PROCEEDINGS OF THE 10TH SYMPOSIUM ON THE GEOLOGY OF THE BAHAMAS AND OTHER CARBONATE REGIONS

Edited by
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Production Editor:
Dana Bishop

Gerace Research Center
San Salvador, Bahamas
2001

Front Cover: The reef crest indicator species, *Acropora palmata*, on Gaulin's Reef, San Salvador Island. Gaulin's Reef is a classic bank-barrier reef that has shown remarkable resilience following two significant disturbances: El Niño-induced warming of the sea surface in 1998 and Hurricane Floyd in September, 1999 (see Peckol et al., this volume). Photo by Janet Lauroesch.

Back Cover: The oolite shoals of Joulter's Cay, north of Andros Island, Bahamas, site of the pre-meeting field trip. Photo by Ben Greenstein.

ISBN 0-935909-69-9

PALEOMAGNETIC DIRECTIONS FROM EPIKARST PITS AT BARKERS POINT AND ROCKY POINT SAN SALVADOR ISLAND, BAHAMAS

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ABSTRACT

Previous studies have provided evidence for two distinct paleomagnetic directions at Barkers Point. These directions were obtained from paleosol filled dissolution epikarst pits overlying Pleistocene dune deposits. Multiple directions obtained from these epikarst pits is somewhat surprising, given that horizontally layered paleosols typically yield well-behaved single magnetotype directions.

New samples were collected from Barkers Point and from similar geologic relationships at Rocky Point, in order to investigate further the occurrence of multiple directions from epikarst paleosols. Paleomagnetic directions from two pits at Rocky Point are in agreement with the Fernandez Bay magnetotype, suggesting that the exposure surface post-dates Grotto Beach Formation rocks. Samples from an additional epikarst pit on Barkers Point also yield a Fernandez Bay signature. As both Gaulin Cay and Sandy Point Pits magnetotypes have been previously reported, all three stratigraphic magnetotypes have been observed at this locality. This confirms the diachronous nature of at least some epikarst pit paleosols. Caution should be exercised when interpreting paleomagnetic results from dissolution pit fillings; the underlying rocks can only be said to pre-date the oldest magnetotype.

INTRODUCTION

Paleomagnetic signatures of paleosols on San Salvador Island, Bahamas appear to be an effective technique for discriminating between the paleosols lying above and below the Grotto Beach Formation, where conclusive field relations are absent. Conglomerate tests ensure that the paleomagnetic remanence dates to the origin of the rock (Kirkova, 1994; Panuska et al., 1995). Consistency of directions over distances of 500 meters has been established (Kirkova, 1994). Moreover, the technique has correctly delineated a subtle transition zone between two stratigraphic units, a result corroborated by petrographic data (Panuska et al., 1997). However, a routine sampling of paleosols at Barkers Point yielded some unexpected results (Panuska et al., 1999).

Paleosols exposed at Barkers Point occur as isolated infillings of epikarst pits rather than the more typical laterally extensive paleosol layers. The work of Panuska et al. (1999) has demonstrated two statistically distinct mean paleomagnetic directions. One of these directions is correlated with the Gaulin Cay magnetotype; the other direction has been observed at only two additional localities and has been provisionally termed the Sandy Point Pits magnetotype direction. The recognition of two distinct magnetotypes in epikarst pit paleosols raises serious concerns about the interpretation of data from such settings. The purpose of this study is to extend the sampling at Barkers Point and to sample similar paleosols at Rocky Point in order to evaluate the reliability of correlations made from epikarst pit data.

SAMPLING AND DATA ACQUISITION

Barkers Point

Barkers Point is a small headland, measuring about 20 m by 30 m, on the northwest coast of San Salvador Island. Two paleosol filled epikarst pits were sampled and a total of 15 specimens were analyzed. Paleomagnetic remanence was measured using a Schonstedt SSM-1A spinner magnetometer. Samples were subjected to alternating field (AF) demagnetization in order to clean off the effects of secondary magnetic components. AF demagnetization intensities were increased in 25 Oersted (Oe) increments, with remanence being measured after each cleaning treatment. Characteristic magnetic directions were identified on the basis of observing a decrease of paleomagnetic intensity over several cleaning steps with little or no change in direction.

Eight samples from pocket 4 at Barkers Point were analyzed. Three samples failed to clean to a stable endpoint directions and could not be used in calculation of a mean. The remaining samples responded well to AF cleaning, with secondary components being removed by treatment to 75-100 Oe.

NRM Sample	Geographic Demag	%NRM	Intensity	Dec	Inc
3A	125	41	3.5E-6	351	43
4A	150	46	9.0E-7	350	45
5A	150	32	1.3E-6	360	45
7A	125	24	1.4E-6	349	41
9A	175	17	1.1E-6	359	39
				354	43

$k = 301.5$ $A_{95} = 4.4°$
$R = 4.987$ $N = 5$

Table 1. Paleomagnetic data from Barkers Point Pocket 4. k is the Fisher precision parameter, A_{95} is the 95% statistical confidence limit and N is the number of samples.

These samples yielded a mean direction of 354° declination, 43° inclination (k=301.5, A_{95}=9.9°, N=5) (Table 1). All 7 of the samples collected at Barkers Point Pocket 5 did not yield stable endpoint directions. Panuska et al. (1999) also reported one epikarst pit failing to produce usable data; thus, 2 of 5 pits did not generate interpretable directions.

Rocky Point

Rocky Point is also a rocky headland located about 2 km southwest of Barkers Point. Paleosols at this locality also occur as epikarst pit infillings. Four paleosol pockets were sampled, with 6 to 12 samples collected from each pocket.

NRM Sample	Geographic Demag	%NRM	Intensity	Dec	Inc
24A	125	16	2.4E-6	340	59
27A	150	15	2.4E-6	349	52
30A	125	22	2.6E-6	343	44
33A	150	7	1.2E-6	317	62
				339	55

$k = 53.9$ $A_{95} = 12.6°$
$R = 3.944$ $N = 4$

Table 2. Paleomagnetic data from Rocky Point Pocket 1. k is the Fisher precision parameter, A_{95} is the 95% statistical confidence limit and N is the number of samples.

Pocket 1 produced a mean direction of 339° declination, 55°o inclination (k=53.9, A_{95}=12.6°, N=4) (Table 2). Fully half of the samples collected from this pocket could not be cleaned to stable endpoints. At Pocket 2, only 6 samples could be drilled. Two samples were extremely weak and reproducible measurements could not be obtained. The remaining samples yielded characteristic directions between 125 and 200 Oe and a mean of 1° declination, 40° inclination (k=184.6, A_{95}=6.8°, N=4) (Table 3).

NRM Sample	Geographic Demag	%NRM	Intensity	Dec	Inc
37A	200	25	1.6E-6	0	33
38A	125	35	9.9E-7	3	42
39A	125	49	5.6E-7	357	46
40A	150	43	8.2E-7	4	39
				1	40

k = 184.6 A_{95} = 6.8°
R = 3.984 N = 4

Table 3. Paleomagnetic data from Rocky Point Pocket 2. k is the Fisher precision parameter, A_{95} is the 95% statistical confidence limit and N is the number of samples.

At Pocket 3, 13 samples were collected. Seven of the specimens were demagnetized to 150 Oe peak AF fields, with no signs of nearing a stable direction endpoint. Given the viscous behavior of the samples and the long time required for measurements, analyzing the remaining specimens was considered pointless. No usable data were obtained from this pocket.

NRM Sample	Geographic Demag	%NRM	Intensity	Dec	Inc
54A	175	24	1.1E-6	343	46
55A	150	23	1.5E-6	352	43
56A	150	33	3.0E-6	346	35
57A	150	19	2.0E-6	352	43
59A	125	18	1.6E-6	348	47
60A	75	43	1.3E-6	1	44
63A	150	22	2.6E-6	358	44
64A	175	24	2.8E-6	0	41
				352	43

k = 174.8 A_{95} = 4.2°
R = 7.960 N = 8

Table 4. Paleomagnetic data from Rocky Point Pocket 4. k is the Fisher precision parameter, A_{95} is the 95% statistical confidence limit and N is the number of samples.

Pocket 4 had 8 samples cleaning to good demagnetization endpoints, at AF intensities of 150-200 Oe (4 samples did not clean properly). The mean direction is 352° declination, 43° inclination (k=174.8, A_{95}=4.2°, N=8) (Table 4).

DISCUSSION

Barkers Point

The new mean directions were compared to the established magnetotype directions using the statistical method of McFadden and Lowes (1981). The Barkers Point mean is found to be similar to the Fernandez Bay magnetotype but different from the Gaulin Cay and Sandy Point Pits magnetotypes at 95% confidence. In addition, a previous study (Panuska et al., 1999) indicates the presence of epikarst pits giving Gaulin Cay and Sandy Point Pits magnetotype directions (Figure 1).

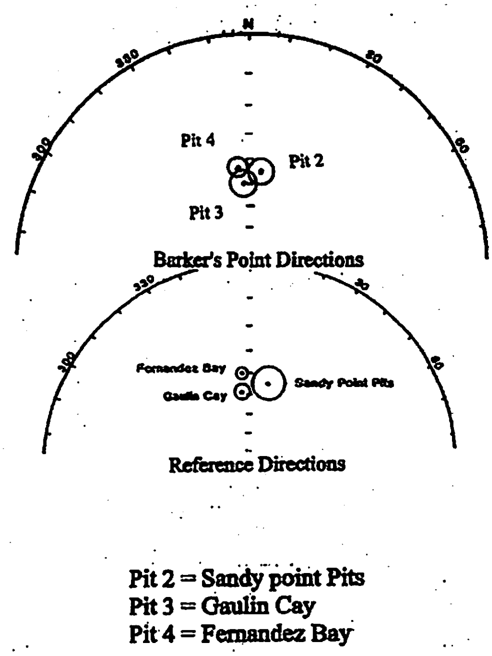


Figure 1. Paleomagnetic directions from Barkers Point paleosol filled epikarst pits. Each of the paleosol pit paleomagnetic directions correlates with a different magnetotype reference direction. Thus, all three magnetozones are represented at a single outcrop.

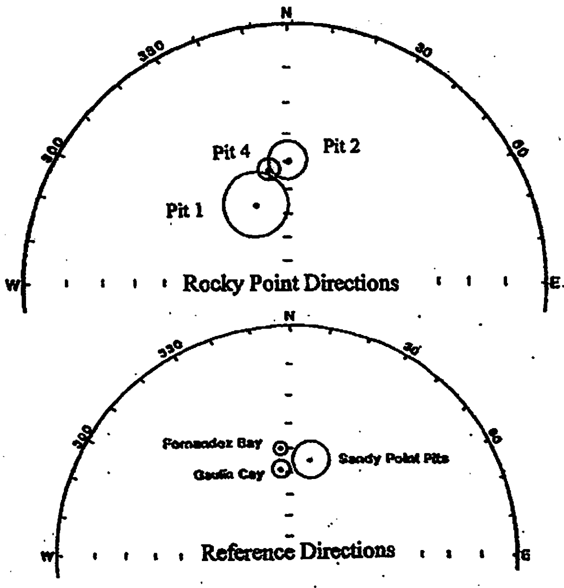
Panuska et al. (1999) suggested the diachronous nature of epikarst paleosol at

Barkers Point based on the occurrence of the two pre-Grotto Beach Formation paleosols (Gaulin Cay and Sandy Point Pits magnetotypes). The observation of a Fernandez Bay paleomagnetic signature at this locality is somewhat unexpected. Given that Barkers Point lies no more than 2 meters above sea level, this implies two periods of paleosol formation on Owls Hole rock, followed by the 5e sea level high stand depositing Grotto Beach marine sediments to elevations of +4 m (Carew and Mylroie, 1995), followed by resumed epikarst pit formation and paleosol accumulation. The survival of early formed epikarst pits is not surprising in view of their very tightly cemented, resistant nature; however, the occurrence of all three magnetotypes at the same horizon without any evidence of intervening Grotto Beach rock is perplexing.

Perhaps the proximity to the platform edge allowed relatively uncemented Grotto Beach sediment to be eroded during marine regression. The resistant nature of the previous paleosols could have allowed survival of the previous epikarst pits until subaerial dissolution and paleosol accumulation could be reestablished. Nevertheless, it is not clear why epikarst dissolution and paleosol accumulation would occur at the same position after this sea level high stand.

Rocky Point

Of the 3 Rocky Point mean directions only Pocket 4 gave unequivocal results. This mean direction is found to be similar to the Fernandez Bay magnetotype and different from both the Gaulin Cay and Sandy Point Pits types. Pocket 2 is also similar to the Fernandez Bay reference direction and different from the Gaulin Cay direction. However, it is found to be similar to the Owls Hole paleosol, type locality for the Sandy Point Pits magnetotype (Figure 2). It should be noted that Pocket 2 is different from the other paleosols correlated with the Sandy Point Pits.



Pit 1 = the Thumb
Pit 2 = Fernandez Bay and Sandy Point Pits
Pit 4 = Fernandez Bay

Figure 2. Paleomagnetic directions from paleosol filled epikarst pits at Rocky Point. Pit 4 correlates with the Fernandez Bay magnetotype and is statistically different from other magnetotypes. Although similar to directions obtained from The Thumb, the Pit 1 correlation is suspect due to low number of samples. Pit 2 is statistically similar to both the Fernandez Bay and Sandy Point Pits magnetotypes; however, the Sandy Point Pits similarity is considered to be an artifact of low number of samples. See text for discussion.

The correlation of Pocket 2 with two type directions might be the result of a low number of samples (N=4). Also the unusually low kappa value (k=50.0) of the Owls Hole direction may also play a role, in as much as this relatively low clustering tends to favor positive correlations. Although the other Sandy Point Pits directions are closer to the Pocket 2 mean direction, their lower dispersions allow the statistic to show them as different. It seems likely that the correlation of

Pocket 2 and the Owls Hole is a false positive and that the true directional affinity of Pocket 2 is with Fernandez Bay, a conclusion supported by numerical simulations for pockets 1 and 2 discussed below. Given this interpretation, it might be necessary to reconsider the provisional assignment of the Owls Hole direction as the magnetotype.

Rocky Point Pocket 1 proved to be dissimilar to all three of the magnetotypes. It was however, found to be similar to the direction from The Thumb (Panuska et al., 1991). The Thumb direction has not been observed anywhere else on San Salvador Island and the correlation with Pocket 1 could be the result of low numbers of samples (N=4 for Pocket 1, N=5 for The Thumb) and low kappa values (k=53.9 for Pocket 1, k=52.4 for The Thumb). Given the uncertainties in the data sets, it is best not to hazard a correlation of Pocket 1.

The problems related to the correlations of Pockets 1 and 2 have prompted an investigation of the relationship of N, the number of samples, to the findings of similarity or difference between mean directions (Obid, 2000). The Fisher precision parameter, k (kappa), is a measure of directional dispersion and whose value is independent of N. In contrast, the circle of 95% confidence is N dependent, with uncertainty of the mean being better constrained at high values of N. Mean directions based on a small sample (N) have large error limits and statistical inference can lead to a finding of similarity simply because error limits are large.

Obid (2000) conducted some numerical experiments by holding the kappa value (k) for Rocky Point Pocket 2 fixed, varying the value of N and then recalculating the McFadden and Lowes (1981) test of similarity. The results of this experiment show that, although the actual data set (N=4) is similar to the Sandy Point Pits direction, increasing the sample size to N=6 causes a statistical dissimilarity between Rocky Point 2 and Sandy Point Pits.

This strongly suggests that the initial finding that Rocky Point 2 is similar to both the Fernandez Bay and Sandy Point Pits directions is erroneous. Although more samples from this pocket would provide the strongest evidence, the numerical experiments strongly suggest that the correlation with Sandy Point Pits is most likely a false positive. Thus, Rocky Point 2 can clearly be assigned to the Fernandez Bay magnetotype. Moreover, any attempt to correlate Rocky Point 1 with any reference direction is not warranted by the small sample size (N=4). The data at Rocky Point show 2 paleosol pockets correlating with Fernandez Bay directions and two pockets giving unstable directions or inconclusive data. At face value, the rocks below the paleosol pockets at Rocky Point probably belong to the Grotto Beach Formation. However, in view of the results at Barker Point and that only two usable mean directions from epikarst pit paleosols have been obtained at Rocky Point, the Grotto Beach stratigraphic correlation must regarded as tentative.

CONCLUSIONS

Paleosol samples were collected at Barkers Point and Rocky Point on San Salvador Island, Bahamas, in order to confirm the diachronous nature epikarst pits paleosols suggested by Panuska et al. (1999). New paleomagnetic directions from an epikarst pit paleosol at Barkers Point correlate with the Fernandez Bay type direction. These data coupled with the previous finding of both Gaulin Cay and Sandy Point Pits magnetotypes indicate that all three paleosol markers can occur in one outcrop, which can easily be mapped as a single paleosol unit. Although stratigraphically distinct paleosols have been shown to merge at the edges of patchy eolian packages (Carew and Mylroie, 1995), this is the first evidence for as many as three paleosols occurring a one stratigraphic level.

The occurrence of multiple paleosol magnetozones at one locality suggests that caution should be exercised when interpreting epikarst pit paleosols. However, a similar geologic setting at Rocky Point shows only a single paleosol magnetotype. It is not known whether Barkers Point is anomalous in recording three magnetotypes or if sampling failed to detect an additional paleomagnetic signature of paleosol filled epikarst pits at Rocky Point.

ACKNOWLEDGEMENTS

We would like to thank the Bahamian Field Station and its staff for logistic and financial support of this project. Thanks also go to the Bahamian Government for granting research permits for this work. J. Obid received generous support from the Bahamian Field Program Scholarship. Finally we thank Drs. Ben Greenstein and Cindy Carney for thoughtful review of the manuscript.

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