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PLEISTOCENE STRATIGRAPHY AND GEOCHRONOLOGY SOUTHWESTERN SAN SALVADOR ISLAND, BAHAMAS

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ABSTRACT

A suite of Pleistocene marine and terrestrial limestone deposits crops out at several localities at the southern end of San Salvador. The uppermost unit at all outcrop localities in this area consists of oolitic eolian calcarenites belonging to the Grotto Beach Formation. At Watling's Quarry this eolianite has been dated at approximately 100,000 years, based on amino acid racemization of *Cerion* sp. found within the dunal deposits. At several localities these oolitic eolianites can be seen to grade downward into marine units which include fossil reefs that yield U/Th ages of at least 125,000 years (oxygen isotope substage 5e). At the Grotto Beach Sea Cliffs in the western portion of the field area, these reef deposits in growth position can be seen to overlie an erosionally truncated bioclastic eolian calcarenite that has been assigned to the Owl's Hole Formation. To the south, at the Owl's Hole type section, the oolitic dune deposits overlie a calcrete paleosol which caps a bioclastic eolianite unit (Owl's Hole Fm.). Traditional paleomagnetic analysis of that paleosol yielded a reversed remnant paleomagnetic signature, indicating an age of 740,000+ years (Matuyama Reversed Epoch). A stratigraphic sequence identical to that at Owl's Hole exists at the Watling's Quarry outcrop. However, the paleosol that caps the bioclastic unit at this locality yielded a normal paleomagnetic polarity. These data suggested that an additional stratigraphic unit might exist between the Owl's Hole and Grotto Beach formations.

A detailed and quantitative petrographic analysis was undertaken to attempt to distinguish these units from one another. The data show striking similarities in the abundance, texture and type of constituents that comprise the bioclastic eolianites at the Grotto Beach Sea Cliffs, Owl's Hole and Watling's Quarry sections; and also among the oolitic eolianites at those three sections. Based on these petrographic similarities, it is interpreted that no new stratigraphic unit exists at this end of the island. This interpretation is supported by cryogenic paleomagnetic analyses which indicate that no paleomagnetic reversals are present at the Owl's Hole, Watling's Quarry or Grotto Beach sea cliffs sections. The cryogenic paleomagnetic results thus suggest that the Owl's Hole Formation is younger than previously reported; however, this formation is still believed to contain the oldest rocks exposed in the Bahamas.

INTRODUCTION

San Salvador Island is an isolated part of the Bahamas archipelago. The subaerially exposed rocks of San Salvador are composed of three main types: 1) terrestrial limestones, consisting primarily of eolian calcarenites; 2) marine limestones, usually shoal, beach, back-beach and fossilized reef deposits; and 3) calcrete paleosols, mainly fossilized residual soils or caliche. Carew and Mylroie (1985) developed a physical stratigraphy of the island based on field observations, Uranium/Thorium dating of fossil corals and speleothems, ^{14}C dating of whole rock samples, amino acid racemization dating of *Cerion* sp., petrographic analyses of thin sections, and stratigraphic relationships of the various limestone units and interlayered paleosol horizons (Fig. 1). The purpose of this study was to determine whether the Pleistocene portion of that stratigraphy needed modification.

The study area, Sandy Point, is located at the southwestern end of San Salvador Island,

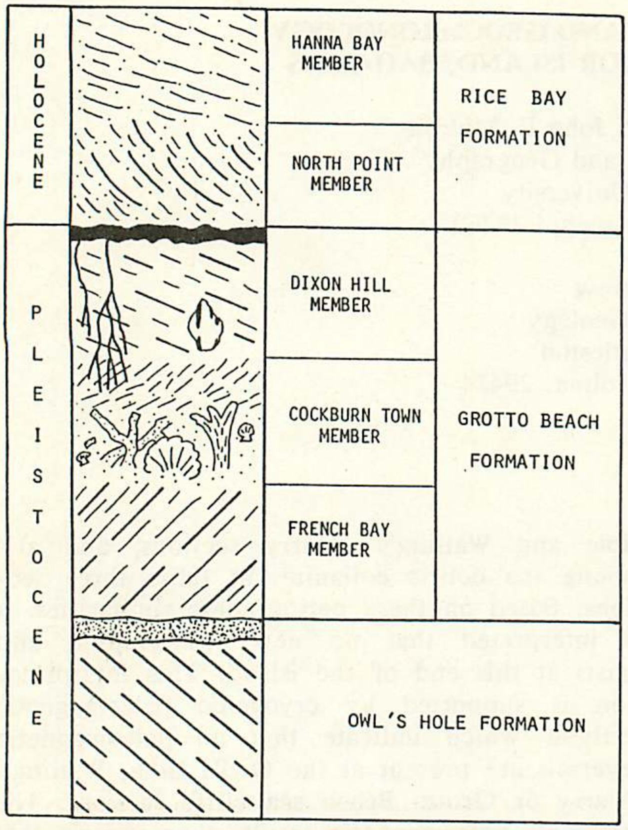

Fig. 1. Physical Stratigraphy of San Salvador. (from Carew and Mylroie, 1985).

where the Pleistocene rock units in question crop out. The rocks exposed in the central field area consist of a series of Quaternary eolianites and paleosols that form a northeast-southwest trending topographic high. The perimeter of the field area is characterized by subtidal, beach and reef deposits that interfinger with the eolianites and paleosols of the central area.

Initial paleomagnetic analyses yielded a reversed polarity for the lower paleosol at Owl's Hole, implying that this paleosol and the underlying bioclastic rock unit (Owl's Hole Formation) at this locality was at least 740,000 years old (Matuyama Reversed Epoch) (Carew and Mylroie, 1985). This reversed signature for the Owl's Hole paleosol was detected in five samples taken at three different times. As such, those authors interpreted the Owl's Hole Formation to be the oldest exposed rock unit in the Bahamas. Based on gross lithologic similarities and an identical stratigraphic sequence at the Owl's Hole and Watling's Quarry sections, Carew and Mylroie (1985) assigned the bioclastic unit below the lower paleosol at Watling's Quarry to the Owl's Hole Formation. Carew and Mylroie (1985) suggested that informal status be assigned to this formation because the base of the unit is not exposed at any outcrop. However, a paleomagnetic analysis of the lower paleosol at Watling's Quarry, done in 1986, revealed a normal polarity. This suggested that if the paleomagnetic data were correct, then an additional stratigraphic unit that was younger than the Owl's Hole Formation, but older than the oolitic Grotto Beach Formation (which has yielded ages of 150,000 to 85,000 years), existed at the base of the section in Watling's Quarry (Fig. 2).

METHODS

A detailed and quantitative petrographic analysis was performed on 64 thin sections. Fifty-six of these samples were collected at 1m intervals from nine measured sections. The other eight samples were taken from surface rock exposures. Figure 3 is a map of Sandy Point showing the localities of all samples collected; figure 4 contains a legend for the petrographic illustrations included in this report. Only three of the measured sections, the Owl's Hole (OH 0-9), Watling's Quarry southwest (WQSW 1-8) and the Grotto Beach sea cliffs (GBC 0-5) sections, will be discussed in this paper as they were the only outcrop localities observed to contain deposits of both the Owl's Hole and Grotto Beach formations. The other six measured sections and the eight surface rock samples were found to consist entirely of deposits belonging to the Grotto Beach Formation.

A total of six samples were collected for sensitive cryogenic paleomagnetic analysis. Four of them were from the Owl's Hole Formation; including the basal bioclastic eolianite and the overlying calcrete paleosol at Owl's Hole, and bioclastic eolianite samples, one each from the base of the Grotto Beach sea cliffs and Watling's Quarry sections. The remaining two samples were from the Grotto Beach Formation, including the upper oolitic eolianite at Watling's Quarry and Owl's Hole.

RESULTS

Owl's Hole Formation

The Owl's Hole Formation crops out at three different localities within the study area. At two of the localities, Owl's Hole (type section) and Watling's Quarry (see Fig. 3), this formation consists of a bioclastic eolianite capped by a calcrete paleosol. At the third locality, the Grotto Beach sea cliffs, the Owl's Hole Formation is

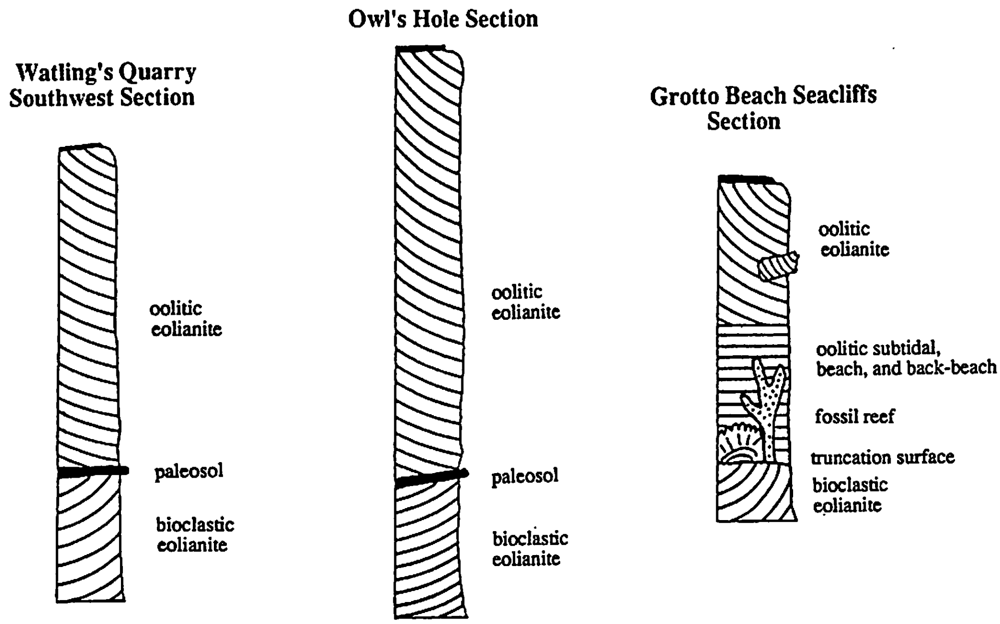

Fig. 2. Diagrammatic sketch of three key outcrops in the study area. Initial (non-cryogenic) paleomagnetic analyses showed a reversed polarity for the lower paleosol at Owl's Hole and a normal polarity for the lower paleosol at Watling's Quarry. This suggested that the bioclastic units at Owl's Hole and Watling's Quarry were not correlative.

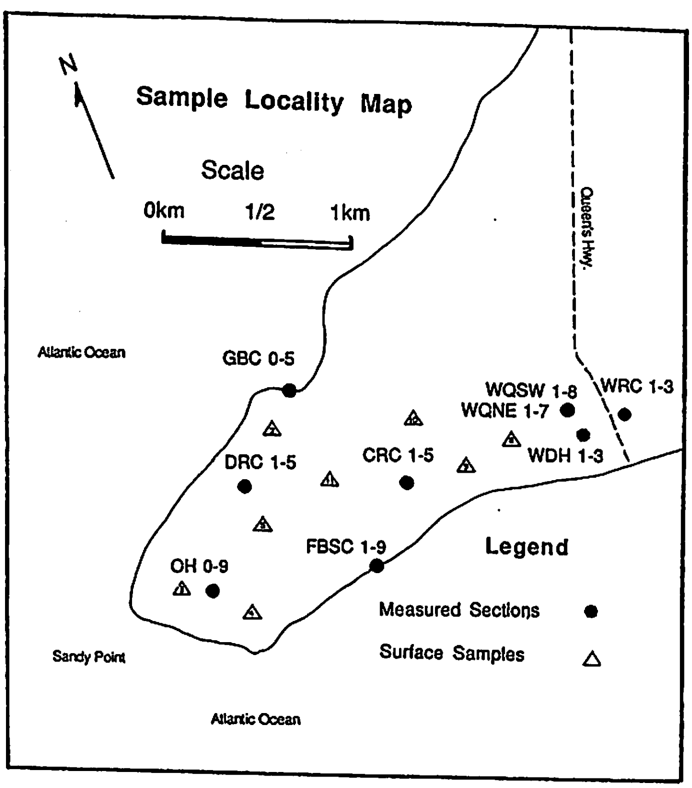

*Fig. 3. Sandy Point sample locality map. Capital letters designate the following sampled outcrops: GBC=Grotto Beach cliffs; DRC=Dripping Rock cliffs; OH=Owl's Hole; FBSC=French Bay sea cliffs; CRC=*Cerion *roadcut; WDH=Watling's dry hole; WQSW=Watling's Quarry southwest; WQNE= Watling's Quarry northeast; WRC=Watling's roadcut. Triangles numbered 2 through 5 represent samples SSJA-2 to SSJA-5; 8 through 11 represent samples SSMA-8 to SSMA-11.*

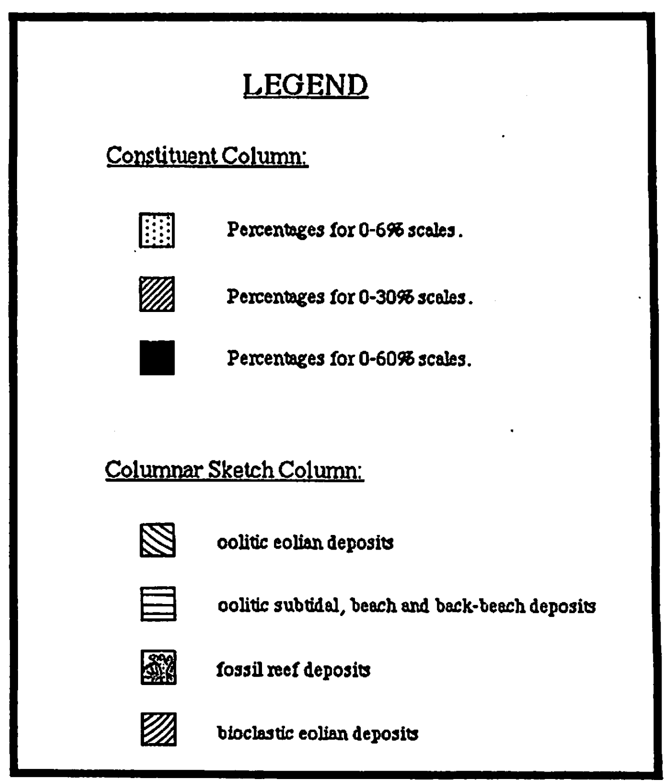

Fig. 4. Legend for petrographic illustrations and measured sections.

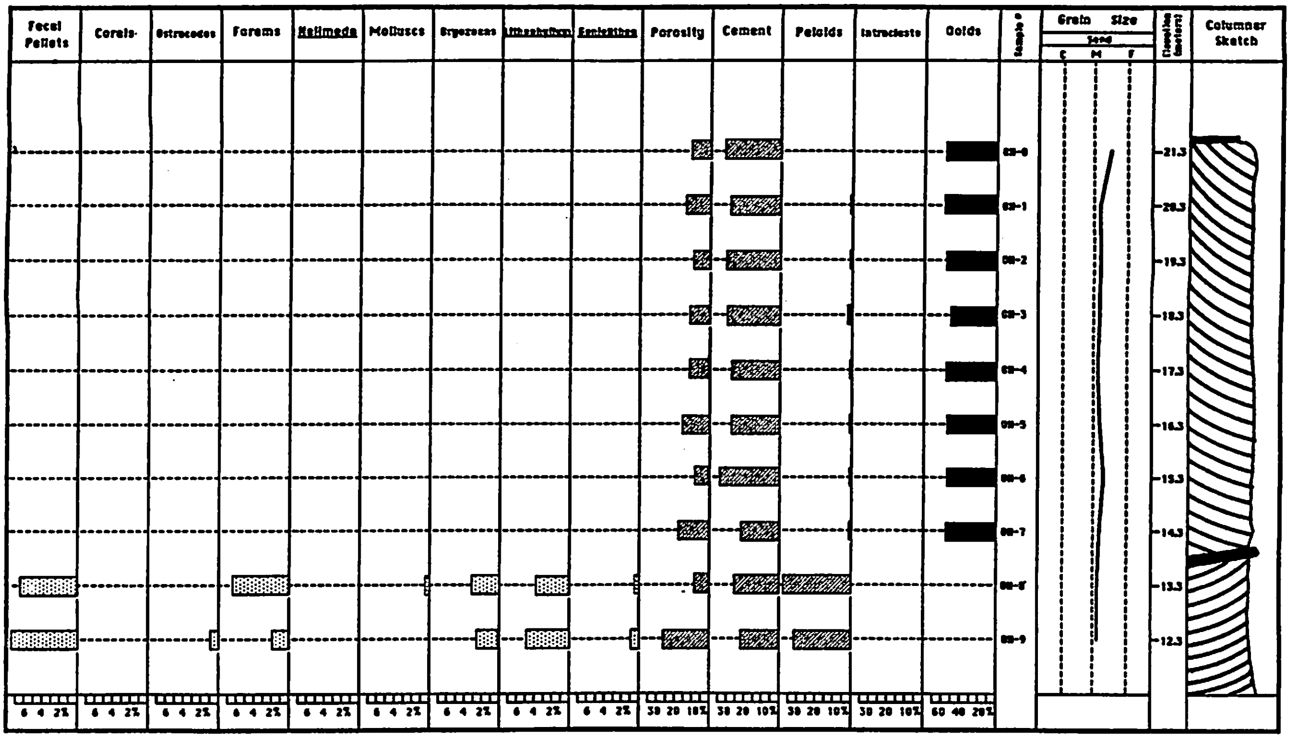

Fig. 5. Petrographic illustration of the Owl's Hole Section.

composed of an eolian calcarenite that has been erosionally truncated, and has no capping paleosol. However, the presence of alveolar texture in the upper meter of this unit is indicative of previous subaerial exposure. Carew and Mylroie (1985) suggested that the paleosol may have been removed by erosion that truncated the unit during the subsequent transgression that resulted in the formation of a 125,000 years old (oxygen isotope substage 5e; Shackleton and Opdyke, 1973) *in situ* fossil reef that is observed to immediately overlie the truncated eolian surface (hardground). It is obvious that the bioclastic eolianite (Owl's Hole Fm.) at the Grotto Beach sea cliffs has been inundated at least twice; during oxygen isotope stage 5e (125,000 years), and at present.

It is important to note that the Owl's Hole Formation consists predominantly of bioclastic allochems. At the type section at Owl's Hole the majority of the allochems consist of fine to medium sand-size skeletal fragments and pellets (Fig. 5). The high percentage of peloids observed in the thin sections from this outcrop of the Owl's Hole Formation is due to the high degree of micritization that this unit has experienced.

Rocks of the Owl's Hole Formation at Watling's Quarry and the Grotto Beach sea cliffs (Figs. 6 and 7 respectively) contain slightly different allochems than were observed at Owl's Hole. These two outcrops of the Owl's Hole Formation contain minor amounts of ooids (2.7%) intermixed with bioclastic grains. In addition, a significant percentage of intraclasts were observed in the Owl's Hole Formation at the Grotto Beach sea cliffs section. The average grain size at these two localities is in the medium sand range.

Four samples collected from the Owl's Hole Formation revealed a normal magnetic polarity by cryogenic paleomagnetic analysis. This suggests that the previously reported age of the Owl's Hole Formation (740,000+ years) (Carew and Mylroie, 1985) is in question.

Grotto Beach Formation

The Grotto Beach Formation overlies the Owl's Hole Formation and is divided into three members (Carew and Mylroie, 1985). From oldest to youngest they are the French Bay, Cockburn Town, and Dixon Hill members (see Fig. 1). The French Bay and Cockburn Town members crop out in the study area.

At the Grotto Beach sea cliffs, the stratigraphic sequence consists of an *in situ* fossilized patch reef. That reef grew on a truncation surface (hardground) that developed on an underlying bioclastic eolianite assigned to the Owl's Hole Formation. Uranium/Thorium age determination of the fossil reef coral yielded a date of 125,000 years (oxygen isotope substage 5e). This

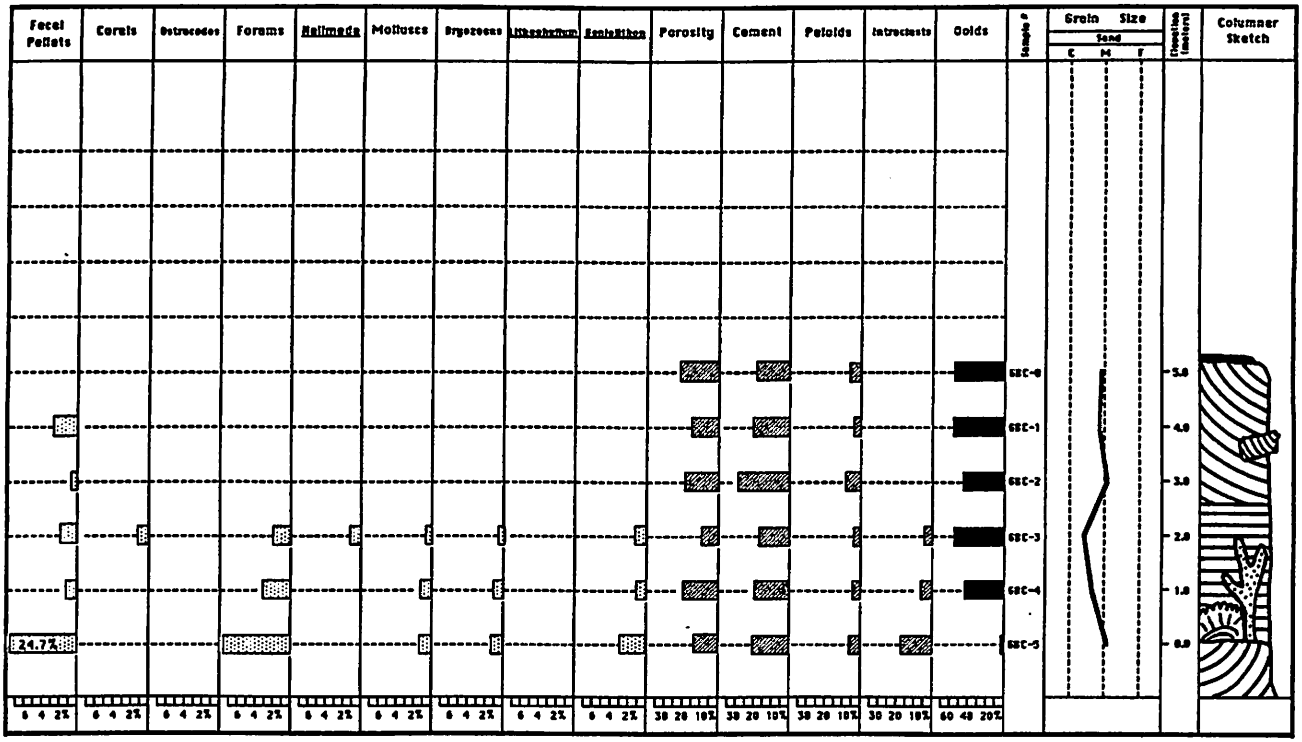

Fig. 6. Petrographic illustration of the Watling's Quarry Southwest Section.

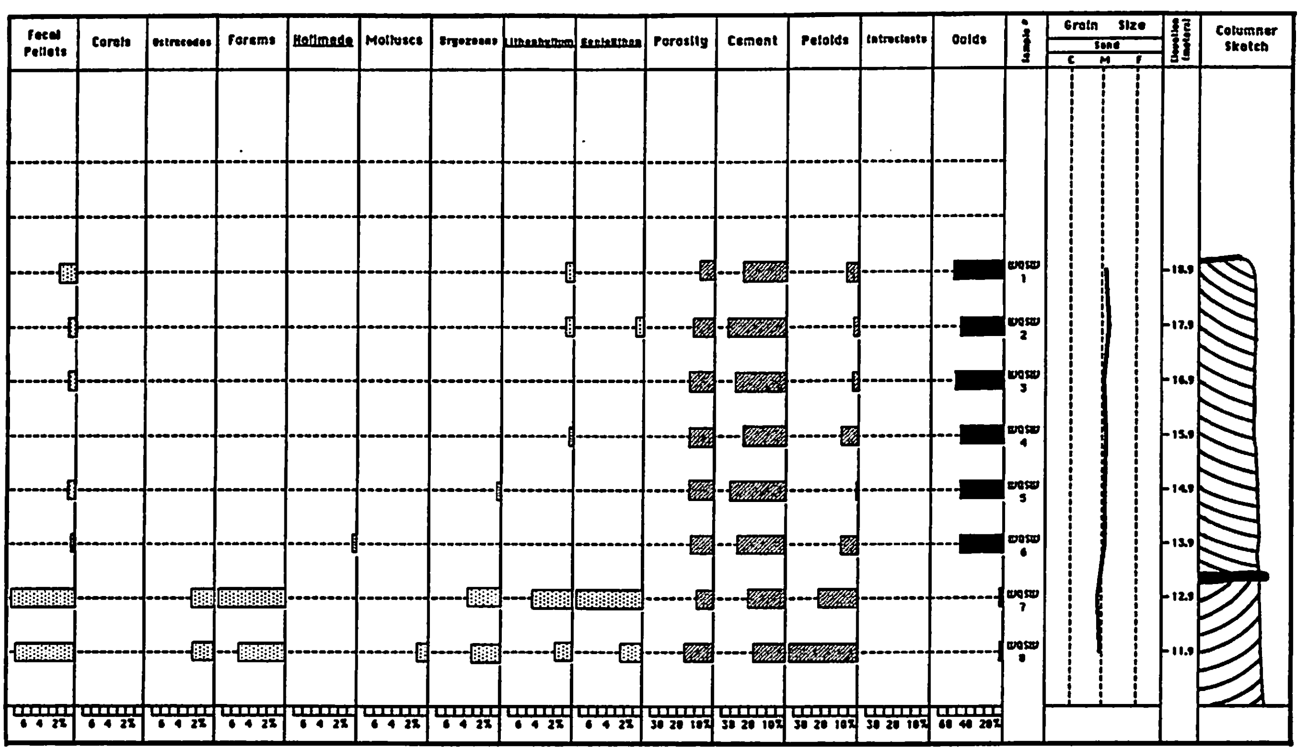

Fig. 7. Petrographic illustration of the Grotto Beach Seacliffs Section.

sequence was interpreted by Carew and Mylroie (1985) as evidence of the Sangamon transgression and still-stand of sea level. The fossil reef is surrounded by and infilled with subtidal, beach and back-beach calcarenites. This is interpreted as a regressive sequence that was deposited by strandline progradation at a sea level still-stand or subsequent marine regression associated with the end of oxygen isotope sub-stage 5e (sub-stage 5d). The rocks assigned to the Grotto Beach Formation at the Watling's Quarry and Owl's Hole sections are composed entirely of dunal eolian calcarenite facies.

All outcrops of the Grotto Beach Formation in the study area are capped by a paleosol. Carew and Mylroie (1985) considered this paleosol to be the Pleistocene-Holocene boundary.

The dominant allochems observed at all Grotto Beach Formation outcrops in the study area were ooids (Figs. 5, 6 and 7). Interestingly, in addition to the ooids a small percentage of bioclastic grains and fecal pellets were observed in the basal portion of several Grotto Beach Formation outcrops including the Grotto Beach sea cliffs and Watling's Quarry southwest. In addition, minor amounts of intraclasts were observed near the base of the Grotto Beach Formation at the Grotto Beach sea cliffs. Both samples from the Grotto Beach Formation that were subjected to cryogenic paleomagnetic analysis revealed a normal paleomagnetic signature.

DISCUSSION

Owl's Hole Formation

The Owl's Hole Formation at all three outcrop localities is interpreted to be eolian based on the presence of steeply dipping (30^0) large amplitude foreset beds and very good sorting. At the type section for this formation, the presence of rhizomorphs and fossilized *Cerion* sp. also lend support to this interpretation.

Considering the paucity of ooids observed in thin sections of the Owl's Hole Formation from the Watling's Quarry and Grotto Beach sea cliffs sections, any one of the following interpretations may apply.

1) The outcrops represent two bioclastic eolian units that were deposited during different sea level events. In this interpretation, the bioclastic units at Watling's Quarry and Grotto Beach sea cliffs represent units that are younger than the bioclastic units at Owl's Hole, but older than the Grotto Beach Formation.

2) The outcrops represent two different units that were deposited at different times during the same sea level event (e.g., transgressive vs. regressive).

3) The outcrops represent one unit that was deposited during the same sea level event, but each had a slightly different source. Sandy Point is surrounded on three sides by water and each of the three outcrops is located on a different side of Sandy Point easily permitting subtle differences in the sediment sources.

Based on the current data, and what was previously believed to be a 600,000 year lacuna, the most likely interpretation is that the Owl's Hole Formation is younger than originally reported by Carew and Mylroie (1985), but still probably represent the oldest rocks exposed in the Bahamas.

The new paleomagnetic data in conjunction with the petrographic results from this study also suggest that the best interpretation would be that the bioclastic eolianites at Watling's Quarry and Grotto Beach sea cliffs sections belong to the Owl's Hole Formation.

Grotto Beach Formation

As was mentioned earlier, the Grotto Beach Formation is predominantly oolitic, particularly in its eolian facies. When this is compared to the dominance of bioclastic material in the Owl's Hole Formation, two possible interpretations are implied:

1) The conditions that existed during the time of deposition of the Grotto Beach Formation were different than those that existed during deposition of the Owl's Hole Formation (i.e. dominantly bioclastic sediment production <u>vs</u> widespread ooid production.)

2) The depositional environments of the areas adjacent to these three localities were different during deposition of the Owl's Hole Formation than they were during deposition of the Grotto Beach Formation.

Of these, the former seems the much more likely.

Geochronology of the Sandy Point Area

The depositional history of San Salvador Island has been discussed by Titus (1980, 1981, and 1983), Carew (1983), Carew and Mylroie (1985, 1987), and Sims (1987). The discussions are based mainly on stratigraphic relationships, petrographic characteristics and absolute ages reported by Carew and Mylroie (1985, 1987) from Uranium-/Thorium analyses of fossil corals and speleothems, amino acid racemization of *Cerion* sp. and ^{14}C analyses of whole rock samples obtained from localities throughout the entire island.

This study is only concerned with the Quaternary deposits of the Sandy Point area. Therefore, the depositional history that follows deals with interpretations made only from rocks in the study area.

It was originally indicated by Carew and Mylroie (1985) that the oldest rocks exposed on San Salvador Island, and possibly the entire Bahamas, were those of the Owl's Hole Formation. These rocks were interpreted to be at least 740,000 years old (Matuyama Reversed Epoch) based on repeated paleomagnetic analyses that yielded a reversed paleomagnetic polarity in the capping paleosol at the type section for this formation (Owl's Hole; Fig. 1). Carew and Mylroie (1985) hypothesized that the Owl's Hole rocks, mainly bioclastic eolianites, represented a 740,000+ year old nucleation point or "ancient" San Salvador to which the modern San Salvador Island accreted, both vertically and laterally. This process was first proposed by Carew (1983), and was later termed catenary development by Garrett and Gould (1984).

However, the cryogenic paleomagnetic analyses reported in this study on the Owl's Hole rocks indicate that no reversed paleomagnetic signature is present, and therefore, the previously reported age of these rocks (740,000+ years) is questionable. The most likely interpretation is that the Owl's Hole rocks are younger than previously reported, but older than the Grotto Beach Formation and are therefore still considered the oldest rocks exposed in the Bahamas (Stowers, 1988). Even though the absolute age of the Owl's Hole Formation is uncertain, as both laboratories stand by their conflicting paleomagnetic results, the sequence of events responsible for the development of the Sandy Point area, as proposed by Carew and Mylroie (1985), remains the same. Only the absolute age of events is reinterpreted in this paper. The proposed sequence of Pleistocene events is as follows:

1) Sometime prior to 150,000 years ago "ancient" San Salvador Island consisted of bioclastic eolian ridges that were deposited in the southwest portion of present or modern San Salvador Island. This period of deposition was followed by climatic conditions conducive to the dissolution of limestone and to paleosol development. These rocks belong to the Owl's Hole Formation.

2) During the initial oxygen isotope stage 5e transgression modern San Salvador began to accrete, both vertically and laterally, to the "ancient" San Salvador. These rocks consist of oolitic subtidal, beach, back-beach and dune deposits and have been assigned to the French Bay Member of the Grotto Beach Formation.

3) During the subsequent still-stand of sea level (approximately +6m above psl), abundant carbonate sediment production and reef growth occurred. U/Th analysis of fossil corals yield ages of approximately 125,000 years (oxygen isotope substage 5e). These rocks comprise the lower section of the Cockburn Town Member (Grotto Beach Formation).

4) During that still-stand, or as sea level fell, the fossil reefs were entombed by subtidal, beach and back-beach deposits, and thus the coastline prograded outward.

5) The final episode in the southwest portion of the island's Pleistocene depositional history is characterized by widespread paleosol development that occurred at the end of Pleistocene time (approximately 15,000 years ago).

SUMMARY AND CONCLUSIONS

This study provides a detailed and quantitative petrographic analysis of the two Pleistocene stratigraphic units exposed in the Sandy Point area of San Salvador Island. These units are the Owl's Hole and Grotto Beach formations. Based on previous paleomagnetic analyses, it was thought that a new stratigraphic unit possibly existed between the older Owl's Hole Formation and younger Grotto Beach Formation. Based on the petrographic similarities between the rocks that could possibly have been assigned to a previously undescribed unit and the Owl's Hole Formation, it is suggested here that no additional stratigraphic unit exists between these two formations. Results of cryogenic paleomagnetic analyses reported here support this interpretation. These results also reveal that the 740,000+ year age for the Owl's Hole Formation is uncertain. The most likely interpretation is that the Owl's Hole Formation is younger than previously reported.

ACKNOWLEDGEMENTS

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