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Cover photo: *Diploria strigosa*, the common brain coral, preserved in growth position at the Cockburn Town fossil coral reef site (Sangamon age) on San Salvador Island. Photo by Al Curran.

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# GEOMORPHOLOGY, STRATIGRAPHY, AND THE QUATERNARY HISTORY OF SAN SALVADOR

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## ABSTRACT

Landscape analysis can be a valuable adjunct to the study of Bahamian stratigraphy. Much of the landscape of San Salvador represents a Sangamon-aged atoll. Depending on the structure of the dune complexes, episodes of transgression and regression can be recognized. Pre-Sangamon, Sangamon, Wisconsin and Holocene stratigraphic units make up San Salvador.

## INTRODUCTION AND BACKGROUND

In a series of earlier reports (Titus, 1980, 1983a, 1983b, 1984), classical 19th century physical stratigraphy has been employed to decipher the surficial stratigraphy of San Salvador. This paper is an update of those reports and focuses on the landscape and recent geologic history of the island.

Today the dominant topographic features of San Salvador are the arcuate dune systems. These lie disconformably upon a Sangamon topography which has three major provinces (Figs. 20, 21). First there is an elevated outer rim which makes up much of the periphery of the modern island. The Queen's Highway follows this rim. Virtually all the exposures of late Sangamon reef are within this province. Behind the rim is a basin province. Many of the fossil dunes now lie within this province but if they were removed, the basin would be continuous across much of the island. Where exposed, a tough karst crust makes strata here hard to examine. Several exposures, however, have yielded marine fossils. The third province is a broad rise in the east-central part of the island. Removal of the dunes from this area would leave a flat plateau of 5 or 6 m in elevation. In the Bahamas such a feature begs for explanation.

Curran and White (1984) offer insights which allow these provinces to be interpreted. Their study of the Cockburn Town fossil reef focused on the vicinity where the rim province is best exposed. They found a regressive facies pattern. The barrier reef is overlain by shallow subtidal and beach facies with some low dune deposits at the top. As reef, beach, and dune sequences are common elsewhere within the rim province and the regressive facies pattern seems characteristic of the province, it is argued that the whole province represents the barrier reef of a Sangamon atoll.

If the barrier reef interpretation is accepted, then the basin province represents the back reef lagoon. The plateau province is 5 to 6 m in elevation, and the Sangamon sea level rise is commonly thought to have been 6 m. Thus a very shallow shoal must have existed within the lagoon (Fig. 20). There seems to be no obvious reason why such a shoal should have formed and it seems more likely that this province represents a remnant of a pre-Sangamon San Salvador. If this is so, then these rocks would be among the oldest exposed in the Bahamas. This is hypothesis until more work is done.

Landscape analysis may be a help in resolving a problem that has emerged in the study of San Salvador stratigraphy. The various dunes systems of San Salvador were produced during several episodes of emergence and submergence. It has not been clear which dunes are emergent and which are submergent. Titus (1984) has, for example, found an emergent facies pattern within a submergent dune system at Grahams Harbour. Carew and Mylroie (1985) refer to the problem several times.

The dune systems of San Salvador display three landscape morphologies. The first and most common occurs when the largest dune is the farthest from the source, most commonly the sea (Fig. 17). Younger dunes are progressively lower. This results from episodes of emergence. As emergence occurs,

large amounts of sediment become exposed. The first formed dunes are largest. As the remaining dunes form, sediment becomes depleted and probably also stabilized by plants. Thus later dunes are smaller. Most of the dunes of San Salvador are associated with such emergent events.

The least common dune system on San Salvador occurs when the largest dunes system is closest to the source area. Progressively smaller dunes are found away from the source (Fig. 18). These seem to be transgressive sand dunes. In Grahams Harbour and at Dixon Hill where transgressive dunes are found (Fig. 1, 2), the facies patterns of the subtidal, beach, and dune deposits rise toward the sea. Carew and Mylroie earlier concluded, on the basis of cave history, that the Dixon Hill dune system was transgressive in origin.

The third dune system type found on San Salvador is a single dune set associated with episodes of emergence (Fig. 19). The dune set making up the rim province of the island belongs to this category. As the Sangamon atoll emerged, dune deposits veneered the periphery of the island (Fig. 21). The dune deposits making up most of the outer cays of the island may record a much more recent episode of emergence.

## LATE QUATERNARY HISTORY

### The pre-Sangamon

The pre-Sangamon history of San Salvador is little known, but there is hope that evidence for that history can be found. Small exposures of old rock are known, and Carew and Mylroie (1985) have even informally named the unit the Owl's Hole Formation. If, as predicted here, pre-Sangamon rocks make up much of the interior plateau of the island, then perhaps more can be learned of the earlier history.

### The Sangamon Grotto Beach Limestone

During the Sangamon, San Salvador must have been a fine atoll. An extensive barrier surrounded a broad lagoon interrupted only by the shallow shoal of the pre-Sangamon province (Fig. 20). The fall in sea level which marked the end of the Sangamon had an enormous effect upon San Salvador. Waters abruptly drained off the island. This emergence was long ago recognized in the strata of the Grotto Beach Limestone (Titus, 1980). Shallow subtidal, beach, and dune deposits can be seen along the cliffs of Grotto Beach, Sandy Point, French Bay, and at Sandy Hook. The Grotto Beach Limestone is largely buried elsewhere on the island (see map).

Carew and Mylroie (1985) have interpreted the cliffs at French Bay and perhaps the dunes east of Great Lake as belonging to an early transgressive member of the Grotto Beach Limestone (the French Bay Member). They cautiously note, however, that such interpretations are difficult. The facies patterns of French Bay are regressive as dune deposits overlie beach deposits. Elsewhere, however (Grahams Harbour; Titus, 1984), such patterns have proven to be deceptive. The earlier discussions of dune patterns should be employed here. The French Bay deposits are part of the rim province and formed as that province emerged. The dunes of Great Lake are also emergent as the older and taller dunes are away from the source while the younger and lower ones are near to it (Figs. 4, 5). The wave cut notch discussed by Carew and Mylroie (p. 38-40) is too young to be of any value. This notch correlates with another one about 100 m north of Grotto Beach. This 4 m sea level rise is thus younger than the Grotto Beach at its type section and thus much younger than early member of the unit. It appears that there is no good reason to recognize any early transgressive member of the Grotto Beach Limestone.

Carew and Mylroie (1985) have proposed that the long recognized emergent facies of the Grotto Beach Limestone be named the Cockburn Town Member. If the Transgressive French Bay Member is not accepted, then the Cockburn Town is not needed and should also be abandoned (N. Am. Strat. Code, Art. 25).

After the initial emergence, the shoal of the Sangamon atoll became an ideal source area for dune deposits. Rising 5 or 6 m above sea level, such sediment caught the prevailing winds and blew off to the west. An emergent dune complex developed such as was described earlier (Figs. 5, 18). The tallest of the dunes are found to the west, farthest from the source area. The younger dunes are arrayed to the east. Figure 22 shows the close juxtaposition of the former

shoal and these late Grotto Beach-aged dunes.

In summary, it is argued herein that the Grotto Beach Limestone represents San Salvador from the time it was a Sangamon atoll to the time when that atoll emerged. Its major elements are a barrier reef and a lagoon, both blanketed by an emergent facies pattern of beach and dune deposits. There is no transgressive sequence.

By early Wisconsin time the island was completely emergent. With this, corals were permanently displaced from their former location (the rim province) to the periphery of the island's platform (Figs. 11, 12). The island's extensive karst features began to develop at this time.

## The Wisconsin Dixon Hill Limestone

The post Grotto Beach 4 m sea level rise would have submerged almost all of the San Salvador platform (Fig. 24) and deposited a veneer of sediment which the future serve as a source of sediment for a new stratigraphic unit, the Dixon Hill Limestone. The best shoal developed along the southeast flank and in the north (Fig. 24).

There is a transgressive and regressive record of this sea level change. The dune complexes of the CCFL Base and Dixon Hill vicinities display the transgressive structure discussed earlier (Figs. 1, 2). The lowest dunes are inland away from the source with the tallest dunes found near the source.

Most of the Dixon Hill dunes are emergent, however. The greatest emergent dune complex stretches from Sandy Point to Crab Cay (Geologic map; Figs. 4, 6, 25). The tallest of these dunes lies inland while the lowest are near the shore. The same emergent dune structure is found at the north end of the island (Fig. 9), and in the Hard Bargain Hill province (Fig. 3).

Between the dunes the Dixon Hill Limestone is generally less than 1 m thick. The unconformity can be seen in sinkholes and along the waterpipe road in the Line Hole Settlement vicinity. The contact may be exposed in Quarry A at United Estates (micrite unit "letter A" of Bain, 1985). Elsewhere the contact can be seen at Crab Cay where dune deposits lay upon Grotto Beach reef deposits. On the east coast it is common to see Dixon Hill dunes extending below sea level while the Grotto Beach corals rise above sea level. The disconformity can safely be inferred. From air photo analysis the disconformity can be seen in the Hard Bargain Settlement vicinity. The contact at the Sandy Point Plantation quarry represents the contact of the Grotto Beach and Dixon Hill Limestone (Fig. 6). This is based upon the examination of air photos. Carew and Mylroie disagree (1985) on the basis of radiometric dates.

Carew and Mylroie (1985) demoted the Dixon Hill to member status and lumped it with the Grotto Beach Limestone. This is wrong. They argue that the abundance of oolites and the karst features characteristic of both units link them. They express (1986, personal communication) doubts about the regional disconformity.

The two units represent separate episodes in the history of San Salvador. The Grotto Beach represents a Sangamon atoll and its emergence in early Wisconsin time. The Dixon Hill represents a Wisconsin-aged cycle of transgression and regression. The separate identities of these events are blurred when they are lumped. Regional disconformities serve to separate lithostratigraphic units at the formational level (N. Am. Strat. Code, 22e) and should not be found within a formation, as Carew and Mylroie propose when they lump the two.

## Late Wisconsin

Having been previously critical of some of Carew and Mylroie's interpretations, I would like to strongly endorse their views upon a late Wisconsin sea level rise. Based upon the solution history of the Lighthouse Cave, Carew and Mylroie (1985) recognized a minor sea level rise sometime around 35 to 40,000 years ago. This view has been received with some skepticism, but they are right.

There is clear stratigraphic evidence for this sea level rise. The Granny Lake Estuary (Hinman, 1980; Thalman and Teeter, 1983; Florentino and Bain, 1984) represents deposits which must be younger than the Dixon Hill dune deposits within which they rest. Similarly the fossil Lake Cockburn deposits (Titus, 1984) must be younger than the Dixon Hill deposits within which they rest. Both the estuary and the lake seem to have been about 2.5 m above present sea level. On the west side of the island in the Line Hole vicinity, there is a small wave-cut

cliff which cuts into both Grotto Beach and Dixon Hill deposits (Fig. 9) but is overlain by Holocene sediments. Notches in this cliff and in the sea cliff on the west side of Sandy Point both appear to be at about 2.5 m elevation. Altogether the Lighthouse Cave, Granny Lake, fossil Lake Cockburn and the sea cliffs are consistent with a low sea level rise occurring after the Dixon Hill Limestone, but before the Holocene.

As a short sea level rise, it did not produce much sediment. The emergence which followed, however, may have produced North Point and most of the outer cays. This is hypothesized on the basis of analogy with the emergent dune deposits of the Grotto Beach rim province and with a prejudice for emergent rather than submergent dunes. This hypothesis fails if the 5,000 year date for North Point reported by Carew and Mylroie (1985) is, in fact, correct.

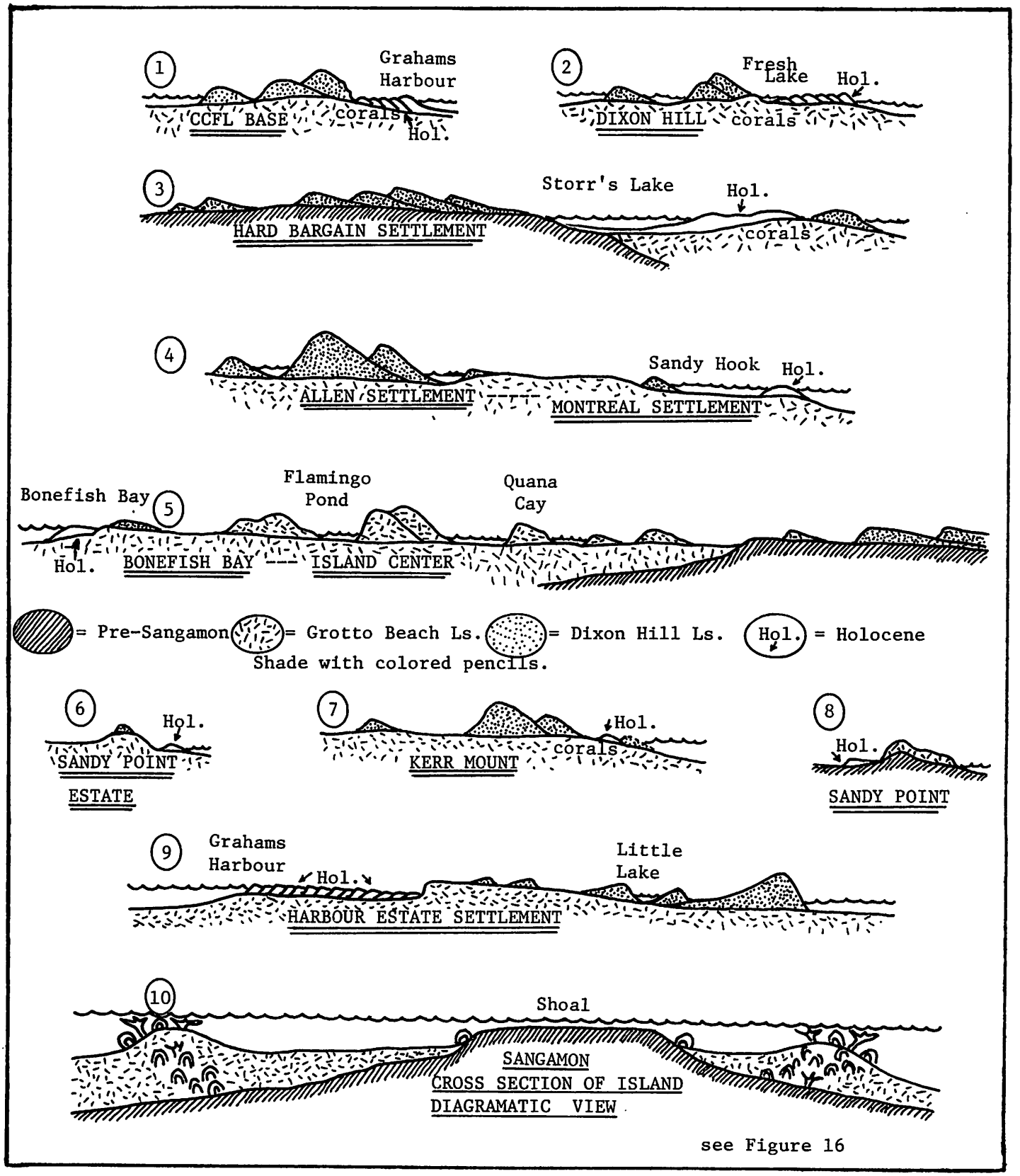
Deposits from the late Wisconsin submergence are rather sparce and probably do not merit full formational status (N. Am. Strat. Code Art. 12). Florentino and Bain (1984) have named the Granny Lake deposits the Granny Lake Oolite and this may best serve as an informal name for all those deposits (Granny Lake Estuary, fossil Lake Cockburn, and perhaps the outer cay dune deposits).

## Holocene

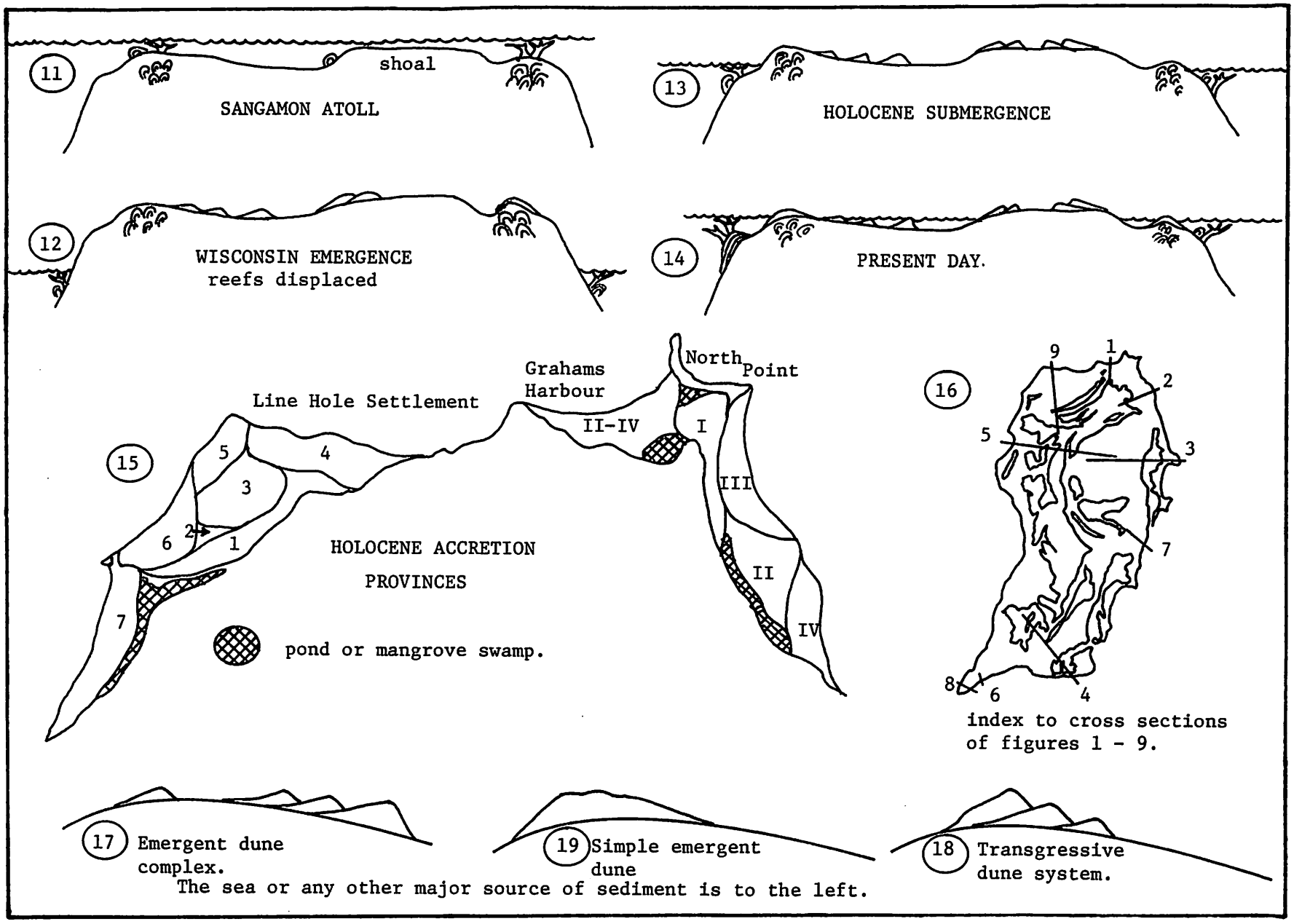
As sea levels have recently risen to their present levels, deposition has occurred at a number of sites around the island's periphery. Some of these were recognized by Adams (1980). Other Holocene deposits were incorrectly lumped in with the older deposits (Titus, 1980, 1983, 1984). Hatten (1983) recognized the Holocene age of some of these rocks and then Titus (1984) mapped the Holocene. Carew and Mylroie (1985) named the Holocene rocks as the Rice Bay Formation with two members, the below present day sea level deposits of the North Point Member and the adjusted to present sea level beds of the Hannah Bay Member. The largest Holocene provinces are in the north (Fig. 15). Air photo analysis and ground surveys show that these provinces have been accreting gradually over time (Fig. 15). In the Grahams Harbour-United Estates vicinity, the provinces are numbered from I-IV. Originally North Point was separate from the rest of the island. Then province I-IV accreted successively. I and II are rock, III is very soft rock and province IV is all sand. Titus (1984) found that the Grahams Harbour sequence (ages II-IV) was deposited during rising sea levels. The oldest beach accretion ridges (Time II) being clearly below sea level while the younger ridges rose to the present day level. Accordingly, the oldest rocks (Time I & II) were deposited when sea levels were lower.

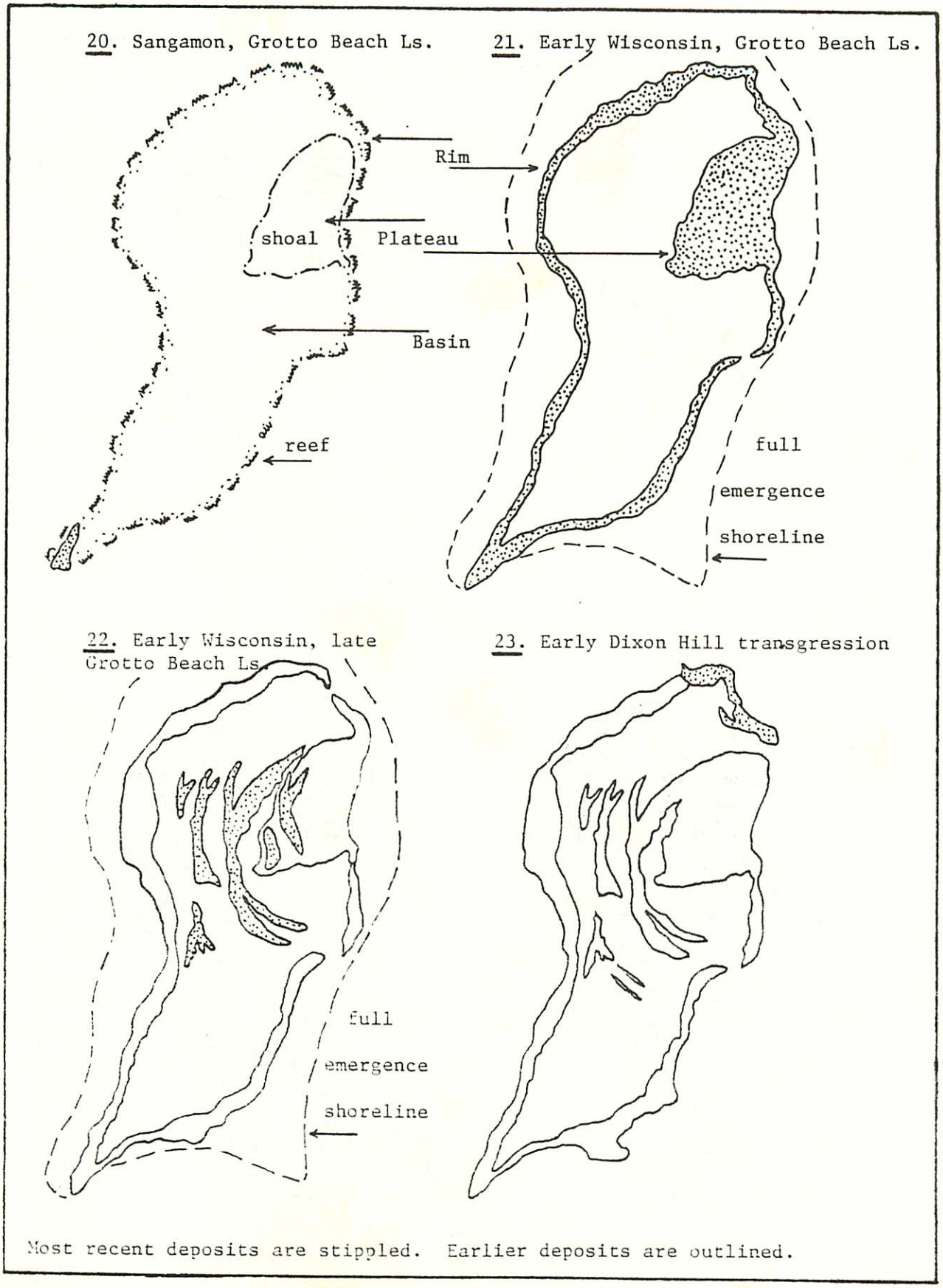
Seven accretion provinces are found in the Line Hole vicinity (Fig. 15). Province 1 is an exact analogue to the Grahams Harbour province. There the swales between the beach accretion ridges are below sea level. Provinces 2, 3, and 4 are mixed rocks and sand and provinces 5, 6, and 7 are mostly sand with some beachrock. Elsewhere on the island, the Holocene provinces appear to be very young, sandy, and generally deposited in adjustment with modern sea levels.

In general, then, the Holocene deposits span a continuous length of time and have been deposited while sea levels gradually rose to their present level. Thus a two-fold subdivision on the basis of adjustment or non-adjustment to present day sea level is artificial. I recommend acceptance of the Rice Bay Formation as a name for all Holocene rocks on San Salvador. These may or may not include North Point and the outer cays, depending on their age. The two members of the Rice Bay are unnecessary (N. Am. Strat. Code, Art. 25).

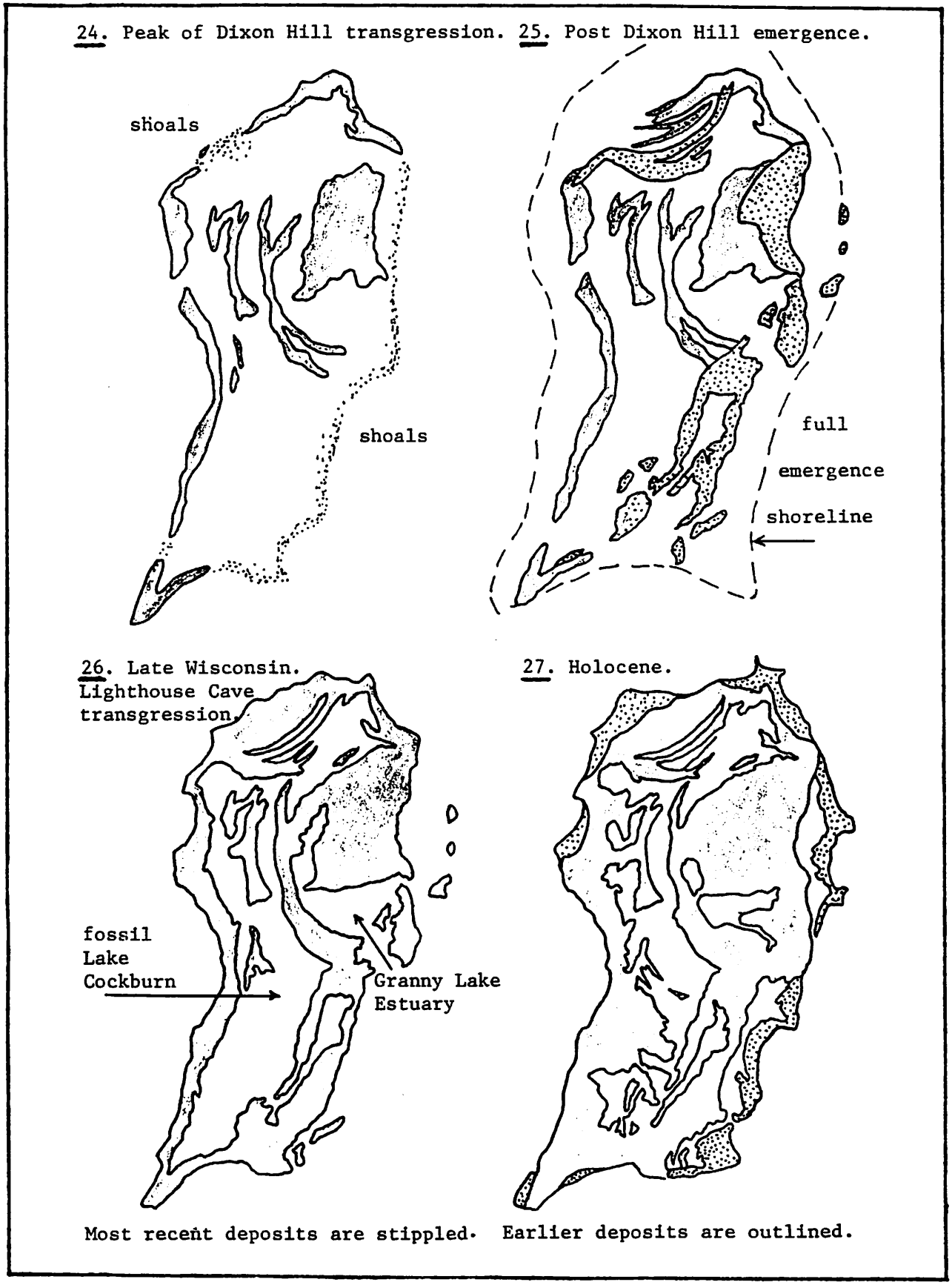


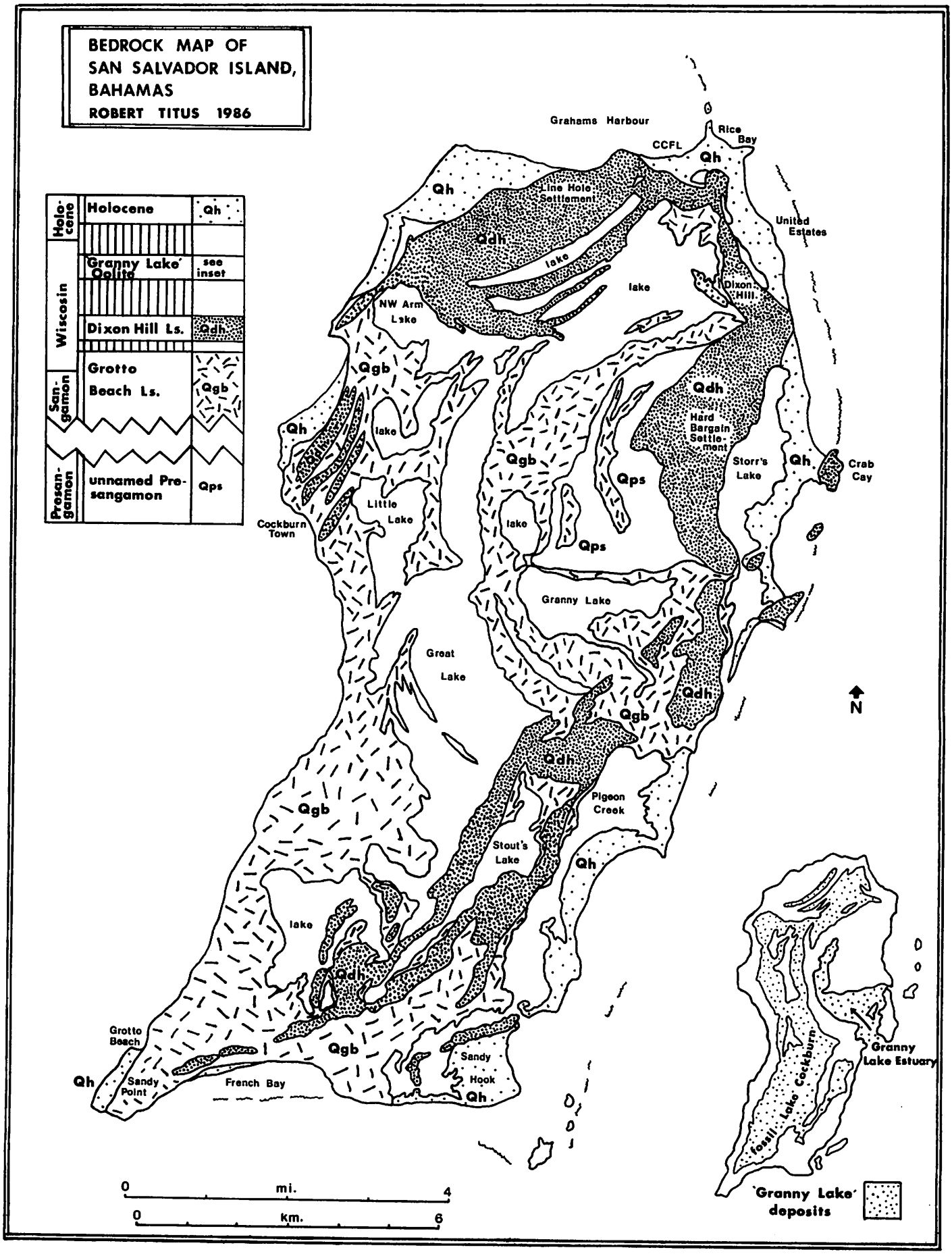

Figs. 1-27 (on this and following 3 pages). Development of the landscape of San Salvador Island.


11
shoal
SANGAMON ATOLL
13
HOLOCENE SUBMERGENCE
12
WISCONSIN EMERGENCE
reefs displaced
14
PRESENT DAY.
15
Line Hole Settlement
Grahams Harbour
North Point
II-IV
I
III
II
IV
1
2
3
4
5
6
7
HOLOCENE ACCRETION PROVINCES
pond or mangrove swamp.
16
1
2
3
4
5
6
7
8
9
index to cross sections of figures 1 - 9.
17
Emergent dune complex.
19
Simple emergent dune
18
Transgressive dune system.
The sea or any other major source of sediment is to the left.




Most recent deposits are stippled. Earlier deposits are outlined.


24. Peak of Dixon Hill transgression.
25. Post Dixon Hill emergence.
shoals
shoals
full
emergence
shoreline
26. Late Wisconsin.
Lighthouse Cave
transgression
27. Holocene.
fossil
Lake
Cockburn
Granny Lake
Estuary
Most recent deposits are stippled. Earlier deposits are outlined.


BEDROCK MAP OF
SAN SALVADOR ISLAND,
BAHAMAS
ROBERT TITUS 1986
Holocene
Qh
Granny Lake Oolite
see inset
Dixon Hill Ls.
Qdh
Grotto Beach Ls.
Qgb
unnamed Pre-sangamon
Qps
Holo-cene
Wiscosin
San-gamon
Pre-san-gamon
Grahams Harbour
Rice Bay
CCFL
Line Hole Settlement
United Estates
Dixon Hill
NW Arm Lake
lake
Hard Bargain Settle-ment
Storr's Lake
Crab Cay
Little Lake
Cockburn Town
Granny Lake
Great Lake
N
Pigeon Creek
Stout's Lake
Grotto Beach
Sandy Point
French Bay
Sandy Hook
Granny Lake Estuary
fossil Lake Cockburn
Granny Lake deposits
0 mi. 4
0 km. 6

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