Remagnetization of the Eocene Oceanic Formation on Barbados, West Indies

by

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ABSTRACT

A paleomagnetic study of 274 samples from the Middle and Upper Eocene Oceanic Formation in Barbados indicates remagnetization after folding. Consequently the outcrops cannot be used for paleomagnetic stratigraphy.

The samples were collected from outcrops at Bath and Gays Cove using a hand core drill. Magnetic measurements were made in a ScT Superconducting Magnetometer. Samples were cleaned using an Alternating Field Demagnetizer.

The intensity of the natural remanent magnetization (NRM) moment ranged between 2×10^{-8} gauss and 225×10^{-7} gauss. For a set of 24 pilot samples the average NRM moment was 25×10^{-7} gauss. Although somewhat weakly magnetized, the magnetic directions were stable. After treating the samples in a 200 oersted peak field the average angular change was 13^{o}. The same set of samples gave an average median destructive field (MDF) of 177 oersted.

All samples analyzed were normally magnetized. A fold test using clusters of samples from different limbs of folds at Gays Cove indicates remagnetization after folding. At Bath the average magnetic direction more closely parallels the present local magnetic field direction after folding than before folding.

INTRODUCTION

The Oceanic Formation on Barbados was deposited during the Eocene and Oligocene epochs. The formation has been studied extensively since the late 1800's, when the similarity of the outcrops with deep sea deposits was first recognized. The major variations of carbonate content in the formation led Senn (1948) to relate the depth of deposition to the Eocene calcium carbonate dissolution depth of approximately 4 km. A recent stratigraphic and sedimentologic study by G.P. Lohmann confirms the depth of depsition of 4 km and describes the microfossil in the Oceanic Formation (Lohmann 1974). The biostratigraphy of the Middle and Late Eocene Epoch can be seen in figure 2.

The Eocene section of the Oceanic Formation is made up of calcareous oozes varying in carbonate content between approximately 30% and 80%. The section overlays a Tertiary melange deposit named the Scotland Formation. A Pleio-Pleistocene coral cap covers the Tertiary deposits except in the north-east corner of Barbados where they outcrop through an erosional window (Figure 3.).

The tectonic stresses that acted upon the Oceanic Formation during the uplift have caused extensive deformation of the sections. The exposed outcrops show plunging folds dipping 24^{o} - 45^{o} in a mainly NE-SW direction. (Table 1.)

OBJECTIVES

The main purpose of this study was to evaluate the Oceanic Formation on Barbados for paleomagnetic stratigraphy. It was hoped that this Eocene outcrop would provide an opportunity to correlate biostratigraphy with the paleomagnetic time scale as inferred from marine magnetic anomalies.

Sedimentological and stratigraphic studies have resulted in biostratigraphic descriptions for the Oceanic Formation. G.P. Lohmann's work would be of particular interest as the specimens for this study were sampled at the same locations as the samples for Lohmann's study (Lohmann 1974).

The samples for this study span approximately 11 m.y. between 48 and 37 m.y. B.P. Heirtzler et. al. have interpreted close to 30 geomagnetic polarity reversals from lineated marine anomalies for this time interval (Figure 2). At least three of these polarity intervals are over 1 m.y. years long. The lack of well-dated rocks from marine deposits of Eocene age has resulted in a number of interpretations of the Geomagnetic time scale for this time period. The anomaly pattern remains generally the same, while the assigned ages differ. For example, La Brecque et. al. (1977) has shifted Heirtzler et.al.'s polarity pattern 3 m.y. forward in time. A similar shift was made by Ness et. al. (1979)

To calibrate the times of polarity changes for the Eocene Epoch, a set of well dated magnetically reliable rocks would be very useful. The purpose of this study was to determine whether the outcrops from the Oceanic Formation on Barbados would fulfill the requirements. Radiometric dating of the samples may be possible using the numerous ash layers found through the section. Such a study would be desirable if the paleomagnetic properties were reliable.

ABBREVIATIONS

The following abbreviations are used in this report; AF, alternating field ; G, gauss (emu/cm^3) ; H200, AF demagnetized at 200 oersted. ; J_{nrm}, intensity of natural remanent magnetization ; MDF, median destructive field ; NRM, natural remanent magnetization ; oe, oersted ; GADF, geocentric axial dipole field ; I, inlination ; D, declination ; N, number of samples ; k, precision parameter (Fisher 1953) ; α_{95}, circle of 95% confidence (Fisher 1953).

INSTRUMENTATION

Measurements were made in a superconducting magnetometer (Figure 1, Goree 1976). The superconducting shield provides almost perfect control of the magnetic shield in the measurement region. The magnetic moment of a sample is measured by inserting the sample into the shielded region and using an ultrasensitive superconducting magnetometer circuit.

As a sample is inserted into the superconducting pickup coil a current is induced in the coil due to the change in the magnetic flux linking the coil. Since the coil is superconducting this induced current does not decay with time. The amplitude of the current circulating in the coil is a function of the position of the sample, the magnetic moment of the sample and the coupling between the pickup coils and the sample. Measurement of this induced current is made with a Josephson Junction technique and is a direct measure of the magnetic moment of the sample along the axis of the pickup coil (Josephson 1962, Anderson 1963).

The current measurement is made by connecting a small, but equal inductance field transfer coil which is then measured with the superconducting magnetometer.

The data produced by the superconducting magnetometer is an analog signal that is a linear function of the component of the moment in the direction of the measurement axis. In this case a two-axis super conducting magnetometer was used measuring the axial and one radial component simultaneously. A rotation of the sample through 90^{o} about the system axis provided the third component of the total moment.

A single-axis, AC Demagnetizer was used to remove the soft unstable magnetization without affecting the more stable remanent magnetization. Demagnetization is accomplished by subjecting the specimen to a 400 Hz alternating magnetic field which decays at a linear rate to zero. The peak level of the magnetization field can be set to any value between 5 and 1000 oersteds.

During demagnetization the specimen is mounted in the center of a coil located within a multilayered magnetic shield. A sample holder provides for orienting the sample for demagnetization along any one of three orthogonal axis.

PILOT STUDY

A pilot study was carried out on 24 samples to assess the likely paleomagnetic reliability of the outcrops. Each sample was treated in a progressively stronger peak AF in steps of 50 oersted. The progressive demagnetization was continued up to 400 oersted peak field, or until the specimen was too weakly magnetized to be accurately measured. A measurement was considered reliable if the remanent moment was above 35 x 10^{-8} gauss-cm^3. The NRM moments ranged between 30 x 10^{-8} gauss-cm^3 and 924 x 10^{-7} gauss-cm^3 with a mean of 138 x 10^{-7} gauss-cm^3. The sample volumes were typically 5.5 cm^3.

The most strongly magnetized samples were visibly iron-oxide stained. Weathering of the numerous ashbeds in the sedimentary section is the most likely source of the staining.

The average median destructive field (MDF) for 22 of the specimens was 177 oersted. The two samples excluded at this point were too weakly magnetized to be measured after treatment in a 50 oersted alternating field. The MDF is defined as the peak AF needed to eliminate 50% of the original NRM. A histogram shows the distribution of the quite varied MDF's (Figure 4a). The larger number of samples fall within a typical range for sedimentary rocks, 150 - 300 oersted.

The magnetic directions and intensities for NRM and H200 were used for the basic analysis. Six specimens were excluded as they were too weakly magnetized after the 200 oersted treament.

The ratio of remaining remanence intensity after AF treatment at 200 oersted to the original NRM intensity was computed for the 18 samples used. The results are displayed in a histogram. (Figure 4b) Again the behaviour of the samples varies quite strongly, yet stays within reasonable limits with a mean of 51%.

The angular change of magnetic directions for the NRM and the H200 were computed. (Figure 4c) The average was 12.5^{o}, ranging between 0.7^{o} and 25.6^{o}. A strong correlation exist between high magnetic intensity and low angular change.

All the samples in the pilot study were normally magnetized. The magnetic directions for NRM and for the 200 oersted treated samples were plotted on stereographic projections . (Figure 5a,b,c.) The mean directions were computed along with the precision parameter k and α_{95} . (Table 2, Figure 5a,b,c.) The magnetic directions for the original NRM are quite scattered, with a mean direction of 36^{o} inclination and 7^{o} declination of 7^{o}. The k-value is 11 which gives an α_{95} of 9^{o} (Figure 5a, Fischer 1953). After treatment at 200 oersted , the magnetic directions move somewhat closer together. Greatest clustering of magnetic directions is evident for the 200 oersted treated samples when the beds are kept in the present dipping orientation. (Figure 5b) The higher k-value of 28 for the beds in the present dipping directions compared with a k-value of 6 for horizontal bedding confirms the better fit. The α_{95} values are 7^{o} for the high k-value and

15^{o} for the low k-value.

The 95% confidence limits of the k-values were computed to determine the significance of the difference (Cox 1969). The lower confidence limit for the high k-value of 28 remains high at 17 and does not overlap with the high confidence level for the k-value of 6 that is raised to 10. The lower confidence limit for k=6 is 4 (Table 1).

The conclusions drawn from the pilot study were the following. The samples collected from outcrops of the Eocene Oceanic Formation have stable if somewhat weak magnetic properties. The specimens were easily measured and responded smoothly to progressive AF cleaning.

The higher precision parameter k=28 for the beds kept in their present dipping orientation suggests that the rocks were magnetized in this position rather than in a flat lying structure. This needed to be confirmed. The decision to continue the study and analyze the remaining 250 samples wasobvious.

MAIN STUDY

The remaining 250 samples were analyzed with similar methods as the pilot samples. Six sets of strikes and dips made a natural division into six different groups, five from

Gays Cove and one from Bath.

The magnetic directions and remanence intensities were measured for NRM followed by measurements in a progressively stronger peak alternating field at 50, 100, and 200 oersted. The NRM and H200 values were used for the analysis. All samples were normally magnetized. The NRM moment varied between 20×10^{-8} gauss-cm^3 and 1240×10^{-7}gauss-cm^3. After demagnetization at 200 oersted, 25 samples were excluded from the study as their magnetic moments were lower than 35×10^{-8} gauss-cm^3. For the remaining 225 samples the ratio between J_{H200} and J_{nrm} was calculated (Figure 6a). The ratio varied strongly and gave a mean of 48%, which is similar to that of the pilot study. The angular change between the original NRM magnetic direction and the direction for each 200 oersted treated sample was calculated. The larger portion of the samples have angular changes smaller than 10^o (Figure 6b). As in the pilot studya high remanence intensity generally was associated with a small angular change.

From the magnetic directions the mean inclination and declination was calculated for each site, along with the precision parameter k and the circle of 95% confidence α_{95}. (Table 2).

The Gays Cove sites all show similar trends of magnetic directions clustering near each other (Figure 7a-e). At Bath the magnetic directions vary greatly (Figure 8). A fold test that will be discussed in the following section was carried out to determine whether the beds were remagnetized before or after folding.

The mean magnetic direction for the Bath samples moved noticeably closer to the Gays Cove mean when the beds were kept in their present dipping structure (Figure 9a,b) This would suggest remagnetization after folding. When the beds are kept in the present structure the mean magnetic direction for Bath falls close to the present day local field, while the Gays Cove samples agree with the Geocentric Axial Dipole Field for a latitude of 13^{o} .

FOLD TEST

The six sets of samples used in the main study came from different limbs of folds in the formation. Mean inclinations and declinations were calculated for a horizontal bedding and for the present dipping structure of the beds. The purpose of this calculation was to determine whether the outcrops were remagnetized before or after folding.

At Gays Cove the prefolding mean magnetic direction was $I=6^{o}$, $D=15^{o}$, with $k=63$, $\alpha_{95}= 10^{o}$. The post folding direction was ; $I=28^{o}$, $D=8^{o}$, with $k=177$ and $\alpha_{95}=6^{o}$

(Table 2, Figures 9 and 10). The 95% confidence limits on the k-values were computed to determine the significance of the different k's (Table 2). The lower limit of confidence for the post folded k was 53. The high limit of confidence for the prefolded k was 126, so the k's do overlap. Statistically it is therefore conceivable that no conclusion of remagnetization before or after folding could be made at the 95% level. However the very high precision parameter for the postfolded mean direction , the closeness to the Geocentric Axial Dipole Field, and the closer mean direction for the Bath samples strongly point towards remagnetization after folding.

SUMMARY

Contrary to our original hope the outcrops of the Eocene Oceanic Formation cannot be used for paleomagnetic stratigraphy. The exposed rocks were all remagnetized after they gained their present position, as inferred by a fold test at Gays Cove and the closeness of the mean magnetic direction at Bath to the present day local field. Table 3 and figure 10 summarize the results of the study.

The cause of the remagnetization is not known. The effect of weathering of the outcrops could be determined by a comparison with drillcores taken inland from the outcrops. The Formation is stratigraphically important enough to consider such a study, as the formation spans a period of time where the marine magnetic anomalies have not been calibrated.

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Figure Captions

1. Crossection of superconducting magnetometer.

2. Compilation of biostratigraphy for Middle and Late Eocene at Gays Cove and Bath. Three versions of magnetic reversals for this period of time (Lohmann 1974, Berggren et.al. 1978, Heirtzler et.al. 1968, La Brecque et.al. 1977, Ness et. al. 1979).

3. Map of Barbados showing the Tertiary formations and the locations where samples for this study were collected.

4a. Median destructive field for 22 pilot samples.

4b. Ratio of remaining remanence intensity after treatment at 200 oersted to the original NRM intensity for 18 pilot samples.

4c. Angular difference between magnetic directions for NRM and 200 oersted treated pilot samples.

5a,b,c. Magnetic directions and α_{95} for; a. NRM where the present bedding was kept. b. H200 for present bedding. c. H200 for horizontal bedding.

6a. Ratio of remaining remanence intensity after treatment at 200 oersted to the original NRM intensity for 225 samples in the main study.

6b. Angular difference between magnetic directions for NRM and 200 oersted treated samples, main study.

7a-e. Magnetic directions and α_{95} for the five sites at Gays Cove when the present structure of the beds was kept.

8. Magnetic directions and α_{95} for the Bath samples, present structure of beds.

9a. Mean magnetic directions for all six sites <u>before</u> folding. GADF is an abbreviation for Geocentric Axial Dipole Field. Present represents the present local field on Barbados.

9b. Mean magnetic directions <u>after</u> folding. See 8a.

10. Summary of mean magnetic directions before and after folding.

TABLE 1

PILOT STUDY

	I	D	N	k	α_{95}	k_{low}	k_{high}
NRM, present bedding	36	7	24	11	9	7	17
H200, present bedding	30	10	24	28	7	17	42
H200, horizontal bedding	13	5	24	6	15	4	10

Median Destructive Field ; 177 oersted

Angular change between NRM and H200 ; 12.5o

J_{H200} / J_{NRM} ; 51%

Explanatory caption; I, inclination ; D, declination ; N, number of samples ; k, precision parameter (Fisher 1953) ; α_{95}, circle of 95% confidence (Fisher 1953); k_{low}, lower 95% confidence on k (Cox 1969) ; k_{high}, higher 95% confidence on k (Cox 1969).

TABLE 2

200 oersted treatment

Site	N	Dip direc.	Dip	Prefold I	Prefold D	Postfold I	Postfold D	Ang. diff	J_{H200}/J_{nrm}	k	α_{95}
1	10	30	30	6.5	16.5	35.5	13.4	18	45	15	13
2	48	54	24	10.1	14.8	27.7	9.3	17	40	9	7
3	34	90	30	18.5	21.4	26.6	9.1	10	32	27	5
4	70	45	40	-6.5	10.0	25.7	5.7	10	50	14	5
5	17	71	45	2.2	11.5	22.7	2.0	17	48	5	18
Bath	46	247	40	45.5	-49.5	48.9	-3.7	21	53	4	12

TABLE 3

SUMMARY

	I	D	N	k	α_{95}	k_{low}	k_{high}
Geocentric Axial Dipole Field (Lat. 13°)	25°	0°					
Present Field Epoch 1965-1970	43°	-12°					
Prefolding Mean Gays Cove	6°	15°	5	63	10°	19	126
Postfolding Mean Gays Cove	28°	8°	5	177	6°	53	354
Prefolding Mean Bath	45°	-49°					
Postfolding Mean Bath	49°	-3°					

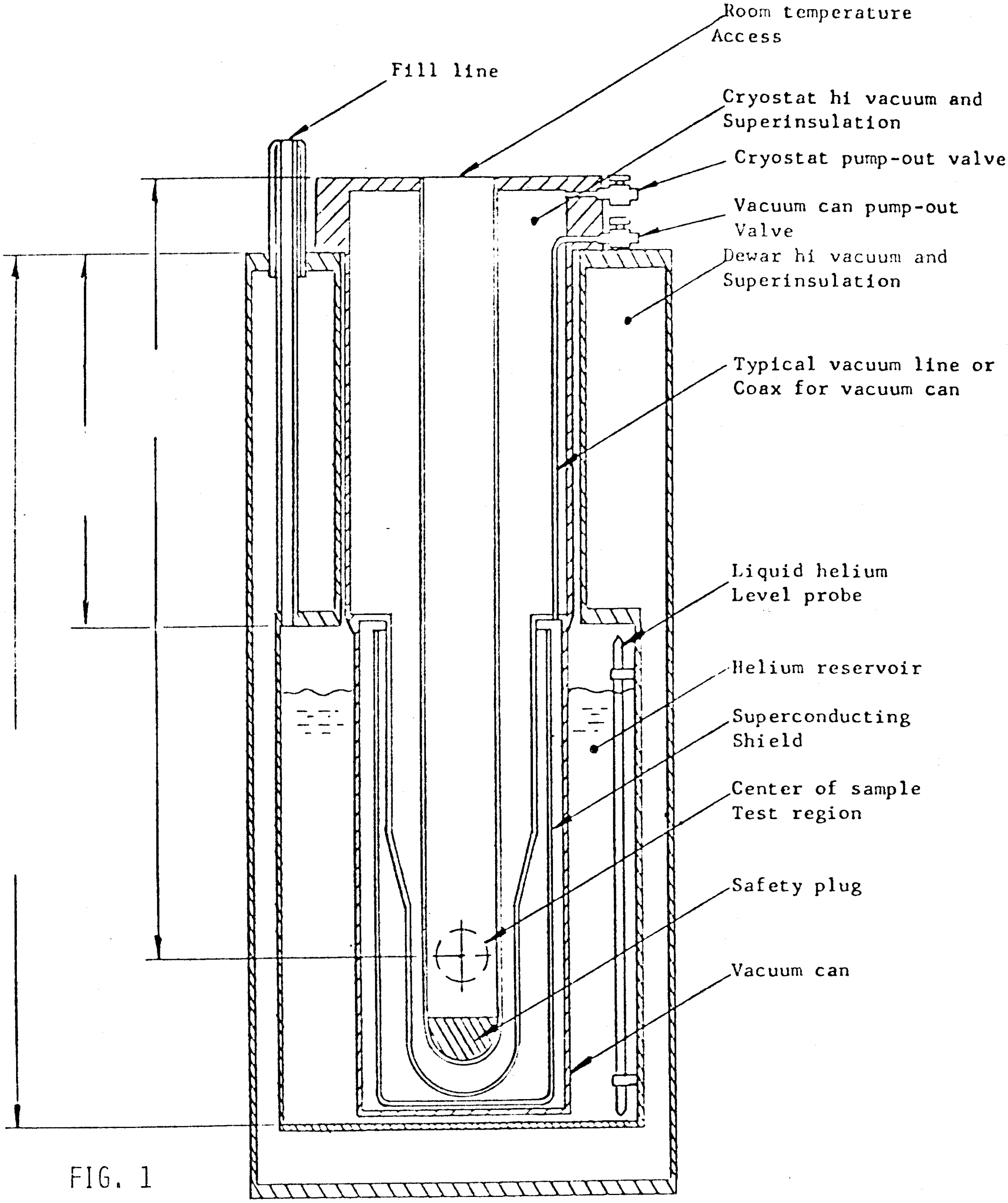

Room temperature
Access
Fill line
Cryostat hi vacuum and
Superinsulation
Cryostat pump-out valve
Vacuum can pump-out
Valve
Dewar hi vacuum and
Superinsulation
Typical vacuum line or
Coax for vacuum can
Liquid helium
Level probe
Helium reservoir
Superconducting
Shield
Center of sample
Test region
Safety plug
Vacuum can

FIG. 1

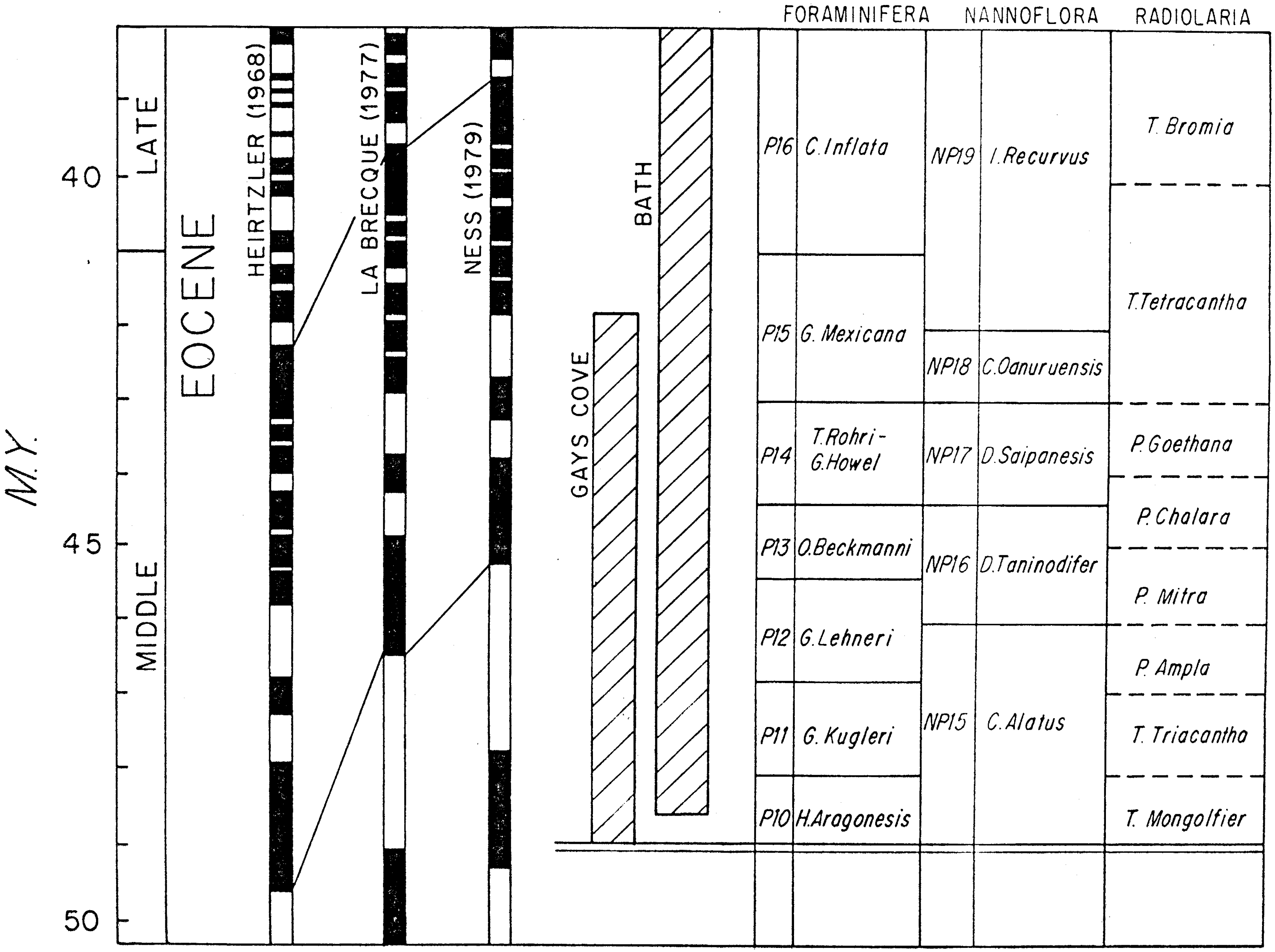

FORAMINIFERA
NANNOFLORA
RADIOLARIA
M.Y.
40
45
50
LATE
MIDDLE
EOCENE
HEIRTZLER (1968)
LA BRECQUE (1977)
NESS (1979)
GAYS COVE
BATH
P16
C. Inflata
P15
G. Mexicana
P14
T. Rohri-
G. Howel
P13
O. Beckmanni
P12
G. Lehneri
P11
G. Kugleri
P10
H. Aragonesis
NP19
I. Recurvus
NP18
C. Oanuruensis
NP17
D. Saipanesis
NP16
D. Taninodifer
NP15
C. Alatus
T. Bromia
T. Tetracantha
P. Goethana
P. Chalara
P. Mitra
P. Ampla
T. Triacantha
T. Mongolfier

FIGURE 2

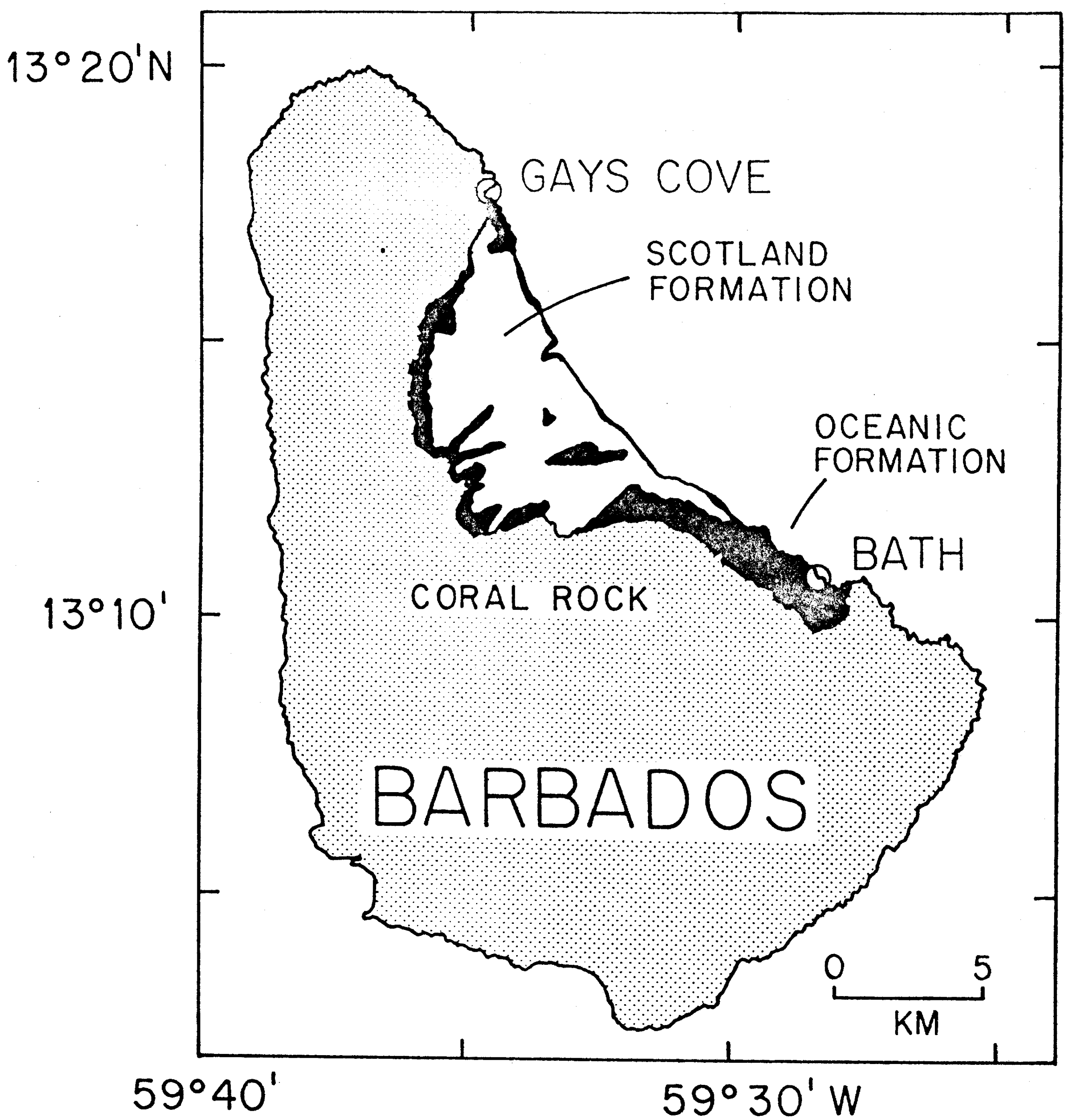

13°20'N
GAYS COVE
SCOTLAND
FORMATION
OCEANIC
FORMATION
BATH
13°10'
CORAL ROCK
BARBADOS
0
5
KM
59°40'
59°30' W

FIGURE 3

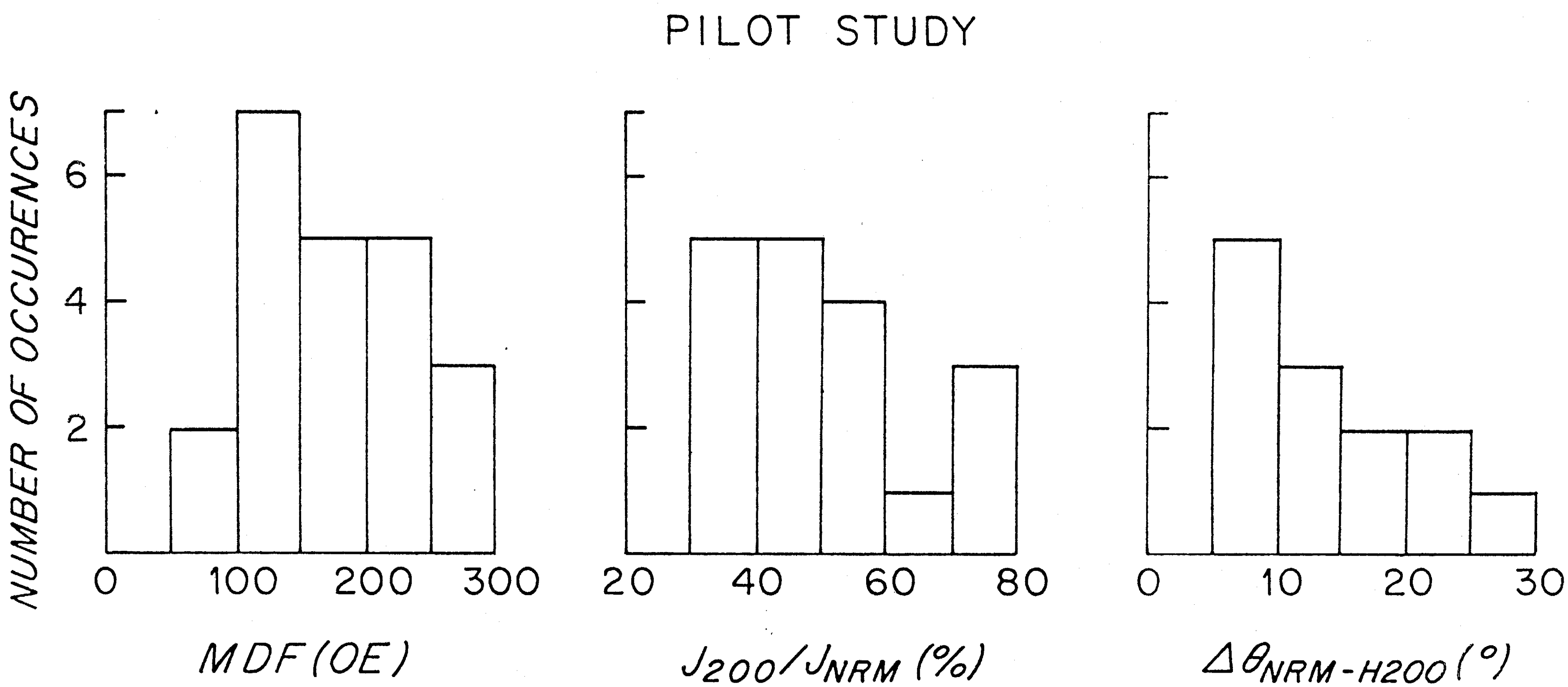
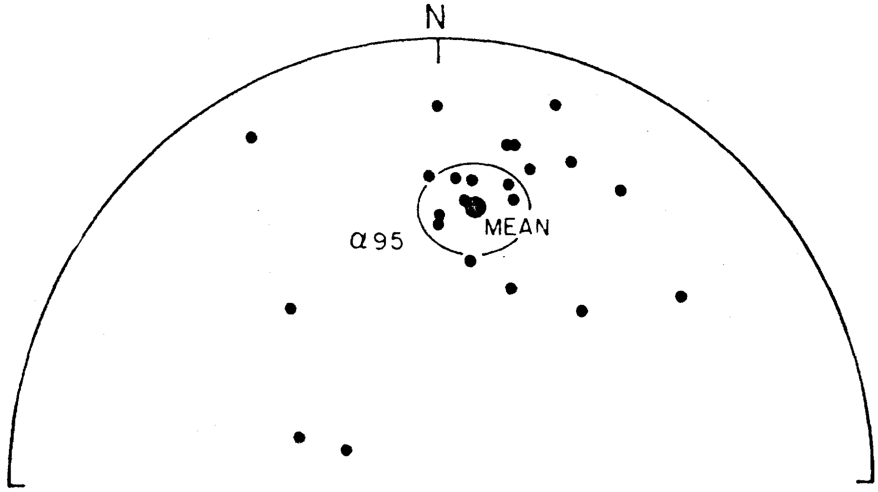
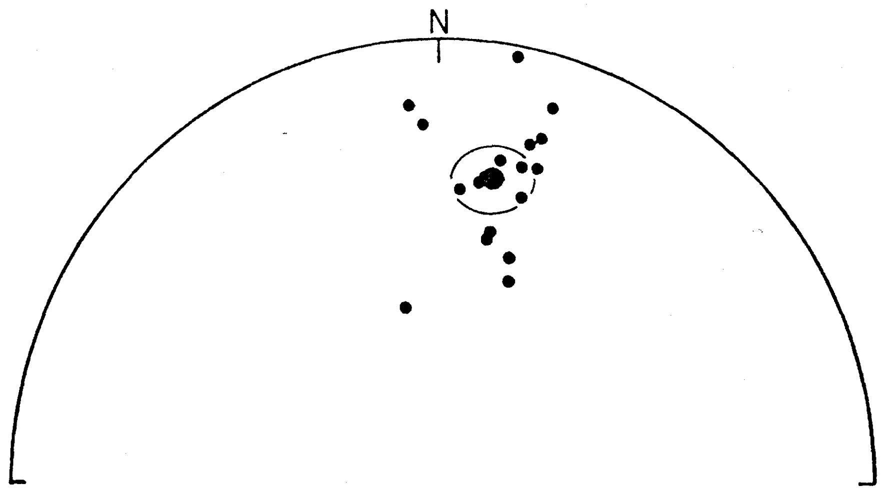

PILOT STUDY
NUMBER OF OCCURENCES
2
4
6
0
100
200
300
MDF (OE)
20
40
60
80
J200/JNRM (%)
0
10
20
30
Δθ NRM-H200 (°)

FIGURE 4

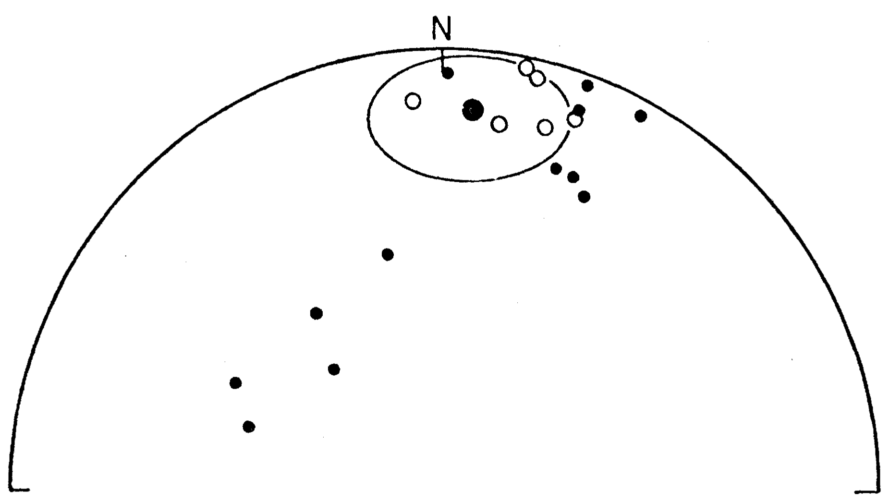
PILOT STUDY



A) NRM PRESENT BEDDING



B) H 200 PRESENT BEDDING



C) H 200 HORIZONAL BEDDING

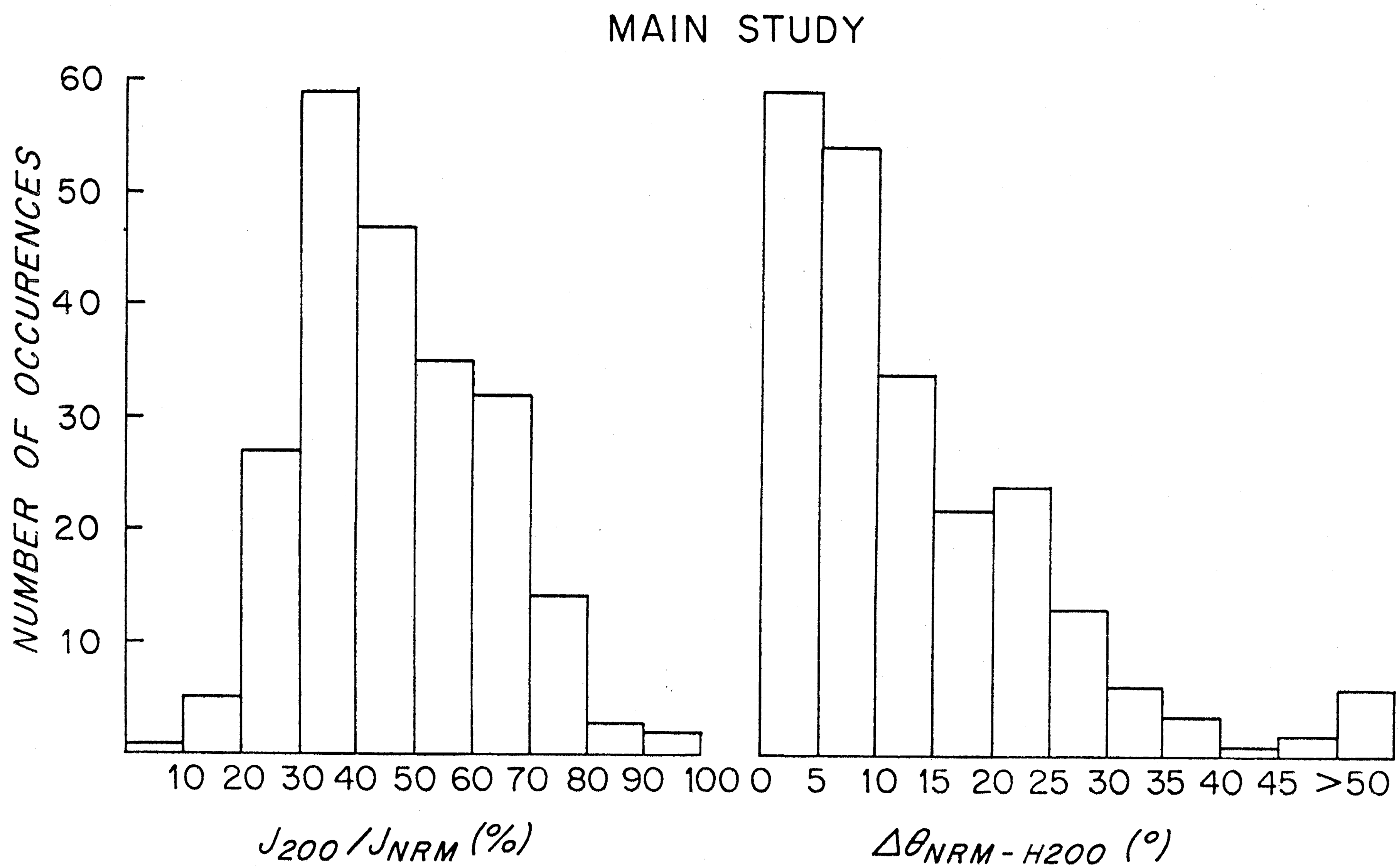

MAIN STUDY
NUMBER OF OCCURENCES
60
50
40
30
20
10
10 20 30 40 50 60 70 80 90 100
J_{200}/J_{NRM} (%)
0 5 10 15 20 25 30 35 40 45 >50
$\Delta\theta_{NRM-H200}$ (°)

FIGURE 6

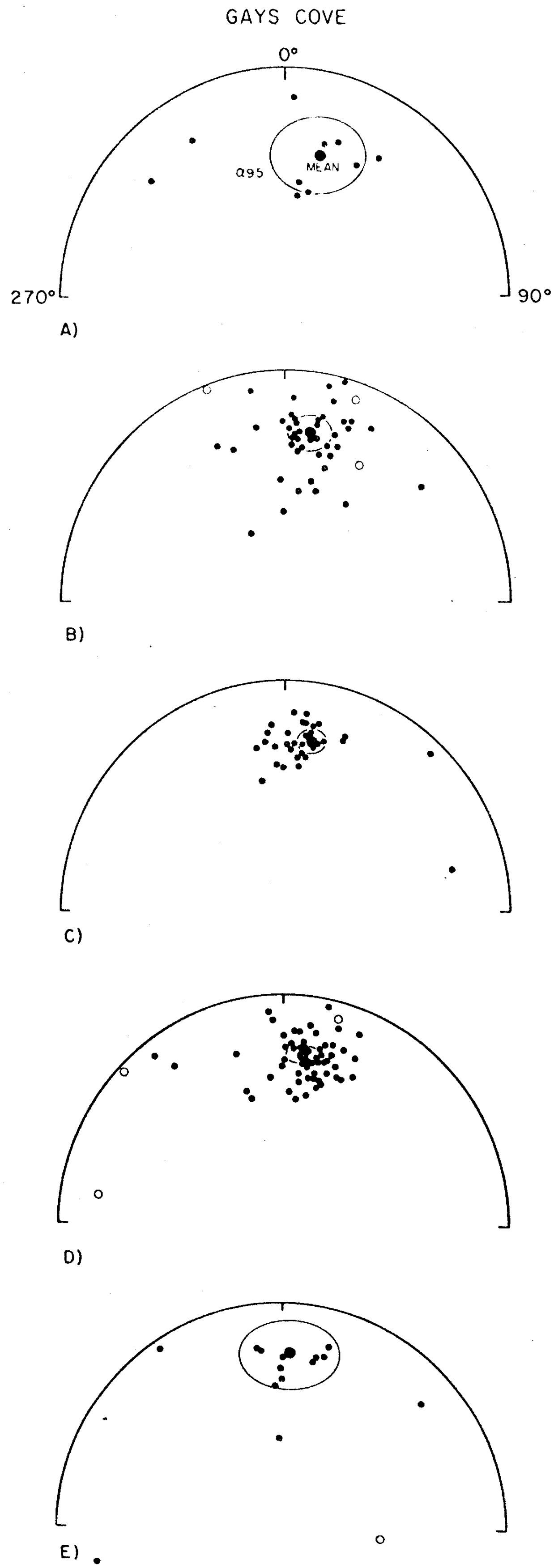


FIGURE 7

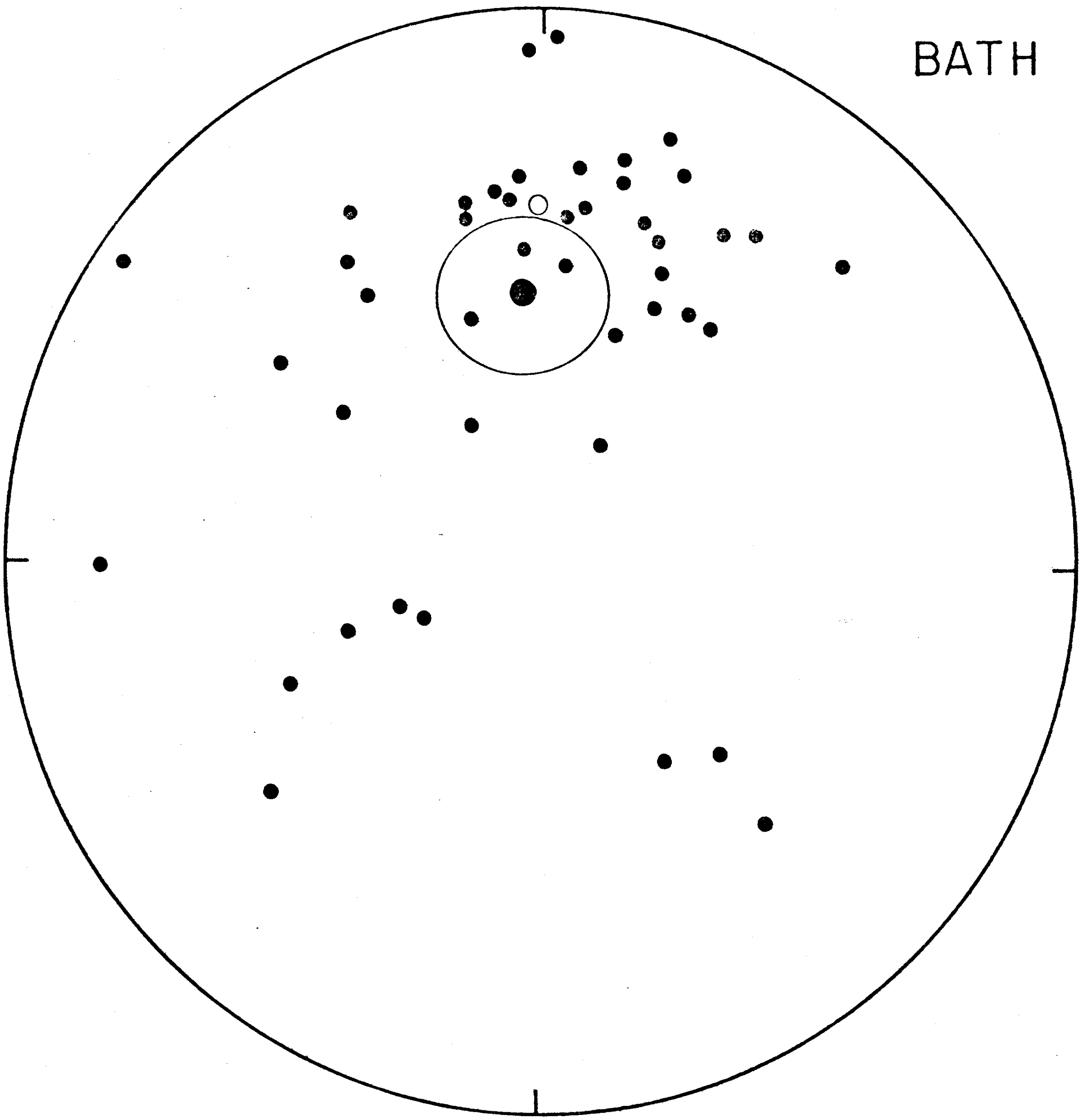


FIGURE 8

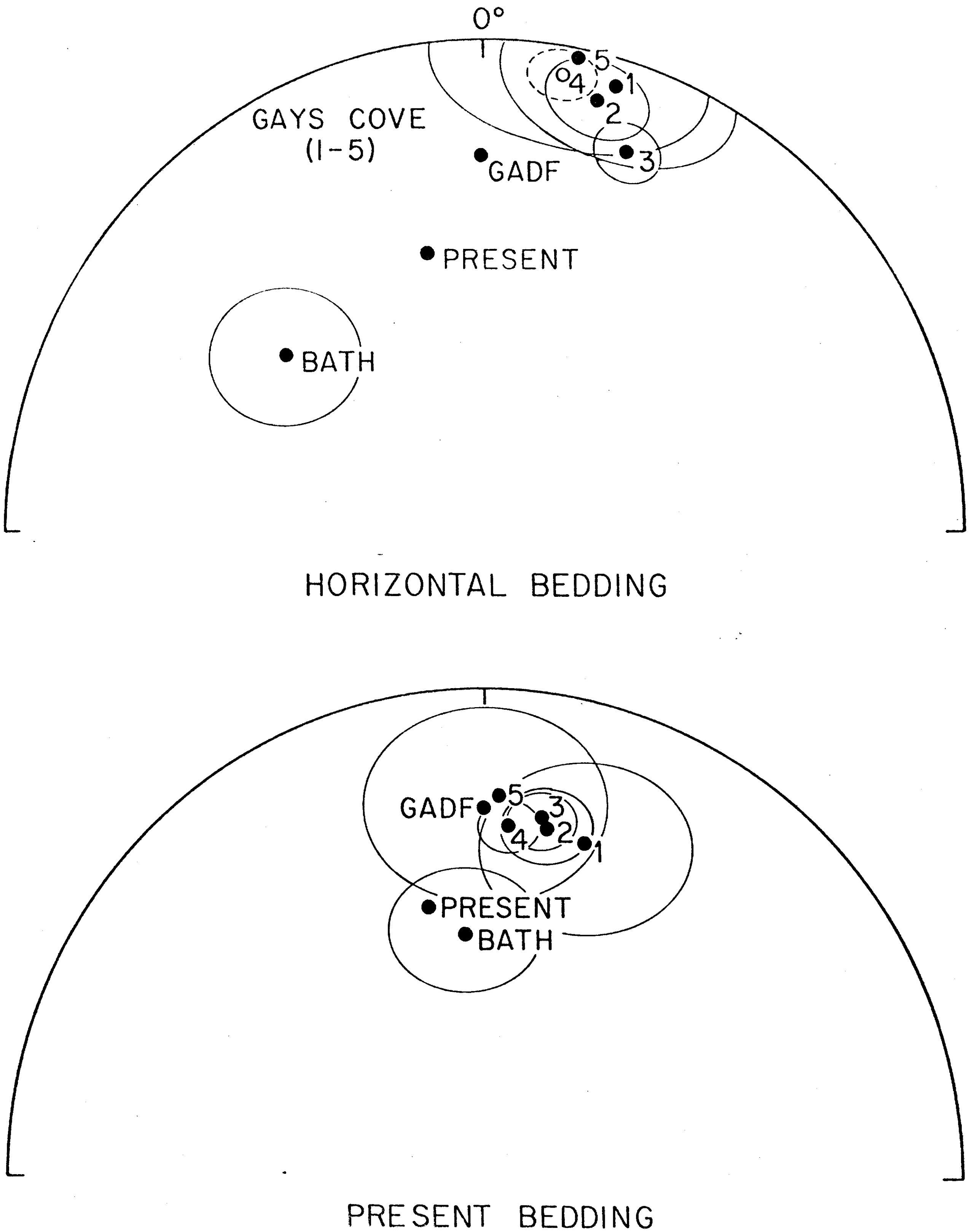

0°
GAYS COVE
(1-5)
5
4
1
2
3
GADF
PRESENT
BATH
HORIZONTAL BEDDING
GADF
5
3
4
2
1
PRESENT
BATH
PRESENT BEDDING

FIGURE 9

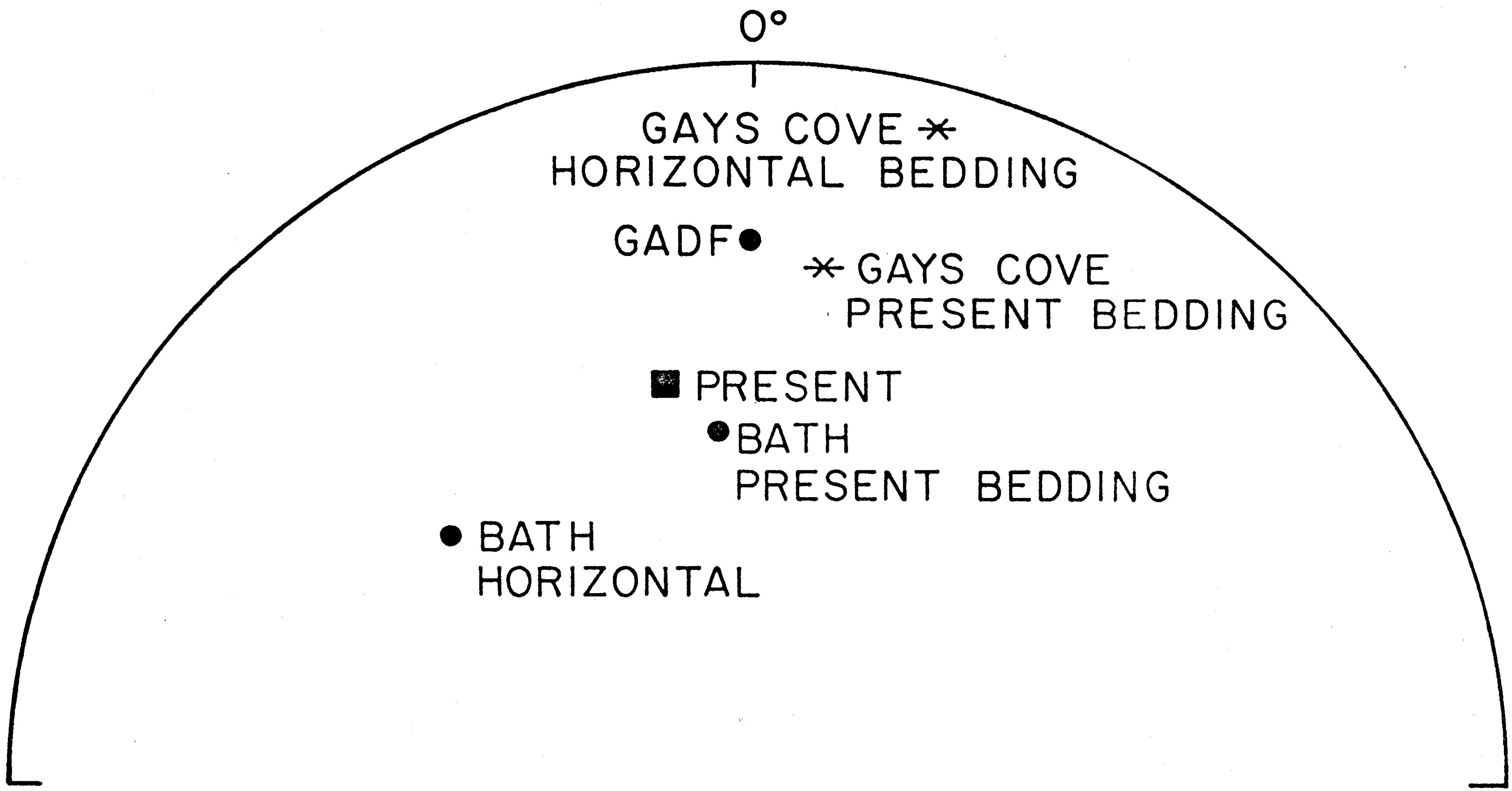

0°
GAYS COVE
HORIZONTAL BEDDING
GADF
GAYS COVE
PRESENT BEDDING
PRESENT
BATH
PRESENT BEDDING
BATH
HORIZONTAL

FIGURE 10