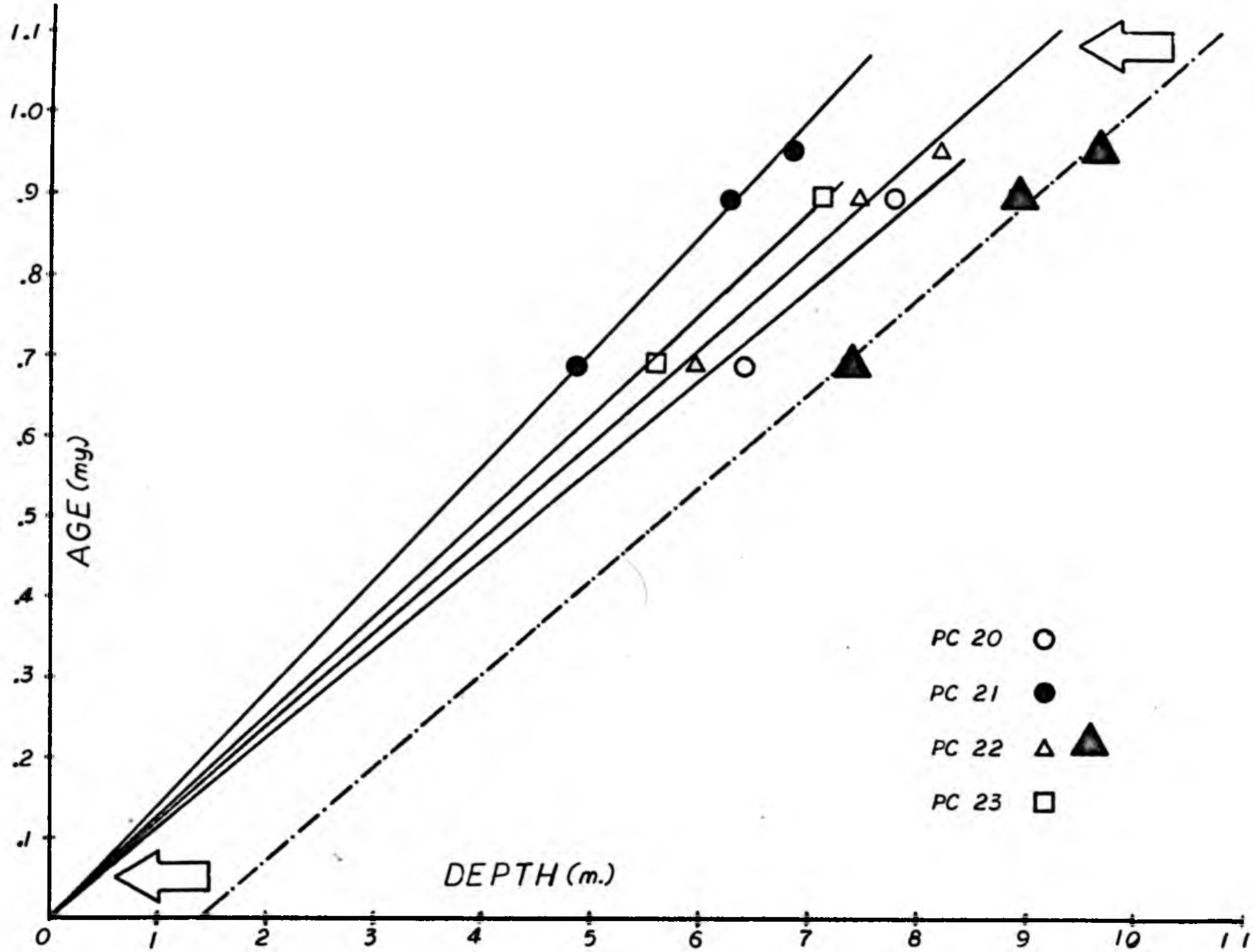

PC 23
INTENSITY
INCLINATION
DECLINATION
DEPTH (M.)
PC 22
INTENSITY
INCLINATION
DECLINATION
DEPTH (M.)

FIGURE 5

FIGURE 6



AGE (my)
DEPTH (m.)
PC 20
PC 21
PC 22
PC 23
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
1
2
3
4
5
6
7
8
9
10
11

have had 140 cm. subtracted from them to remove this break. Thus this core is considered to be 974 cm. long instead of 1,114 cm.

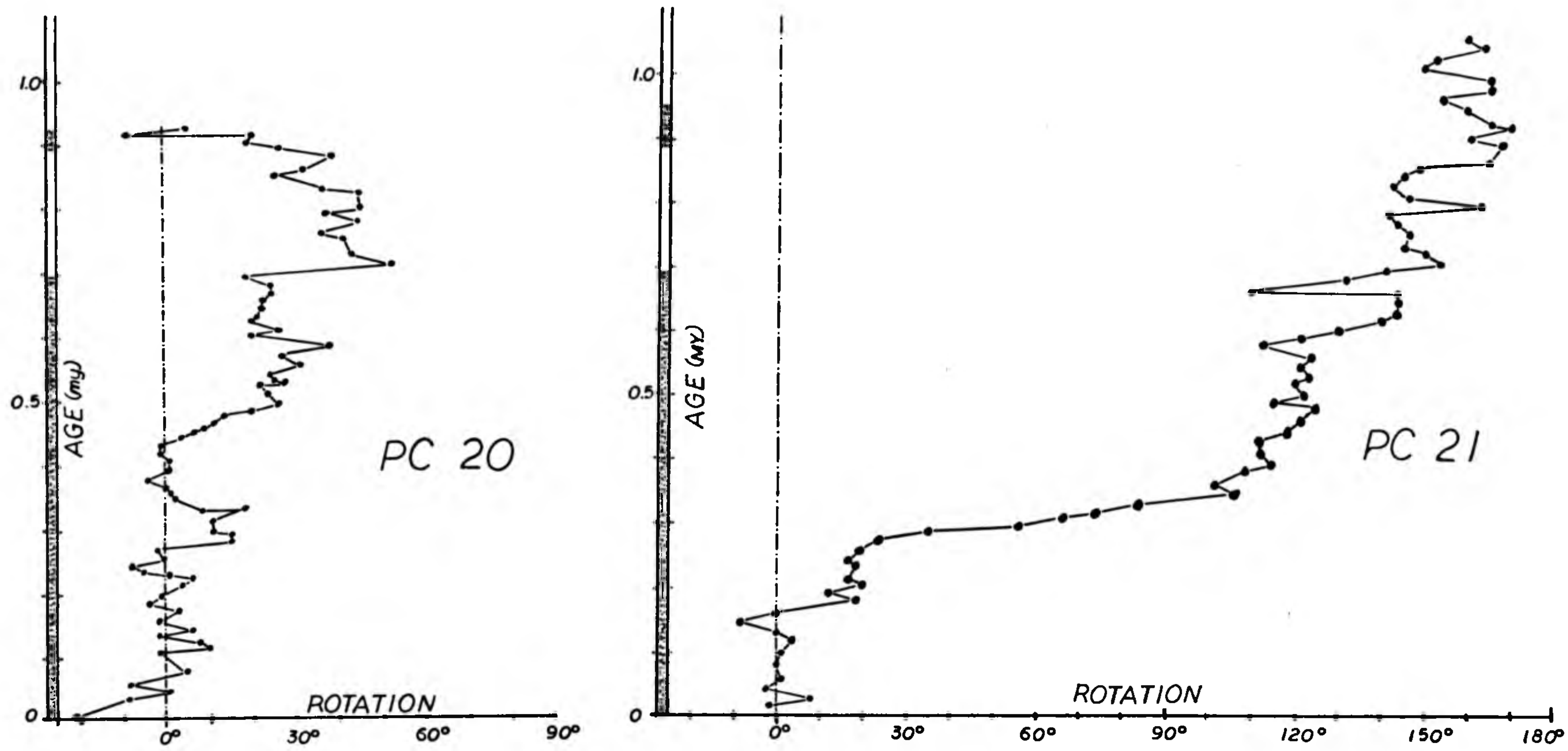
The calculated rates of sedimentation based on the paleomagnetic data of these four cores range from .72 to .89 cm. per 1,000 years. Rates for the individual cores are listed in the appendix.

CALCULATED RELATIVE ROTATION OF THE PALEOMAGNETIC VECTORS WITHIN THE CORES

Figures 7 and 8 are plots of changes of declination relative to the 100 cm. declination within each core versus age. Counter-clockwise rotation is plotted as positive. The sedimentation curves were used to interpolate ages for each sample in these figures. The 100 cm. depth was arbitrarily chosen as a zero reference because the top sections of these piston cores were disturbed. In several of the cores this disturbance extended 70 to 80 cm. down from the top of the core. Because the greatest rate of change of the declination vector in the cores occurs after several meters of core with relatively constant declination, the selection of the depth is not very crucial.

The inclination of the present day magnetic dipole in the Fiji Plateau is 40°S and inclination measurements are sensitive to flow of sediments into the core barrel. Thus figures 7 and 8 do not include any measurements which contained an inclination measurement greater than 45°. Measurements which yielded intensities

FIGURE 7



1.0
0.5
0
AGE (my)
ROTATION
0°
30°
60°
90°
PC 20
1.0
0.5
0
AGE (MY)
ROTATION
0°
30°
60°
90°
120°
150°
180°
PC 21

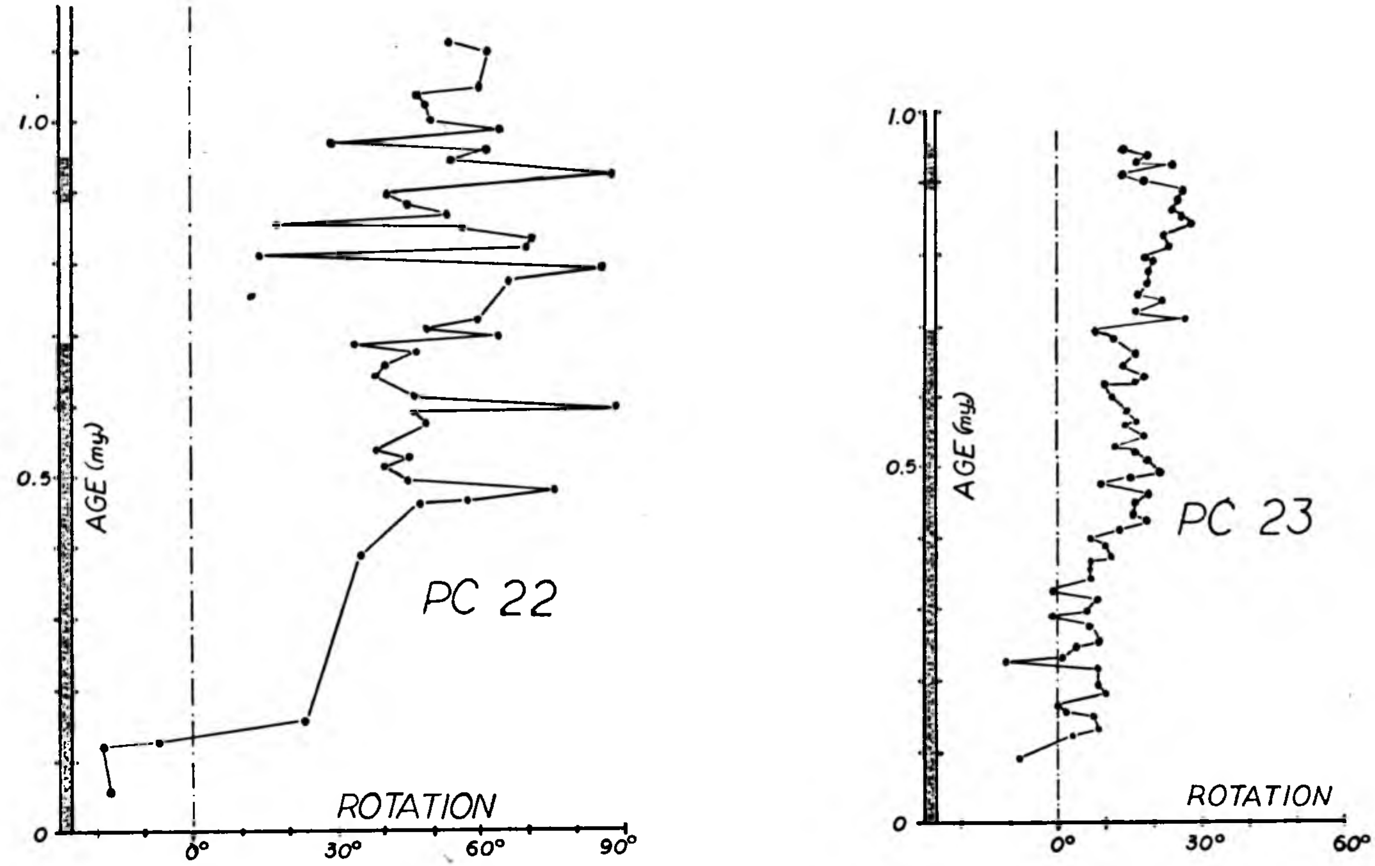

1.0
0.5
0
AGE (my)
0°
30°
60°
90°
ROTATION
PC 22
1.0
0.5
0
AGE (my)
0°
30°
60°
ROTATION
PC 23

FIGURE 8

of magnetization less than 1×10^5 at 50 Oe demagnetization were also excluded from these figures for the reasons discussed earlier. Using these criteria, almost a meter and a half of sediments in core 22 are disturbed below the break at 180 cm. None of the other cores are affected by these criteria except in the top few centimeters.

DISCUSSION

Figure 9 shows changes in declination that would occur in a core on a crustal block rotating counter-clockwise. The arrows extending from the core indicate the magnetic declination vectors for that point on the core if the top of the core is oriented parallel to the earth's magnetic field. The vectors describe a spiral.

All four cores examined in this thesis show counter-clockwise rotation of the crustal block upon which they were collected. Figure 10 summarizes the relative rotation rates of the individual cores with respect to time.

The shapes of the curves suggest that the rate of rotation of this portion of the Fiji Plateau has been irregular and that the rotation was more rapid from about 0.2 to 0.5 million years ago. An alternative interpretation of these curves calls for a decrease in the sedimentation rate over this period of time. The fact that a line can be drawn through the depths of polarity reversals in Figure 6 with a reasonably close fit, coupled with the large differences in

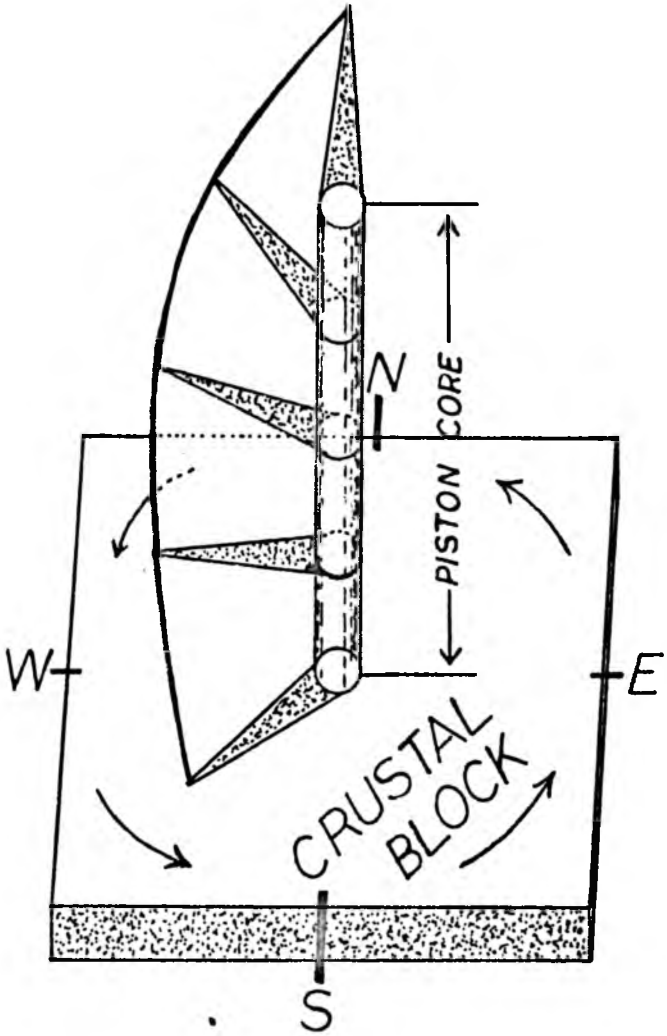
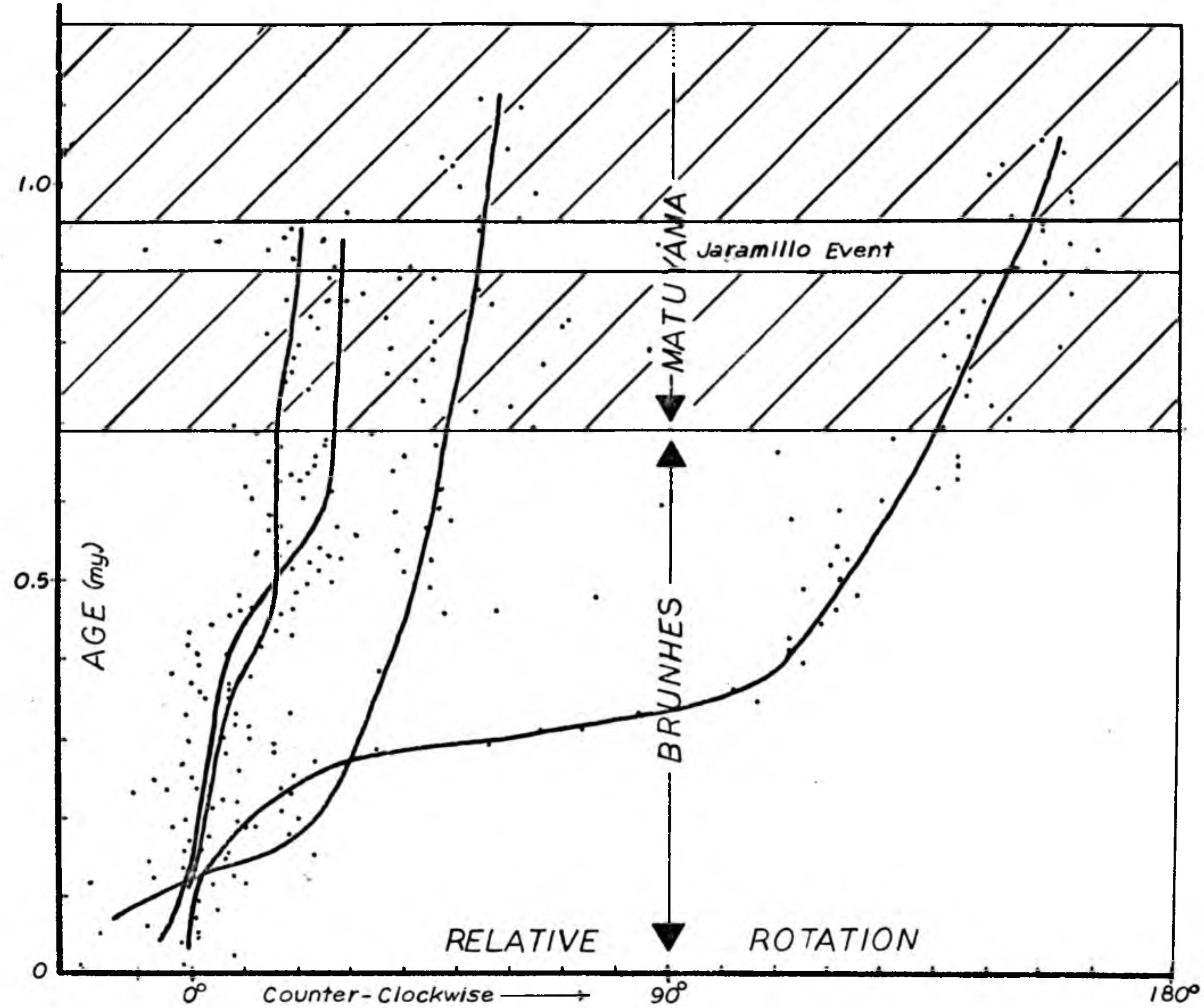


FIGURE 9

FIGURE 10



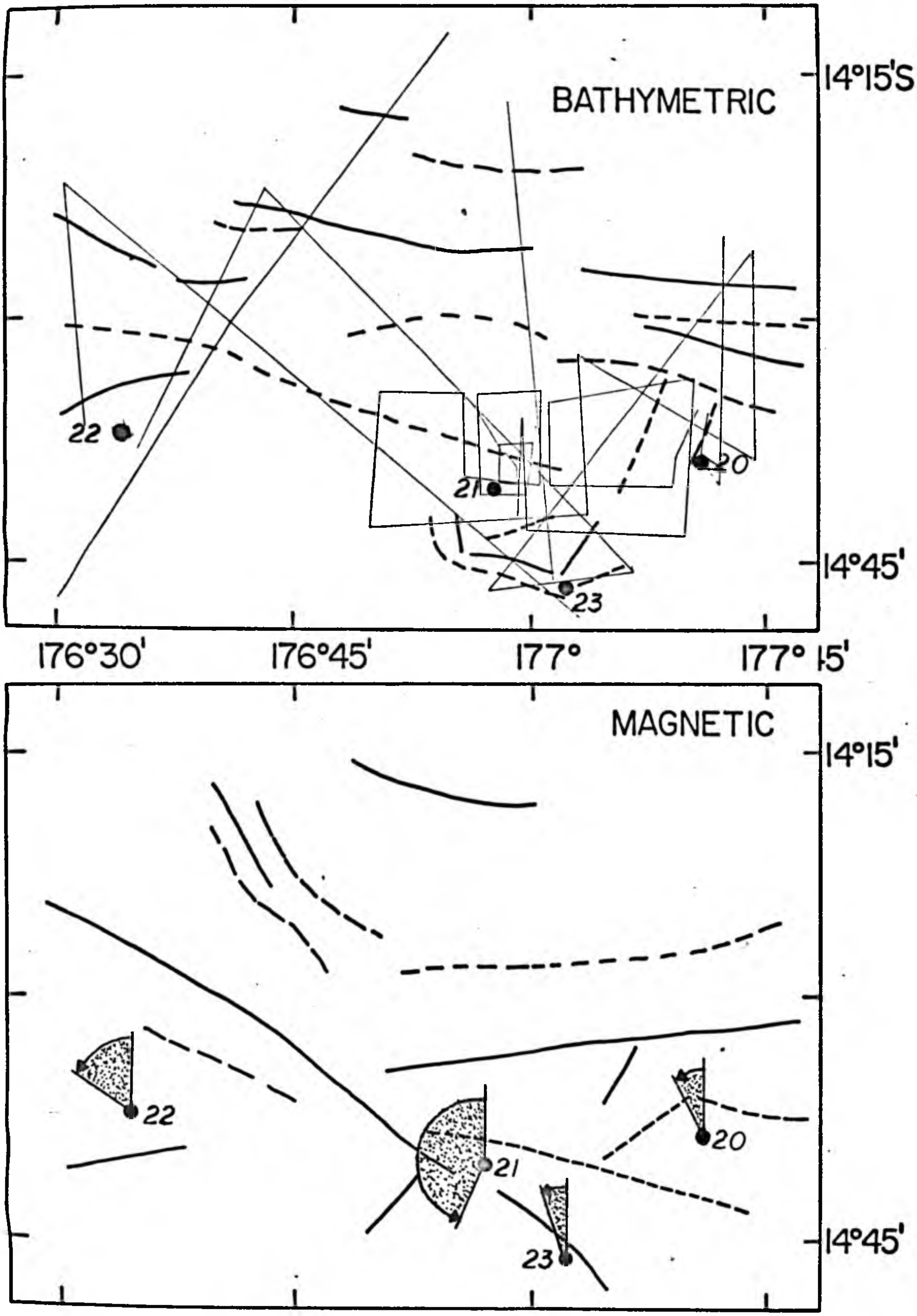
1.0
0.5
0
AGE (my)
MATUYAMA
Jaramillo Event
BRUNHES
RELATIVE ROTATION
0°
Counter-Clockwise ⟶
90°
180°

amounts of rotation found in core 21 over this time period suggest an interpretation of irregular rotation.

The reasons for the much larger rotation recorded in core 21 are not known. Malahoff (1971) includes two figures which summarize surveys by Halunen and others of the trends of magnetic anomalies and bathymetry of the area where these cores were collected. The results of this thesis are plotted on these figures in figure 11. It is interesting that core 21 was collected close to what appears to be an intersection of two magnetic trends. The large rotation in this core may be indicative of motions of a small plate within the plateau while the 20-50 degree rotations suggested by the other cores probably reflect a more general motion of the plateau.

It does not seem likely that the apparent rotation of the declination vector measured here is due to a spinning piston coring apparatus. Hays and others (1969) and Foster and Opdyke (1970) as mentioned above attribute changes which they observed in the declinations of three Equatorial Pacific piston cores to twisting of the coring apparatus although as discussed previously they were using unlined, extruded cores.

The possibility that the coring apparatus was rotating cannot be totally discounted but several reasons can be presented which indicate that this is not the case. Most of the measured rotation occurs over a small interval in the middle of the core after from



BATHYMETRIC
14°15'S
14°45'
22
21
20
23
176°30'
176°45'
177°
177° 15'
MAGNETIC
14°15'
14°45'
22
21
20
23

FIGURE 11

one to two meters in which the declination remains relatively constant. All four cores show a counter-clockwise rotation while other cores collected in other areas of the Western Pacific with the same equipment and procedures have not shown consistent changes of declination with depth. The sense and amounts of rotation are compatible with geophysical evidence.

The results from only four cores cannot be considered conclusive proof of the rotation of the entire Fiji Plateau but do offer strong evidence to support the concept of at least this portion of the plateau having undergone a discontinuous counter-clockwise motion in the last million years. The data suggests that this rotation has been in the vicinity of 20 to 50 degrees with possibly small crustal blocks undergoing much larger motions. It would be interesting to try to correlate the increase in rotation rate from . 2 to . 5 million years with other tectonic events in this highly seismic area. Anomalously high rates of heat flow have been observed over this plateau (Sclater and Menard 1967) and the structure of the sub-bottom seen with sub-bottom profilers shows a chaotic complex of fault blocks and faulted sediments.

A more detailed geophysical survey of the Fiji Plateau is planned for the fall of 1971. A number of additional piston cores will be collected as a part of this program. The sedimentary paleomagnetism of these additional cores should provide a strong tool with which to unravel the tectonic history of this complex region of the earth's crust.

APPENDIX

CORE NO.	LATITUDE	LONGITUDE	DEPTH (m)
PC 20	14 39.8S	177 11.6W	2840
PC 21	14 41.5S	176 58.5W	2815
PC 22	14 37.0S	176 34.0W	2890
PC 23	14 47.4S	177 02.9W	2812

LENGTH (cm)	REVERSALS (cm) depth	SED. RATE cm/1,000 yrs.	MAX. ROT. Million yrs.	TOTAL ROT. Degrees
822	630 & 780	89	.42-.60	20-30
755	485, 625, 685	72	.29-.35	140-160
974	590, 750, 830	85	.15-.40	50*
763	560, 710	80	.35-.45	20-25

*Depth values in this core are corrected for a 140 cm. gap below 180 cm. as discussed in the text.

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