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Front Cover: Lee-side exposure of a fossil parabolic dune viewed from the Grahams Harbour side (west) of North Point, San Salvador, Bahamas. These Holocene carbonate eolianites have been assigned to the North Point Member of the Rice Bay Formation (Carew and Mylroie, 1995). The eolian cross-stratification dips below present sea level, proving that late Holocene sea-level rise is real. Top of the dune is about 7 meters above the sea surface. Photo by Al Curran.

Back Cover: Dr. Noel P. James of Queen's University, Kingston, Ontario, Canada, keynote speaker for this symposium. Noel is holding a carving of a tropical fish created by a local artist and presented to him at the end of the symposium. Photo by Al Curran.

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PALEOMAGNETIC EVIDENCE FOR THREE PLEISTOCENE PALEOSOLS ON SAN SALVADOR ISLAND, BAHAMAS

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ABSTRACT

Paleomagnetic signatures of paleosols on San Salvador Island appear to provide a useful stratigraphic correlation criterion. New data from Barkers Point suggest that the paleosol at this locality is a composite of two separate directions. One direction correlates with the Gaulin Cay magnetotype, while the mean direction produced from a separate pocket of paleosol at the same locality is in agreement with directions obtained from the paleosol in the Owl's Hole pit cave. This is the first correlation that has been observed with the Owl's Hole data. Moreover, data from Moon Rock Pond appear to corroborate the validity of this new stratigraphic marker, which we provisionally term the Sandy Point Pits magnetotype.

Data from a new paleomagnetic sample locality at Crab Cay suggests that these rocks are part of the Owl's Hole Formation. Unfortunately, the most reasonable interpretation of the local field relationships suggests that those rocks correlate with the Grotto Beach Formation. Work is in progress to resolve this apparent contradiction.

INTRODUCTION

Over the past few years, we have been evaluating paleomagnetic directions from paleosols on San Salvador Island as stratigraphic correlation criteria. Following initial pilot studies (Hudson & Panuska, 1990; Panuska et al., 1991), we have established the stability of magnetization (Kirkova, 1994; Panuska et al., 1995a) and proposed two magnetotypes, which appear to allow the recognition of pre- and post-Grotto Beach Formation (Pleistocene) paleosols. Following this promising work, we have been expanding the sampling coverage to assess the geographic distribution of the magnetotypes and perhaps gain some insights into the details of the stratigraphic architecture of the island.

As a result of this effort, we have discovered evidence for the composite nature of some paleosol localities. Additionally, paleomagnetic directions have been obtained which correlate with a mean direction previously reported and largely disregarded as an isolated anomaly. This paper discusses the new data and outlines the evidence for a third magnetotype of pre-Grotto Beach age.

GEOLOGIC SETTING

The stratigraphy of San Salvador Island consists of 3 formations (Carew & Mylroie, 1995). The oldest unit is the Owl's Hole Formation, which is a Pleistocene peloidal/bioclastic eolianite. This eolianite unit most likely represents more than one sea level highstand (e.g. oxygen isotope stage 7, 9, 11). Overlying the Owl's Hole is the Grotto Beach Formation.

Grotto Beach rocks are commonly ooid rich and include a variety of depositional settings: beach, subtidal, coral reef, and subaerial dunes. U/Th geochronology of corals has yielded a variety of ages that center on approximately 125 Ka and correlate with the oxygen isotope 5e sea level highstand (Chen et al., 1991). Both transgressive and regressive phases of Grotto Beach strata are recognized.

Overlying the Grotto Beach Formation is the Rice Bay Formation. Both beach and dune facies rocks composed of poorly-cemented peloidal/bioclastic grains are present. The formation is entirely of Holocene age, as demonstrated by ^{14}C dating (Carew & Mylroie, 1985, 1987).

Boundaries between these units are often marked by prominent paleosols. No more than two paleosols can be identified in any one exposure on the island. Although early mineralogic work has suggested as many as 5 paleosols (McCartney & Boardman, 1986), more recent studies (Boardman et al., 1995) indicate that paleosol variety is a function of local environmental conditions and thus paleosol mineralogy has no implication as a stratigraphic marker.

The Holocene Rice Bay rocks are easily distinguished from the Pleistocene units based on induration. Subaerial dune facies of the Grotto Beach Formation and the Owl's Hole rocks are difficult to distinguish in the absence of contiguous stratigraphic relationships. While the occurrence of significant ooids usually implies Grotto Beach affinities, assignment of rocks without obvious ooids can be problematic. However, correlation of paleosols with paleomagnetic magnetotypes appear to be useful in identifying paleosols as being deposited above or below the Grotto Beach Formation (Panuska et al., 1995b): respectively termed the Fernandez Bay and Gaulin Cay magnetotypes.

PALEOMAGNETIC DATA

In order to provide more constraints on the nature of the island's stratigraphy, paleomagnetic samples were collected from three new localities. These include two coastal outcrop exposures at Barkers Point and Crab Cay and one locality at Moon Rock Pond, an interior saline lake. All samples were measured on a Schonstedt SSM-1A spinner magnetometer. In order to remove secondary components of magnetization, samples were cleaned in 25 Oe (Oersted) increments using a Molespin Shielded Alternating Field Demagnetizer.

The outcrop at Barkers Point consists of Pleistocene eolianite facies, with abundant phyto-ichnomorphs (using the terminology of White & Curran, 1998). Paleosol occurs discontinuously as well-lithified accumulations in epikarst dissolution pits. Four to six samples were collected from each of three dissolution pits.

Samples collected from paleosol Pocket 1 failed to clean up to stable vectors decaying towards the origin. Three of the six samples drilled showed demagnetization trends towards the east with no evidence of resolving a characteristic direction at peak AF fields of up to 175 Oe. Because of the poor demagnetization behavior, it was considered pointless to analyze the remaining samples from this pocket.

In contrast, the samples from Pockets 2 and 3 generally showed well-behaved straight-line decay towards the origin with little deviation and only rare secondary components. Most secondary components were removed by AF cleaning to 75 Oersteds or less. Two specimens cut from the same sample, from Pocket 3, did not yield a characteristic direction; these specimens displayed the same easterly demagnetization trend described for the samples in Pocket 1.

The mean characteristic direction for Pocket 2 is 7° declination, 45° inclination (k=301, A95= 4.4°, Table 1), while the direction for Pocket 3 is 356° declination, 50° inclination (k=224, A95= 6.1°). Despite the fact that these directions were obtained from paleosols formed on top of the same unit and about 6 meters apart, the directions are distinctly different. Each data set is internally consistent and has small circles of 95% confidence.

It should also be noted that 3 of the 5 samples from Pocket 2 appear to display an additional component of magnetization (termed Component B). This component is resolved at AF demagnetizations of 75 - 100 Oe and is inferred by 2 consecutive demagnetization steps

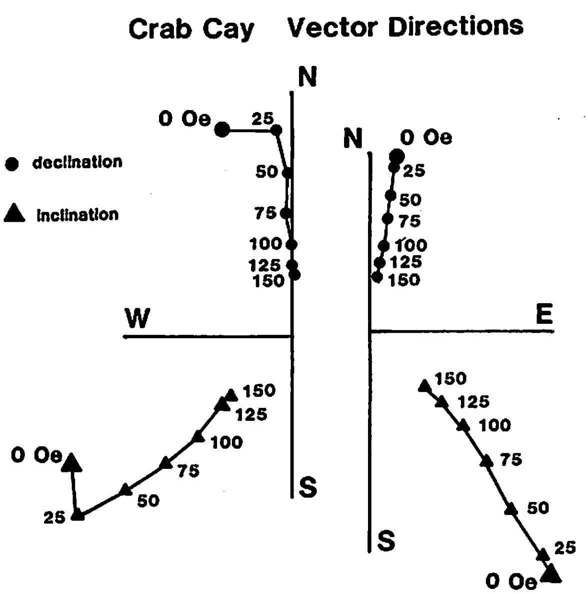

Figure 1. Demagnetization vector plot of sample from Pocket 2. Component B, defined by two points and found in three of five samples, agrees with the mean direction of Pocket 3. The characteristic (highest coercivity) component is used in calculating the mean for Pocket 2. Circles show declination in the north-south, east-west plane. Triangles indicate inclination in the vertical, up-down plane.

defining a trend towards the origin before shifting to the final characteristic component (Figure 1). The mean direction for Component B is 357° declination, 48° inclination. This direction is virtually identical to the direction for Pocket 3. However, it must be emphasized that the two demagnetization steps observed in the three samples could simply be a fortuitous correlation. Nevertheless, if the occurrence of two components of magnetization can be confirmed in other samples from other localities, it could prove to be an additional and useful correlation criterion.

At the second locality, samples were collected from a 2 meter wide dissolution pit on the north side of Crab Cay. This locality consists of phyto-ichnomorph-rich eolianite and is mapped as a regressive Grotto Beach (Cockburn Town Member) deposit (Carew & Mylroie, 1995). Along the southern flank of Crab Cay there is a fossil coral reef, which is correlated with the substage 5e highstand. The eolianite of Crab Cay appears to overly the reef deposits.

The well-laminated, well-cemented, upper portion of the paleosol has rather strong initial (NRM) intensities. Minor secondary components were removed by 50 - 100 Oe AF demagnetization. The mean paleomagnetic direction is 2° declination, 49° inclination (k=260, A95= 4.2°).

At the third locality, an extremely well-indurated, bright red, paleosol was sampled along the north shore of Moon Rock Pond. An eolianite ridge to the north of this locality is mapped as Owl's Hole Formation. Field relationships do not indicate whether the paleosol stratigraphically overlies the dune or projects beneath it.

For the most part, the Moon Rock Pond samples responded well to AF cleaning. Characteristic directions were isolated between 150 and 300 Oe peak field strengths. One sample (64A) failed to clean to a stable demagnetization end point, although the measured directions were in general agreement with the characteristic directions obtained from the other samples.

Barkers Point, Pocket 2 - Paleomagnetic Data

Sample	Demag	%NRM	NRM Intensity	Geographic Dec	Geographic Inc
27A	275	19	1.0E-6	4	46
27B	175	16	8.8E-7	7	46
28A	125	25	1.1E-6	3	45
29A	175	20	9.1E-7	13	38
30A	200	17	9.0E-7	5	48
				7	45

k = 281.6 A95 = 4.6°
R = 4.986 N = 5

Pocket 2 - Component B

Sample	Demag	%NRM	NRM Intensity	Geographic Dec	Geographic Inc
27A	75	50	1.0E-6	357	48
28A	100	32	1.1E-6	356	48
30A	100	33	9.0E-7	359	47
				357	48

k = 4699.5 A95 = 1.8°
R = 3.0 N = 3

Barkers Point Pocket 3 - Paleomagnetic Data

Sample	Demag	%NRM	NRM Intensity	Geographic Dec	Geographic Inc
31A	200	13	2.7E-6	354	45
32A	125	25	1.6E-6	352	47
33A	175	14	2.1E-6	356	55
34A	175	14	1.8E-6	3	51
				356	50

k = 224.2 A95 = 6.1°
R = 3.987 N = 4

Crab Cay - Paleomagnetic Directions

Sample	Demag	%NRM	NRM Intensity	Geographic Dec	Geographic Inc
2A	125	22	8.3E-6	358	51
3A	150	32	1.0E-6	1	45
5B	150	26	6.8E-6	8	47
6B	150	33	2.6E-6	355	47
7B	175	24	1.1E-6	2	51
9B	125	25	5.5E-6	10	54
				2	49

k = 260.4 A95 = 4.2°
R = 5.981 N = 6

Moon Rock Pond - Paleomagnetic Directions

Sample	Demag	%NRM	NRM Intensity	Geographic Dec	Geographic Inc
58A	250	37	3.4E-6	353	46
60A	150	47	4.5E-6	4	45
61A	300	31	5.6E-6	2	41
62A	200	54	2.6E-6	7	45
63A	150	40	3.5E-6	4	44
				2	44

k = 366.0 A95 = 4.0°
R = 4.989 N = 5

Another sample (59A), gave southerly, negative directions but did not yield a clear endpoint direction and was an order of magnitude weaker than its companion samples. This is most likely a magnetically unstable sample and was not considered further. The mean direction is 2° declination, 44° inclination (k=366, A95= 4.0°).

DISCUSSION

The Barkers Point data are somewhat unexpected as the two pockets yielding well-defined characteristic directions were different from one another. Pocket 3 is statistically the same as the Gaulin Cay magnetotype and is different from the Fernandez Bay magnetotype (using the test of McFadden & Lowes, 1981). This suggests that the eolianite at this locality belongs to the Owls Hole Formation. The data for Pocket 2, from the same geologic context, are different from both Pocket 3 and the Gaulin Cay and Fernandez Bay magnetotype reference directions (Figure 2).

During the initial paleomagnetic studies of San Salvador Island, Panuska et al. (1991) reported a direction of 13° declination, 44° inclination for the paleosol overlying the Owl's Hole Formation, at the type locality in the Owl's Hole pit cave. This direction was not reproduced in subsequent studies at other locations and was considered anomalous. The Pocket 2 mean direction is statistically the same as that Owl's Hole direction, suggesting that both Pocket 2 and the Owl's Hole means are stratigraphically valid correlation criteria. Moreover, the Moon Rock Pond mean direction is statistically similar to the Owl's Hole and Pocket 2 directions but different from the Gaulin Cay and Fernandez Bay type directions (Figure 3). This lends very strong support to the concept of a second pre-Grotto Beach Formation paleosol, that is, two separate paleosols that occur above and/or within the Owl's Hole Formation.

We tentatively propose establishing a third magnetotype direction using the paleomagnetic mean direction determined from the

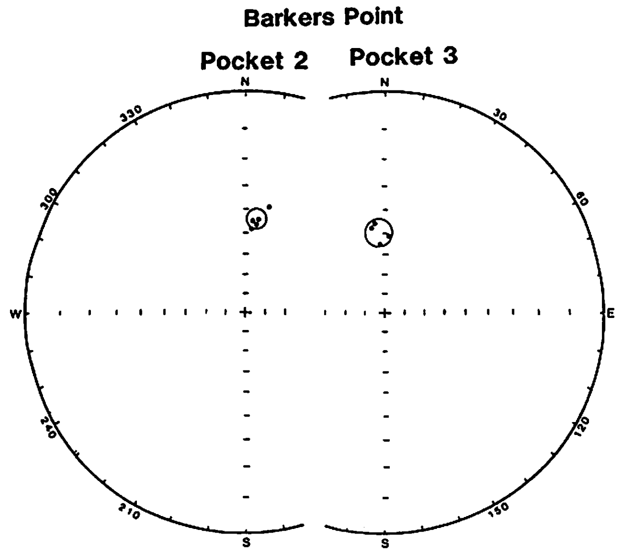

Figure 2. Stereographic plot of Barkers Point mean directions. Dots indicate mean directions with circles of 95% confidence. Pocket 3 shows excellent correlation with the Gaulin Cay magnetotype direction. Pocket 2 is correlated with the direction produced from the paleosol in Owl's Hole.

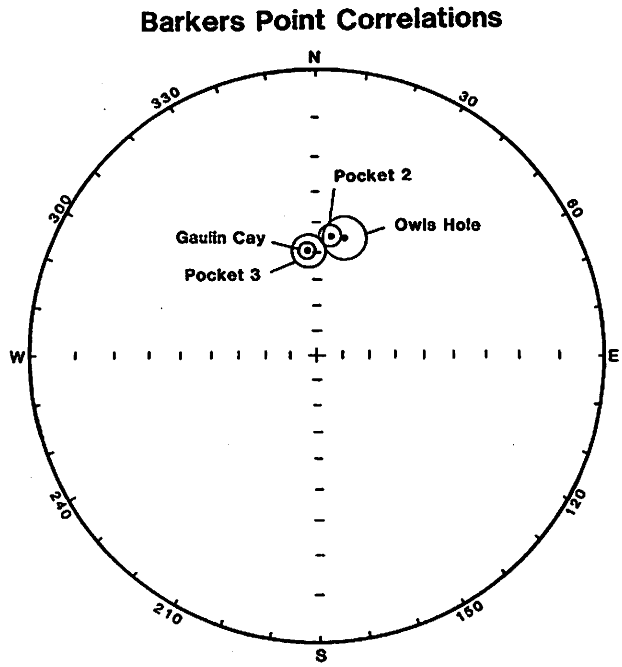

Figure 3. Stereographic plot showing the correlation of Barkers Point Pocket 2 and Moon Rock Pond mean directions with Owl's Hole mean direction. Symbols are described in Figure 2.

paleosol in Owl's Hole. In order to avoid confusion with existing stratigraphic nomenclature, we term this the Sandy Point Pits magnetotype (Figure 4). Both the Sandy Point Pits and Gaulin Cay magnetotypes occur below the Grotto Beach Formation and are thus older than the Fernandez Bay magnetotype. It is not possible to establish the relative ages of the Sandy Point Pits and Gaulin Cay types unequivocally. However, component B identified in Pocket 2 agrees with the direction of Pocket 3 at Barkers Point. It could be argued that this component is a partial overprint imposing Gaulin Cay/Pocket 3 direction on the Pocket 2 paleosol. If this interpretation is correct, it implies that the Gaulin Cay/ Pocket 3 direction is younger than the Sandy Point Pits type direction (Figure 5). Given the fact that the component B direction is not well-constrained, the suggested age relationship of the Gaulin Cay and Sandy Point Pits magnetotypes must be considered speculative.

The direction observed in the Crab Cay paleosol is in statistical agreement with the Gaulin Cay type direction. It is also different from both Fernandez Bay and Sandy Point Pits directions. The paleomagnetic correlation would appear to indicate that the paleosol is of pre-Grotto Beach age and that the eolianite below is the Owl's Hole Formation. Unfortunately, the paleomagnetic data are at odds with the geologic mapping: Cockburn Town Member of the Grotto Beach Formation. Although the fossil coral reef along the southern flank of Crab Cay has not been dated directly, all dated coral reefs on San Salvador have ages consistent with deposition during oxygen isotope stage 5e. It is extremely unlikely that the Crab Cay reef can represent any unit but the Grotto Beach Formation. The eolianite comprising Crab Cay occurs at higher elevation than the fossil reef; however, there are no contact relationships demonstrating that the eolianite definitely lies in superposition above

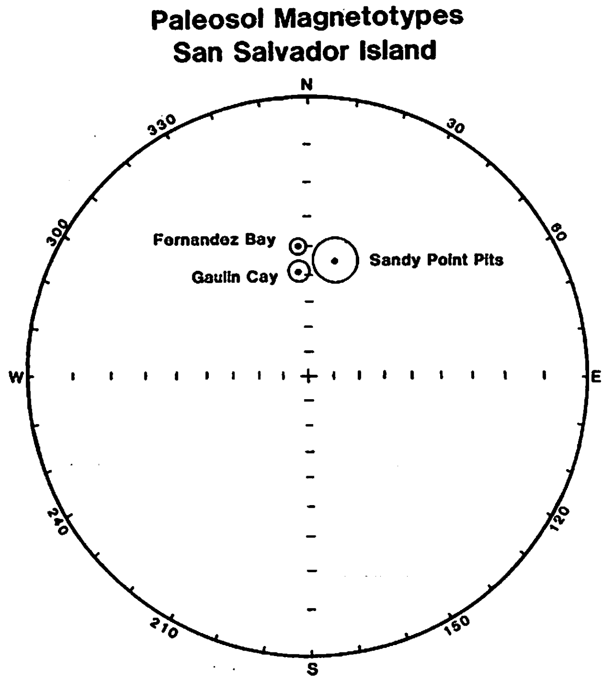

Figure 4. Stereographic plot showing three magnetotype directions. The mean direction obtained from the bottom of the Owl's Hole is termed the Sandy Point Pits magnetotype in order to avoid confusion with the Owl's Hole Formation. Symbols are described in Figure 2.

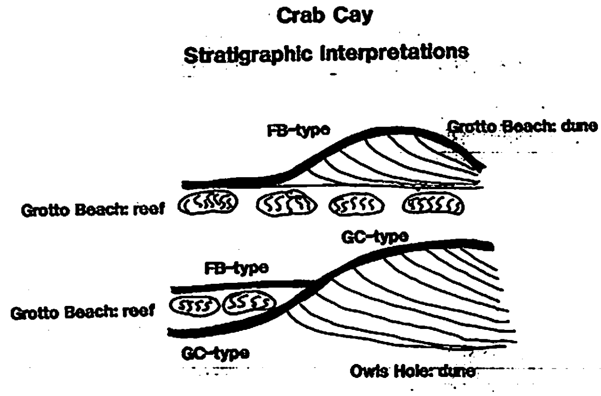

Figure 6. Two possible stratigraphic interpretations of Crab Cay. In the first model, the Grotto Beach reef deposits extend beneath the Crab Cay dune and the paleosol blankets both deposits. This interpretation requires that the Gaulin Cay type paleomagnetic directions observed above the dune are erroneous. Both reef and dune deposits should be covered with Fernandez Bay (FB) type paleosols. In the second model, the Crab Cay dune belongs to the Owl's Hole Formation and the overlying Gaulin Cay (GC) type paleosol projects below the Grotto Beach reef deposits. Fernandez Bay type paleosol is predicted to overly the reef rock. This hypothesis is currently being tested.

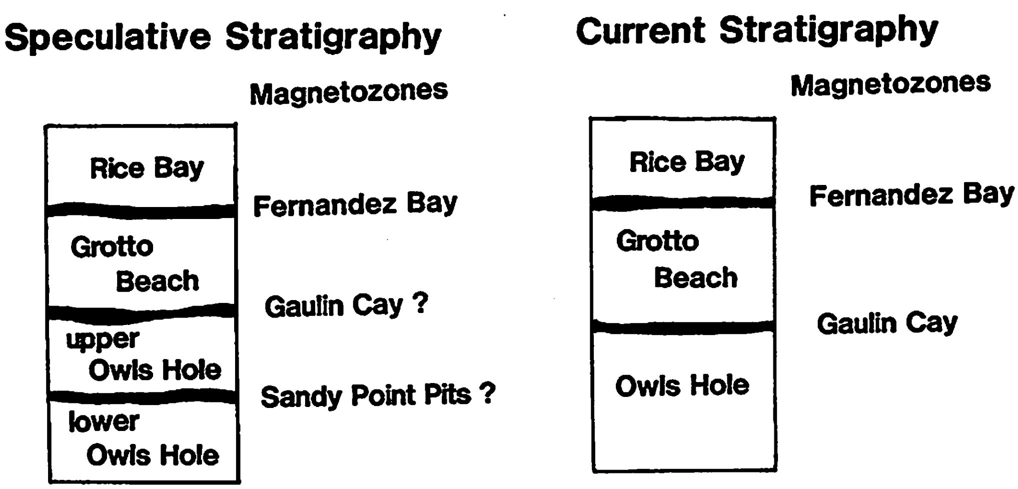

Figure 5. Speculative stratigraphy for San Salvador Island. Current stratigraphic models of San Salvador Island can only demonstrate two paleosols in outcrop. With the discovery of the Sandy Point Pits direction, there is evidence for an upper and a lower Owl's Hole Formation. The relative positioning of Gaulin Cay and Sandy Point Pits magnetotypes is speculative (see text).

the reef deposits.

There are two possible interpretations of the stratigraphy at Crab Cay (Figure 6). In the first interpretation, the eolianite is a regressive phase 5e dune overlying the reef and the paleosol overlies both dune and reef. In this case, the paleomagnetic correlation would be in error. The second scenario posits that the eolianite is an Owl's Hole Formation dune and that the reef was deposited stratigraphically above and to the southwest of the Crab Cay dune, but topographically below the dune (see Figure 6). The exposure surface represented by the paleosol on top of the dune should then project beneath the fossil coral reef and Crab Cay would have stood as a topographic high during 5e time.

These stratigraphic interpretations can be tested by sampling the paleosol overlying the fossil reef and resampling the paleosol on the dune. If the first scenario is correct, we predict a Fernandez Bay direction for the paleosol on the reef as well as the dune. Finding significant ooids in the Crab Cay dune would also provide powerful evidence for a Grotto Beach age. However, it should be noted that ooids have not been found in any appreciable abundance in regressive phase, Cockburn Town Member dunes on the eastern side of the island. Thus, although petrography of the deposits will be examined for characterization purposes, it is unlikely that petrology will yield any definitive evidence. The second scenario predicts that a Fernandez Bay direction will be observed above the reef and that a Gaulin Cay direction will be confirmed overlying the eolianite. If this second stratigraphic model is correct, the implication is that the island's depositional system is considerably more complex than currently recognized and that catenary deposition on subaerial nucleation sites is probably widespread. We are currently planning to test these competing hypotheses.

CONCLUSION

New paleomagnetic data are presented for three paleosol localities. Two paleosol filled epikarst pits at Barkers Point yield statistically distinct directions. Pocket 3 correlates with the previously established Gaulin Cay magnetotype of pre-Grotto Beach age. Pocket 2 is not the same as either the Gaulin Cay or Fernandez Bay magnetotypes, but is statistically the same as the mean direction from the paleosol in the Owl's Hole (previously reported), which until now had no apparent utility in stratigraphic correlation. Additionally, a mean direction produced for the paleosol at Moon Rock Pond agrees with the directions from both Barkers Point-Pocket 2 and the Owls Hole. We provisionally suggest that the paleomagnetic mean direction from the Owls Hole be referred to as the Sandy Point Pits magnetotype, a second Pre-Grotto Beach Formation paleosol.

Paleomagnetic data from the paleosol overlying the eolianite at Crab Cay yields a Gaulin Cay type direction. These data suggest that the dune at Crab Cay belongs to the Owls Hole Formation. However, the Crab Cay eolianite is mapped as Cockburn Town Member of the Grotto Beach Formation. We are currently acquiring more data in an effort to resolve this discrepancy.

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