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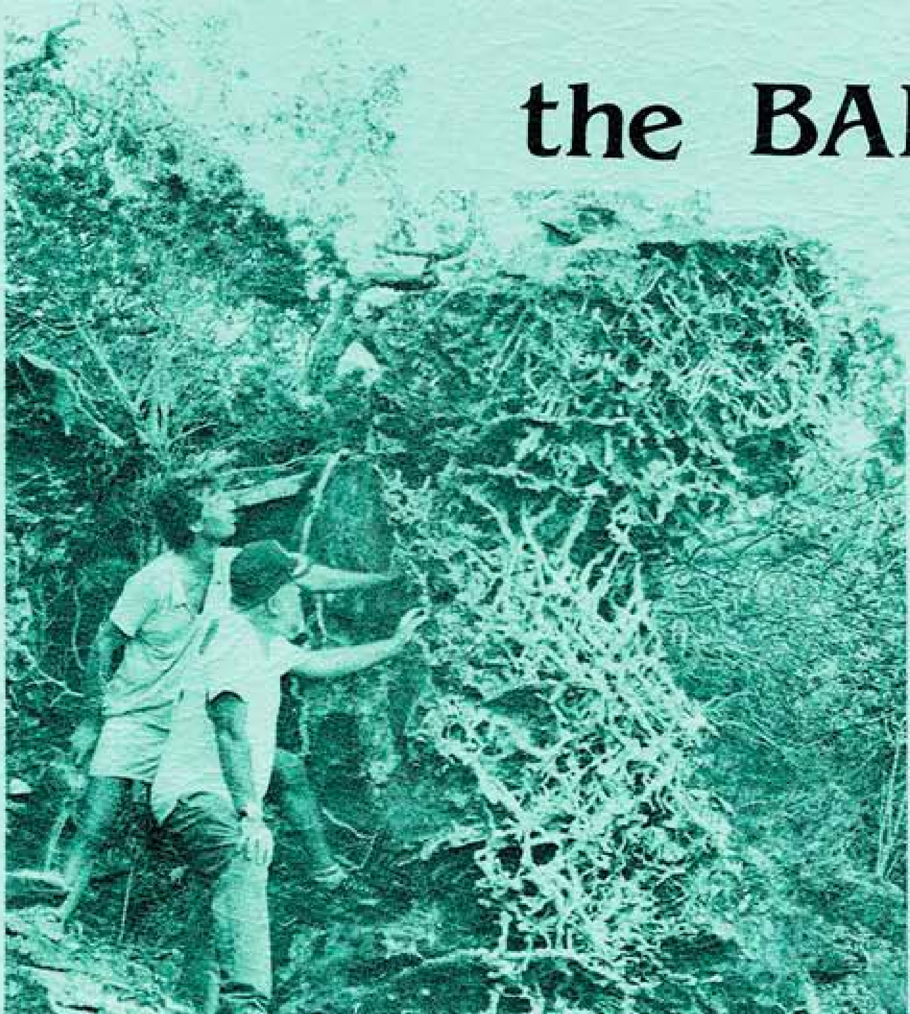

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PHYSICAL STRATIGRAPHY OF SAN SALVADOR ISLAND, BAHAMAS

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Abstract

In several earlier reports (Titus, 1980; 1983a; 1983b) a general framework has been worked out for the late Quaternary stratigraphy of San Salvador. Two formations have been recognized; each displays an emergent facies pattern. Recent studies have revealed more about the very latest Pleistocene and Holocene stratigraphy of the island.

Sea cliffs, wave-cut notches and lake deposits all indicate that there was a sea level rise of about 2.5 m in the recent past. Application of simple stratigraphic principles demonstrates that these features are very latest Pleistocene in age and very likely they formed during the sea level rise that Carew and Mylroie (1983) have argued for.

During the late Holocene sea levels have risen to their present day levels. During this transgression beach accretion ridges have formed at a number of locations on the periphery of the island.

A growing body of evidence is supporting the view that there have been three episodes of sea-level high stands during the late Quaternary. One ended about 120,000 years ago. A second occurred soon thereafter. The third appears to be the controversial high stand at 35,000 years ago as advocated by Thom (1973).

Introduction

Stratigraphic analysis in the Bahamas is different from nearly everywhere else. Classical stratigraphy focuses upon the vertical sequences of sedimentary rocks. Facies interpretations may add an important horizontal component, but vertical sequences are of paramount importance. The late Quaternary history of San Salvador, like the rest of the Bahamas, has been dominated by a sequence of short and rapid marine transgressions and regressions. Sediments have been deposited during marine transgressions, reworked during regressions, and cemented during periods of emergence. Deposition has occurred mostly in low lying areas around the periphery of the island, areas most easily affected by transgression.

Deposition has not produced thin uniform sheets of sediment. Instead, deposition has been concentrated into what I will call sedimentary "provinces". Wind patterns account for some of these provinces. The large dune deposits of the Line Hole Settlement vicinity are an example of such a province. Beach accretion in protected embayments constitutes another form of province. A good example of this type occurs at Sandy Hook on the southeast corner of the island. Lake deposits make up a third type of province found within the island's interior. Thus San Salvador is made up of a series of such sedimentary provinces. Over a period of time they have been accreting around the periphery of the island and it as grown in size.

To understand the history of the island, each province must be recognized, correctly interpreted, dated and then placed into a logical sequence of events. This is one of the reasons that working out the stratigraphy and history of San Salvador has been a difficult and time-consuming task.

The purpose of this article is to update and revise studies reported earlier (Titus, 1980; 1983a; 1983b). In these earlier reports the late Quaternary stratigraphy of San Salvador was divided between two major stratigraphic units, the Grotto Beach Limestone and the Grahams Harbour Limestone. Both were viewed as being Pleistocene in age, and both were interpreted as representing episodes of emergence. Other lesser stratigraphic units, Pleistocene lake and Holocene beach deposits, were also described.

Recent field work, however, has shed a great deal of light on the stratigraphy of San Salvador and now the earlier studies need extensive revision. In brief, Holocene rocks are more common on San Salvador than had been previously recognized, and there were three, not two episodes of emergence during the past 140,000 years. This report will focus on these revisions. The paper is not a comprehensive one, but instead, is meant to complement the earlier reports, especially Titus (1983b).

Holocene Stratigraphy

Beach accretion ridges -- Over the past several thousand years sea levels have been rising. As they approached to within 7 m of their present level, a series of beach accretion ridges began to accumulate at various locations on the island. With time, successive ridges accreted and became cemented so as to become permanent parts of the island. These small "provinces" can be seen clearly on aerial photographs. They are found at Grahams Harbour, Barkers Point, north from Victoria Hill Settlement, Bonefish Bay, Sandy Point, French Bay and Sandy Hook (see index map of San Salvador).

The deposits are not well cemented, but they are resistant enough to produce low sea cliffs, such as the one at Grahams Harbour. Where exposed these deposits lie unconformably upon late Pleistocene deposits. The lower beds are generally beach deposits which grade upwards into dune deposits.

From the air, a clear pattern can be seen. A ridge and swale topography developed as the successive ridges were formed. Close inspection reveals that each ridge formed at slightly higher elevation than the previous one (Fig. 1). Clearly, this can be related to the rise in sea level of the past few thousand years. As sea levels rose the water tables rose as well. Because of this the oldest, farthest inland dune ridges are now flooded. Behind each ridge province there is thus a pond or a swamp where this submergence has occurred.

The most recently formed of the beach ridges rise about six m above sea level, the most ancient ones are submerged below about 1 m of pond water. Consequently it would appear that deposition of these ridges began when sea level rose to about 7 m below its present level, and it has continued ever since then. If sea levels continue to rise in the future, then the dunes will continue to accrete seawards while the older dunes will continue to be flooded by an enlarging pond.

Dune deposits -- Beach accretion was the dominant late Holocene sedimentary process going on along the western side of the island. On the eastern side, however, different processes occurred. There, great heaps of dune material were being formed. These dunes are found first at United Estates east of the Queens Highway from Northeast Point to the coast east of Brandy Hill Settlement. A second dune "province" occurs east of Storr's Lake. Storr's Lake was isolated and formed when these dunes were deposited. The third dune province occurs east of Pigeon Creek. It accounts for the formation of Pigeon Creek.

These dunal deposits are hummocky with no obvious

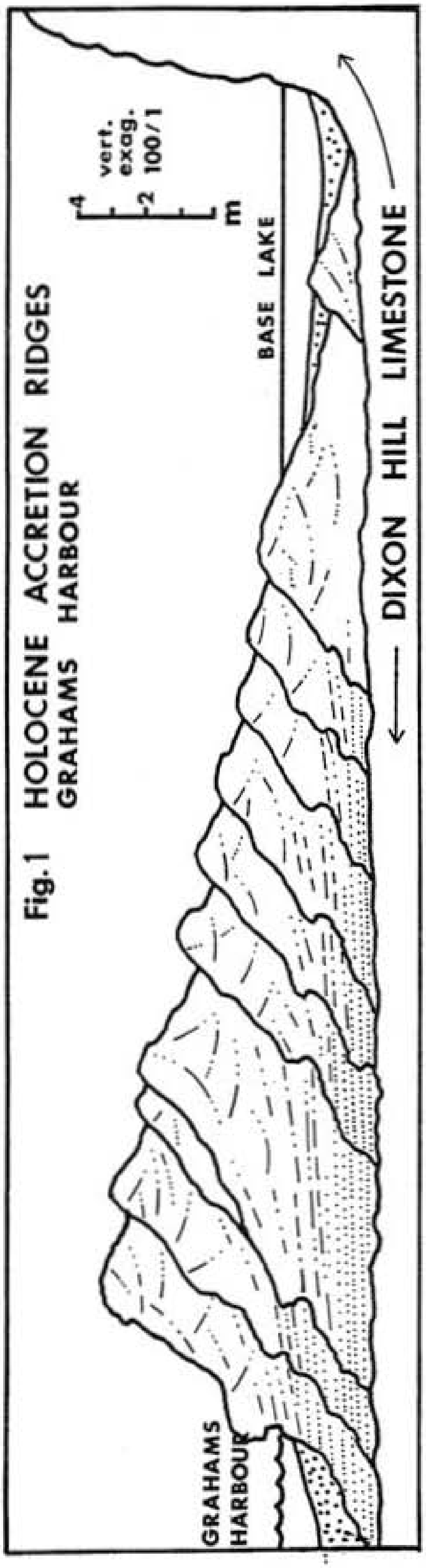


Fig. 1 HOLOCENE ACCRETION RIDGES GRAHAMS HARBOUR

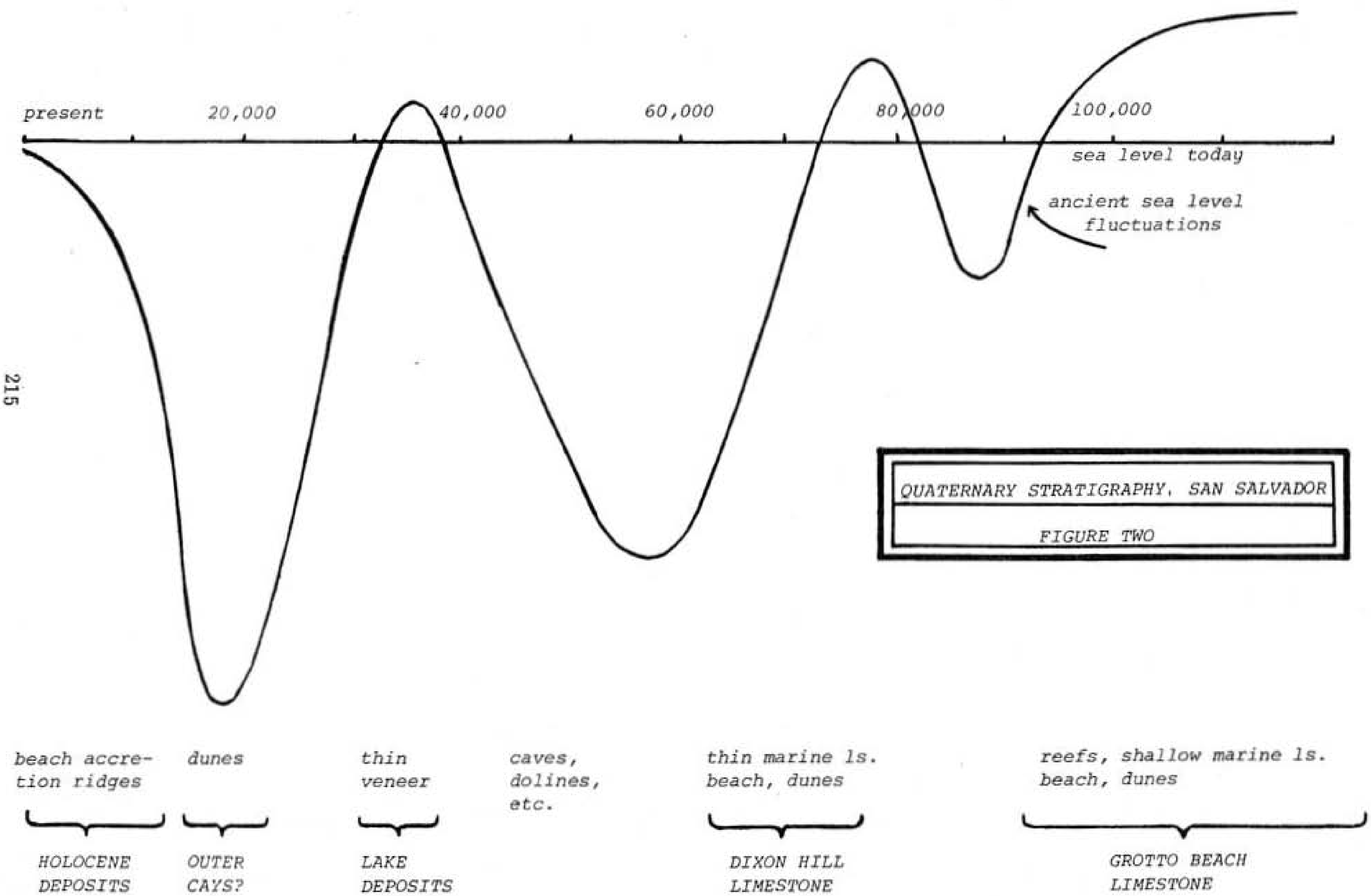
depositional patterns. It is possible that, as in the west of the island, an accretionary process has occurred. Like the beach accretion ridges, the dune elevations are higher near the ocean. At United Estates there are ponds lying behind the dunes. These ponds are reminiscent of the ponds which formed behind the beach accretion ridges as sea levels rose.

The Late Holocene dune deposits are easily distinguished from older Late Pleistocene deposits which occur nearby. The Holocene sands are poorly cemented. The deposits are best cemented at sea level along the coasts. They also have a very weak surficial crust of lightly cemented material. Beneath the crust and above sea level the deposits are scarcely cemented at all.

Thalman and Teeter (1983) have suggested that several of the bluffs which occur along this Holocene coast were once island which served as nuclei for the adjacent dunes to form around. The bluff south of Holiday Track Settlement is a good example. The bluff may or may not have been an island, but it probably is older than surrounding sediments. Unlike adjacent dune deposits it does have a karst crust, a feature which must have taken some time to have formed. This is the youngest karst crust on the island and it is underlain by entirely uncemented sands.

The age of the eastern dune tracts is hard to prove, but it does seem reasonable to assume that they are contemporary with the accretion ridges of the west and thus late Holocene.

Pleistocene Stratigraphy



QUATERNARY STRATIGRAPHY, SAN SALVADOR

FIGURE TWO

A Late Pleistocene wave-cut bench -- At several locations the late Holocene deposits lie upon a wave-cut bench with a low sea cliff on the landward side. The best example occurs from the southwestern corner of Sandy Point to Grotto Beach. There, a well-developed sea cliff is cut into rocks which are probably about 100,000 years old (Carew, 1983, sample C-5). Another example occurs between Victoria Hill Settlement and Line Hole Settlement. This cliff is not very high, but it does show up well on aerial photographs. This bench lies upon rocks which are about 75,000 years old (Carew, 1983, sample C-4).

The age relationships are clear. The bench is older than the late Holocene deposits which lie upon it, and younger than the 75,000 year old rocks it is cut into. Carew (1983) and Carew and Mylroie (1983) argue that there was a sea level rise which they date at between 35,000 and 40,000 years of age. The evidence from the physical stratigraphy of the island is quite consistent with their views.

Lake Cockburn -- The sea level rise which accounted for the wave-cut bench was a modest one. Grottos cut at this time on Sandy Point seem to have an elevation of about 2.5 m. The base of the sea cliff at Victoria Hill Settlement appears to have the same elevation. If a sea level rise of this magnitude actually occurred, then it can be predicted that the lakes of San Salvador were expanded and their shorelines would have corresponded with today's 2.5 m contour. To test this hypothesis, evidence of such a shoreline was searched for with some success. Exposed bedrock at the 2.5 m contour is rare. Nevertheless, many boulders and cobbles have been turned up by road building and agriculture. A number of locations at the 2.5 m level have yielded rocks containing fossils diagnostic of shorelines. Several species of the genera Anomalocardia and Cerithidea were particularly common and useful in recognizing shorelines. The distribution of these fossil assemblages along the 2.5 m contour apparently bears out the prediction that the lakes of San Salvador did expand to that level. At that time many of the presently separated lakes merged to form a single large lake, Lake Cockburn (see Titus, 1983b).

Thalman and Teeter (1983) discovered that the Granny Lake vicinity had been submerged and converted into a tidal estuary by a sea level rise which they suggested was Sangamon in age. I agree fully that the Granny Lake vicinity was indeed an estuary, but I differ in regards to its age.

As a Sangamonian sea level rise is universally accepted, that age interpretation is a very attrative one. Nevertheless, there is no need for the estuary to be that old, and there may be some problems with such an age estimate.

The 2.5 m sea level rise postulated above makes an adequate explanation for all the observed Pleistocene features of the Granny Lake estuary. Indeed, even if there had been an estuary during Sangamonian time, it would have had to have been reflooded during the later event.

An extensive Wisconsin sedimentary history is argued for in this article (see below). If this was the case, then there are more problems with the Sangamonian hypothesis. Extensive Wisconsin aged deposits might well have been expected to have buried all or much of the Granny Lake estuary. The estuary has, for example, a very well-preserved tidal channel. Such a low elevation feature might have survived such a long time without being buried, but this does not seem likely.

The geographic setting of the Granny Lake estuary may be inconsistent with the Sangamonian estimate. The mouth of the Granny Lake estuary was located at the very northernmost tip of Pigeon Creek (Hinman, 1980; 1983). The mouth was bounded on either side by the strata which now make up Kerr Mount and the dune deposits of South Victoria Hill Settlement. These rocks had to have been there before the estuary. As will be argued later, these deposits are regarded as belonging to the post Sangamonian Dixon Hill Limestone and are probably about 75,000 years old. Thus the Granny Lake Estuary would have to be younger than 75,000 years and not Sangamonian.

As discussed earlier, Carew (1983) and Carew and Mylroie (1983) have proposed that a sea level rise of a few meters occurred about 35,000 to 40,000 years ago. This conclusion was based on a stalagmite of this age containing serpulid worm tubes. This compelling but scanty evidence can now be unified with the conclusions presented herein. The stalagmite, the sea cliff and the 2.5 m bench, as well as the Lake Cockburn and Granny Lake estuary deposits, all now appear to belong to the same historical event: the controversial Late Wisconsin sea level rise (see Thom, 1973).

<u>The "Grahams Harbour" Limestone</u> -- In several earlier reports (Titus, 1980; 1983a; 1983b), I argued for a Late

Pleistocene formation named the "Grahams Harbour" Limestone. This unit was described as being composed of subtidal deposits grading upwards into dune facies, and thus it represented a period of emergence.

The Grahams Harbour Limestone was mapped upon the basis of a series of unconformities as well as by the distribution of its large obvious arcuate dune deposits. The unconformities were, by and large, misinterpreted.

The recent recognition of the extensive late Holocene deposits has gone a long way towards undermining the original interpretation of the Grahams Harbour Limestone. The supposed type section of the unit was the sea cliff west of the CCFL Field Station in Grahams Harbour. That sea cliff is now known to be part of the Holocene beach accretion ridge systems and thus those deposits are in no way related to the dune ridges further inland. Thus, and this is embarassing, the type section of the Grahams Harbour Limestone does not belong to that formation.

Despite this probably unprecedented error, I still believe that a valid unit can be retrieved from the shambles of the old Grahams Harbour Limestone. The unit needs to be redefined, renamed and, especailly, a new type locality must be chosen.

The new unit shall be named the Dixon Hill Limestone. The cave at Dixon Hill and the quarry on the west side of the Queens Highway about 1 km to the north shall constitute the type locality. The cave exposes older dune deposits of the unit, the quarry exposes younger beach and dune deposits. There may well be an unconformity at the base of the quarry (see Sass in Adams, 1980; 1983).

The new Dixon Hill Limestone consists of the old Grahams Harbour Limestone without the Holocene beach ridge deposits and with the addition of the dune deposits immediately west of Storr's Lake (see index map of San Salvador).

The unit is most easily recognized on a map or aerial photograph from its large arcuate dune ridge deposits. Its most extensive deposits extend from Crab Cay to the Sandy Point Plantation site (Titus, 1983b). There the unit is a thinner and more discontiuous veneer deposit than has been earlier described.

The Dixon Hill Limestone is also widespread in the vicinity of the Line Hole Settlement. Other lesser areas covered by the Dixon Hill Limestone are found in the type locality of United Estates and extending from Polly Hill Settlement to Little Fortune Hill. There is a minor series of dune deposits in the vicinity of the airport at Cockburn Town.

<u>The Dixon Hill emergence</u> -- The old Grahams Harbour Limestone had been interpreted as representing an episode of emergence, but this was primarily on the basis of evidence gathered from the exposures in Grahams Harbour which are Holocene in age. Despite this error, the original interpretations can still be considered valid; other lines of evidence confirm this.

The emergent facies pattern consists of shallow marine rocks grading upwards into beach deposits followed by dune deposits. Shallow marine deposits, overlain by beach sediments, can be seen in several of the dolines at the Line Hole

Settlement. Beach deposits overlain by dune deposits can be seen in several of the quarries along the Queens Highway on the east side of the island.

The structure of the dune deposits also seem to indicate an emergence. Characteristically, each area blanketed by the Dixon Hill Limestone has multiple arcuate dune ridge systems. In the Line Hole Settlement vicinity, for example, there is a prominent dune system south of Duck Pond. It reaches elevations of approximately 25 to 30 m. North of this there is a second dune ridge system, next to Little Lake. Its average elevation is about 20 m. This dune system lies shoreward from the first; it must have accreted after the first and thus is younger. A third set of dune deposits is found still further towards the shore from the second and its elevation is still lower, about 13 m. On the plain before the third set are the youngest dunes, several small sets which rise only 4 to 6 m above sea level.

Thus sets of dunes accreted one at a time, each one at a lower elevation than the one before it. Similarly, the other "provinces" of the Dixon Hill Limestone have matching accreted dune sets. All of these provinces seem to have been formed the same way. The dune systems were deposited one at a time as the sea was draining from San Salvador. This is the most striking characteristic common to all provinces of the Dixon Hill Limestone.

<u>The Unconformity</u> -- The "Grahams Harbour" Limestone, as originally misinterpreted, was viewed as being underlain by a prominent island-wide unconformity. Most exposures of this

unconformity have turned out to be at the base of the Holocene deposits. Thus only a few locations remain which may be valid exposures of the basal unconformity of the Dixon Hill Limestone. Among those is the quarry at the Sandy Point Plantation site. Another can be seen overlying reef deposits at Crab Cay. Sass (*in* Adams, 1980; 1983) reported an unconformity with red soils at the quarry north of Dixon Hill (Quarry A). Still another unconformity can be seen beneath the dune deposits along the road south of the airport in Cockburn Town.

Although the evidence for an island-wide unconformity is less extensive than it had previously been thought, it still seems to be a logical expectation.

The Grotto Beach Limestone -- Recent work has shed little new light on the nature of this unit. It needs very little revision.

In the original description of the type section, the Grotto Beach Limestone was said to have been overlain by the Grahams Harbour Limestone. The material above the unconformity is most likely Late Holocene in age and correlated with similar late Holocene deposits to the south (see index map of San Salvador).

Grotto Beach Limestone deposits were reported below an unconformity on Sandy Hook. Further study of this horizon reveals that it is not an unconformity at all but instead it is an unusual coral bearing storm deposit. Resistant to erosion, that horizon formed a small bench which looks like an unconformity.

Other Grotto Beach Limestone deposits were reported between Rocky Point and Grahams Harbour (Titus, 1983b). These are actually exposures of the Dixon Hill Limestone.

Micrite pebbles -- Bain (1984) has argued that the micrite pebbles, on San Salvador, are diagenetic in origin. He is most certainly correct in regards to those grey pebbles which are so common in the dolines and caves of the island. He is probably correct in regards to the shiny, jet black pebbles found on the beaches and within Pleistocene deposits of the island, although a different process must have formed them. The chance that there is a black micrite unit on the island now appears to be remote.

Summary

Figure 2 presents a summary of the current working hypothesis for the Late Quaternary history of San Salvador. The history begins at approximately 120,000 years ago. At that time it is likely that all or almost all of the island was submerged. The Sangamonian interglacial stage, however, was coming to an end. Soon, with the onset of the Wisconsin glaciation, sea levels would drop and a long period of emergence would begin. Deposition, at this time, began with shallow subtidal deposits. Later, as the island actually emerged, beach and then dune deposits formed. All of these deposits belong to the Grotto Beach Limestone and this emergent sequence makes up the right hand bracket of Figure 2.

After perhaps ten or fifteen thousand years of actual emergence there was another period of rising sea levels. This episode was of very short duration and it was followed by another period of emergence. Once again shallow, subtidal deposits followed by beach and then dune deposits were formed. This emergent sequence falls within the bracket on the middle of Figure 2 and it makes up the rocks of the Dixon Hill Limestone.

There then followed a period of thirty to forty thousand years of exposure. Sea levels dropped considerably and most of the karst features of the island began to form. (Some areas of higher elevations, such as Sandy Point, were not submerged during the Dixon Hill sea level rise and there karst feature got an earlier start and formed over longer periods of time.) Most of the caves and dolines of the island probably date to this time.

The next sea level rise occurred at approximately 30,000 to 40,000 years ago. It was a brief event and the rise only reached 2.5 m above the present levels. The only extensive deposits of this event are the thin lake deposits found in the low-lying areas of the island (Lake Cockburn). This sea level rise affected the island primarily in carving the sea cliffs and wave-cut notches around the southwestern and western coasts. Many of the island's dolines were filled or partially filled at this time.

The last major sea level drop followed immediately thereafter. The seas drained completely off the San Salvador platform. It is most likely that the outer cays of San Salvador formed at this time. The cays are better cemented than the late Holocene deposits and so they are probably older. The cays do not show any evidence of the wave-cut notches produced during the sea level rise of 35,000 to 40,000 years ago and thus they are probably younger than this event. Older than the late Holocene deposits and younger than the latest Pleisocene units, the cays are probably early Holocene or about twenty thousand years in age.

The last depositional event on San Salvador was the formation of the beach accretion ridges (Figure 1), a process which continues today.

Acknowledgments

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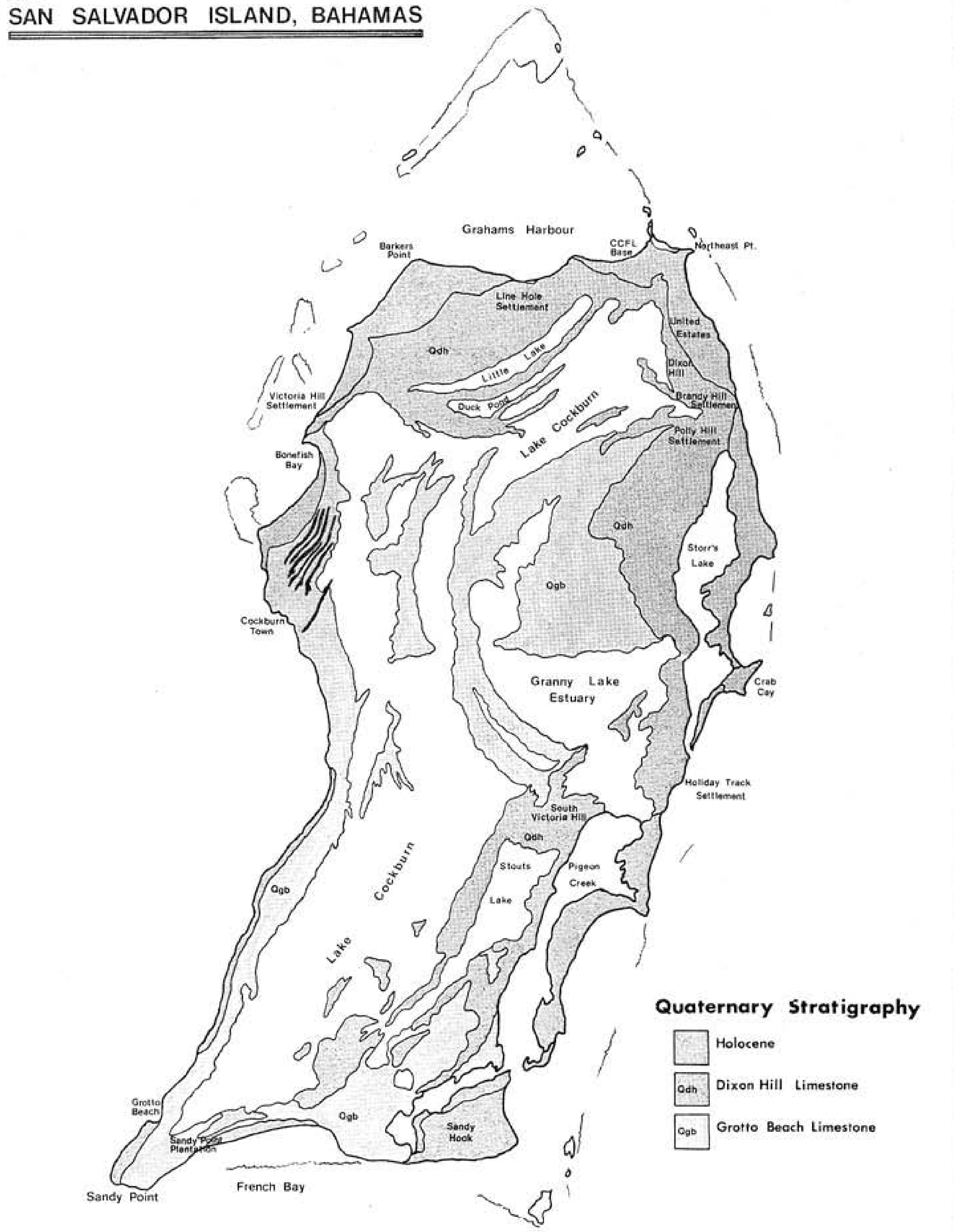
Fig. 2


SAN SALVADOR ISLAND, BAHAMAS
Grahams Harbour
Barkers Point
CCFL Base
Northeast Pt.
Line Hole Settlement
United Estates
Qdh
Little Lake
Dixon Hill
Victoria Hill Settlement
Duck Pond
Lake Cockburn
Brandy Hill Settlement
Polly Hill Settlement
Bonefish Bay
Qdh
Storr's Lake
Qgb
Cockburn Town
Granny Lake Estuary
Crab Cay
Holiday Track Settlement
South Victoria Hill
Qdh
Stouts Lake
Pigeon Creek
Qgb
Lake Cockburn
Quaternary Stratigraphy
Holocene
Qdh Dixon Hill Limestone
Qgb Grotto Beach Limestone
Grotto Beach
Qgb
Sandy Hook
Sandy Point Plantation
French Bay
Sandy Point
Titus 1984

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