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GEOMORPHIC EVOLUTION OF TOPOGRAPHIC LOWS IN BERMUDIAN AND BAHAMIAN ISLANDS: EFFECT OF CLIMATE

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ABSTRACT

Bermudian and many Bahamian landscapes are dominated by Pleistocene eolianite ridges. The eolianites formed when sea level submerged the platforms surrounding the islands, but generally when sea level was below its present position. Therefore, the Holocene sea-level rise has submerged many interdune depressions, and they have become marshes, ponds and lakes.

In the central and southern Bahamas, potential evapotranspiration nearly always exceeds rainfall. Interior ponds and lakes are discharge sites for fresh ground water and have the effect of upconing the fresh-water/salt-water interface. Accordingly, the lakes are saline to hypersaline, and the fresh-water lenses of the islands are partitioned and restricted to the eolian ridges. In Bermuda, rainfall exceeds potential evapotranspiration, producing fresh-water marshes and ponds which help recharge the surrounding limestone with CO_2-enriched fresh ground water.

Interdune depressions of Bermuda that have been submerged by the water table during interglacial epochs have been enlarged through time by lateral corrosion planation from fresh-water lakes and marshes. The depressions were further modified and deepened by vadose dissolutional processes during glacio-eustatic lowstands. Some depressions have been subsequently flooded by marine water, so the borders of these topographic lows are in the marine-marginal environments of bioerosion, on the water side, and erosion by fresh-water/salt-water mixing on the land side. As a result of all these processes, small depressions have enlarged, deepened and coalesced. In the arid central and southern Bahamas, however, the hydrology prevents the initial enlargement during the fresh-water stage; accordingly, topographic lows do not expand laterally, and hypersaline interior marshes and ponds do not evolve into large inshore water bodies. The Bahamian depressions remain essentially the same through time unless invaded by open marine waters.

INTRODUCTION

Besides shorts, grass, and onions, Bermuda is well-known for several geologic features: a carbonate landscape that has taken shape in the last million years (Bretz, 1960); a stratigraphy reflecting intermittent flooding of a shallow platform (Sayles, 1931; Bretz, 1960); a marginal-marine assemblage consisting of eolian limestones, terra-rossa paleosols and related facies (Land and others, 1967). One of the most striking features of the landscape is the presence of the large inshore basins that dominate the outline map of Bermuda (Fig. 1). As stated by Bretz (1960, p. 1729): "The curvilinear fingers constituting the Bermuda Islands enclose or nearly enclose almost 60 square miles of sounds, reaches, harbors, and bays, approximately three times the total land area."

The outline of San Salvador (Fig. 2) is fundamentally different: where Bermuda has inshore basins, San Salvador has broad, shallow lakes. However, San Salvador -- like Bermuda -- has a landscape that has taken shape in the past million years, has experienced the same history of glacioeustatic sea-level fluctuations, and was built up by the accumulation and accretion of the same general type of marginal-marine limestones.

If the geologic history and depositional regime are similar in the two ares, then why should the geomorphology be dominated by

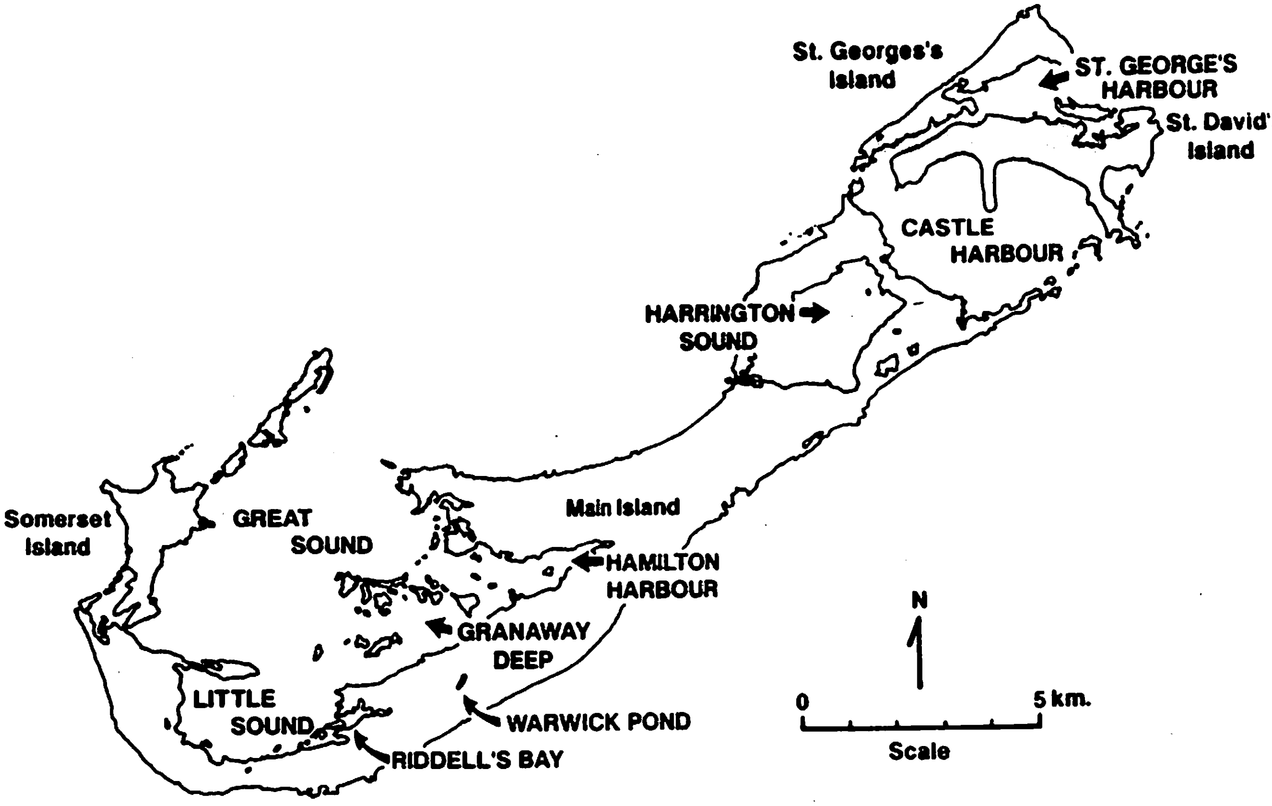

Fig. 1. Outline map of Bermuda. Major islands shown in lower case, major inshore basins or sounds in capital letters. The area of the Riddell's Bay-Warwick Pond depression (curved arrows) is shown in detail in Figure 6.

inshore water basins on one island and shallow inland lakes on the other? In order to address this question, we first consider why the inshore basins are present in Bermuda. It will be argued that these inshore basins are the end result of an evolutionary process that critically depends on a particular ground-water flow system. This flow system is present in Bermuda and absent in the central and southern Bahamas. The reason that the critical flow system is absent in the latter area is that these islands are substantially drier than Bermuda.

THE BERMUDA KARST AND THE ORIGIN OF THE INSHORE WATER BODIES

The significance of chemical erosion in shaping Bermuda's landscape was pointed out by Sayles (1931) and emphasized by Bretz (1960). To Sayles (1931), post-depositional solution was the reason for two geomorphic terrains, which he called "Younger Bermuda" and "Older Bermuda." In Younger Bermuda, the eolian ridges retain their depositional morphology (Vacher, 1973). In contrast, Older Bermuda is a partially submerged core where the dune morphology has been subdued, smoothed out by chemical erosion.

Bretz (1960) went further and, in the title of his paper referred to Bermuda as a "partially drowned, late mature, Pleistocene karst." The cornerstone of the envisaged maturity was the occurrence of the large inshore basins -- uvalas, according to Bretz (1960) -- such as Castle Harbour, Harrington Sound, and the various basins comprising the Great Sound network (Fig. 1).

Geological mapping and investigation of the present day ground-water system have led to a conceptual model (Vacher, 1978) that outlines the steps and processes in the chemical excavation of basins that are now occupied by inshore waters in Bermuda. According to this model, inter-eolianite topographic lows of one interglacial highstand become marshes in later interglacial highstands and eventually evolve into inshore sounds in still later interglacial highstands. The marsh stage of this evolution is particularly important because the marsh is a source of chemically aggressive ground water that flows directly and laterally into the limestones that are adjacent to the submerged part of the topographic low.

The evidence for the evolution is geologic. Inter-eolianite depressions in Younger Bermuda are unaffected by post-depositional alteration. Foresets of the (younger) seaward eolianite overlie windward-topset beds of the seaward flank of the more landward (older) eolianite (Fig. 3). The paleosol between the eolianites of the successive ridges intersects the ground surface along the bottom of the linear topographic depression between the two ridges. The depression has not been lowered.

Marshes occur in front of (landward of) the contact between the Younger and Older Bermuda of Sayles (1931). In the stratigraphic terminology of Figure 4, marshes occur in the topographic depression between the Rocky Bay Formation and older units, or between the Belmont Formation and older units. The paleosol associated with the contact occurs upslope from the bottom of the depression. The depression has been deepened (Fig. 5).

The setting of individual basins of the inshore basins is much like that of the marshes (Fig. 6), with three important differences. First, they are occupied by seawater and are connected to the sea. Second, they occur within Older Bermuda (Town Hill Formation). Third, they occur in front of paleosols within or below the Town Hill Formation, in the same way that marsh depressions are associated with the paleosols beneath the Rocky Bay and Belmont Formations. Commonly there are small, island remnants of older eolianites in the sound (Fig. 6). Small caves are common near the water level of the outer shoreline of the sound.

The evidence for the marsh-related chemical erosion has been developed in the hydrogeochemical study by Plummer and others (1976) of Devonshire Marsh in central Bermuda (Fig. 7). Ground water in the vicinity of the marsh is undersaturated with respect to calcite, has high PCO_2, and low values of rock-derived Ca^{++} (i.e., Ca^{++} in excess of that derived from seawater mixing). The ground water is charged with CO_2 in the marshes, flows outward into the surrounding limestones, and dissolves them. Eolianite exposed in horizontal water-resource galleries next to Devonshire Marsh is riddled with pencil-sized solution tubes below the water table. Further, when the thick deposits of peat are stranded in the vadose zone during a fall in sea level, they can oxidize and significantly contribute to the CO_2 content of descending vadose waters.

The model for the evolution of the topographic lows on Bermuda then has the following steps (Fig. 8).

1. A linear topographic depression originates because a dune ridge forms on the seaward

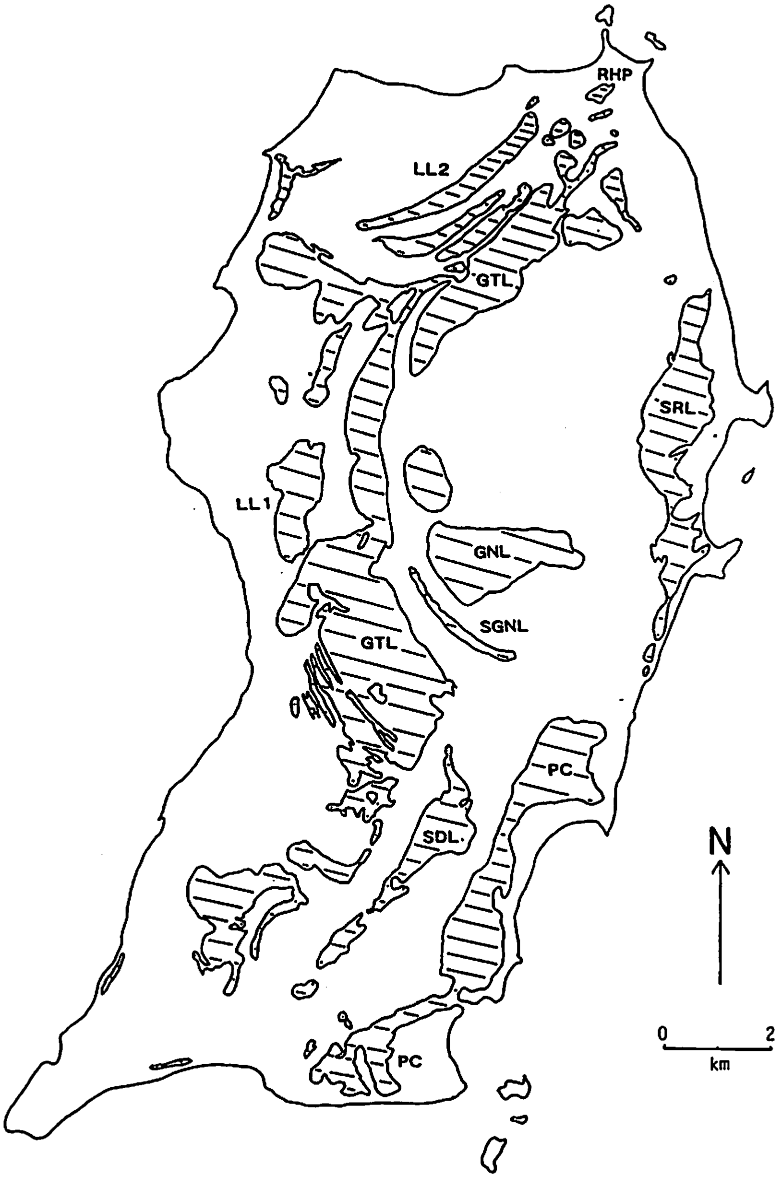

Fig. 2: Outline map of San Salvador Island, Bahamas, showing island shape and inland water bodies or lakes (diagonal line pattern). GTL = Great Lake, LL1 = Little Lake one, LL2 = Little Lake two, GNL = Granny Lake, SGNL = South Granny Lake, SRL = Storrs Lake, SDL = Stoudts Lake, PC = Pigeon Creek. All inland water bodies shown are saline to hypersaline; Pigeon Creek has a direct surface connection to the open ocean, but restricted flow produces local hypersaline conditions. The lakes in most cases clearly occupy depressions between long, arcuate dunes.

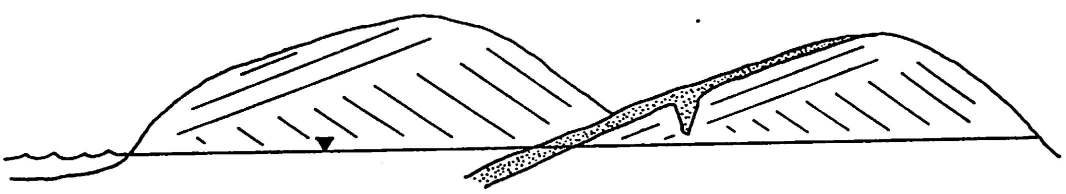

Fig 3: Diagrammatic cross section showing topographic low between successive eolianites within Younger Bermuda. Note that the stratigraphic contact (paleosol) occurs at the base of the topographic low, which in this case has not been deepened by chemical denudation.

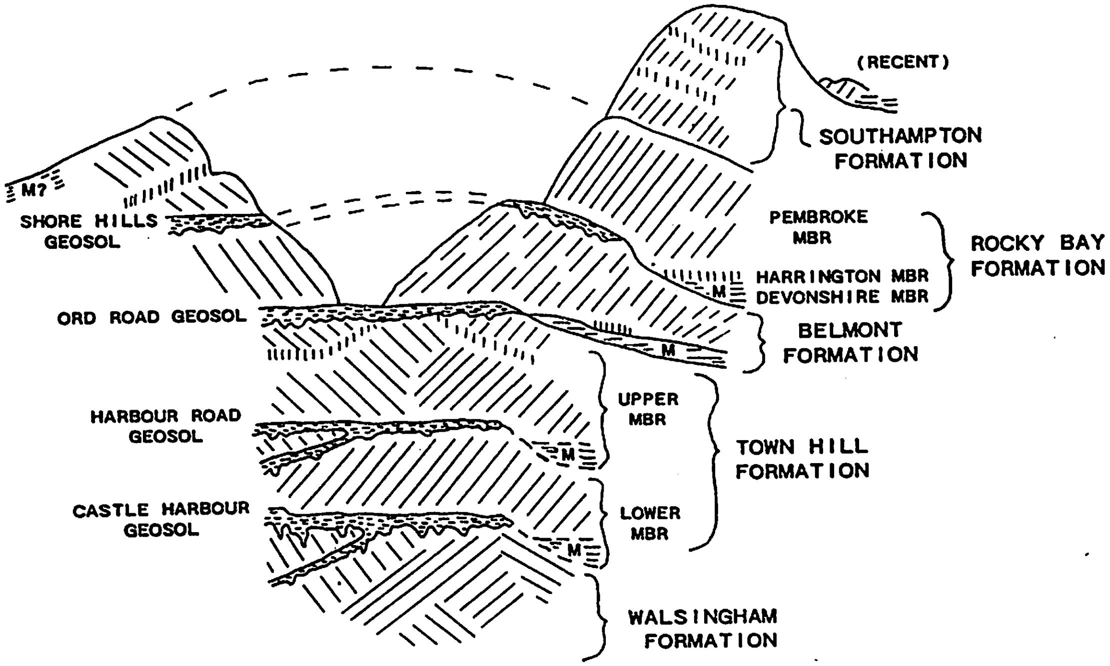

Fig. 4: Rock-stratigraphic terminology for Bermuda (Vacher and Harmon, 1987; Vacher and others, 1989). The Southampton and Rocky Bay Formation represesent the last interglacial (Stage 5) and comprise Younger Bermuda (Vacher, 1973) and the Paget aquifer (Vacher, 1978; Rowe, 1984). The Belmont and Town Hill Formations are Middle Pleistocene and comprise the Belmont aquifer (Vacher, 1978; Rowe, 1984). The Walsingham is believed to be Lower Pleistocene. The symbol "M" represents marine units.

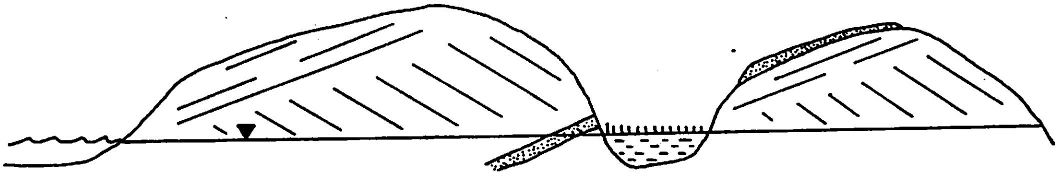

Fig. 5: Diagrammatic cross section showing the geologic setting of a marsh occupying a topographic low between Younger Bermuda (left and seaward) and Older Bermuda (right and landward).

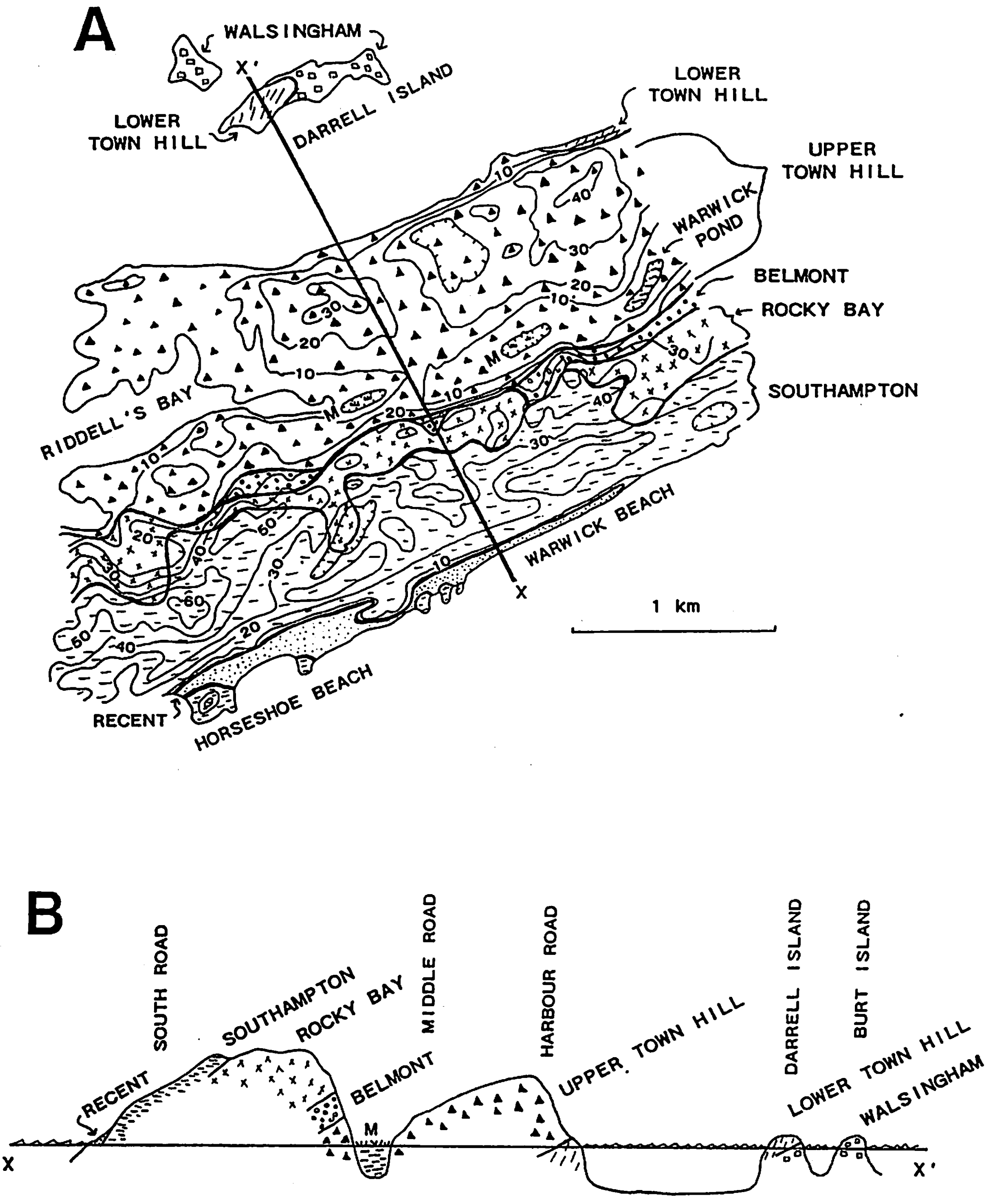

Fig. 6: Geology of topographic lows at Warwick Parish. Figure 6A is the map view; Figure 6B is a cross section along the line X-X'. Contour interval is 10 m. The Riddell's Bay - Warwick Pond depression lies between Younger Bermuda and Older Bermuda. The topographic depression between Main island and Darrell and Burt Islands lies within Older Bermuda and is a part of a composite basin including Great Sound and Little Sound. This represents a more advanced stage of depression development. The depressions labled "M" are part of Pembroke Marsh.

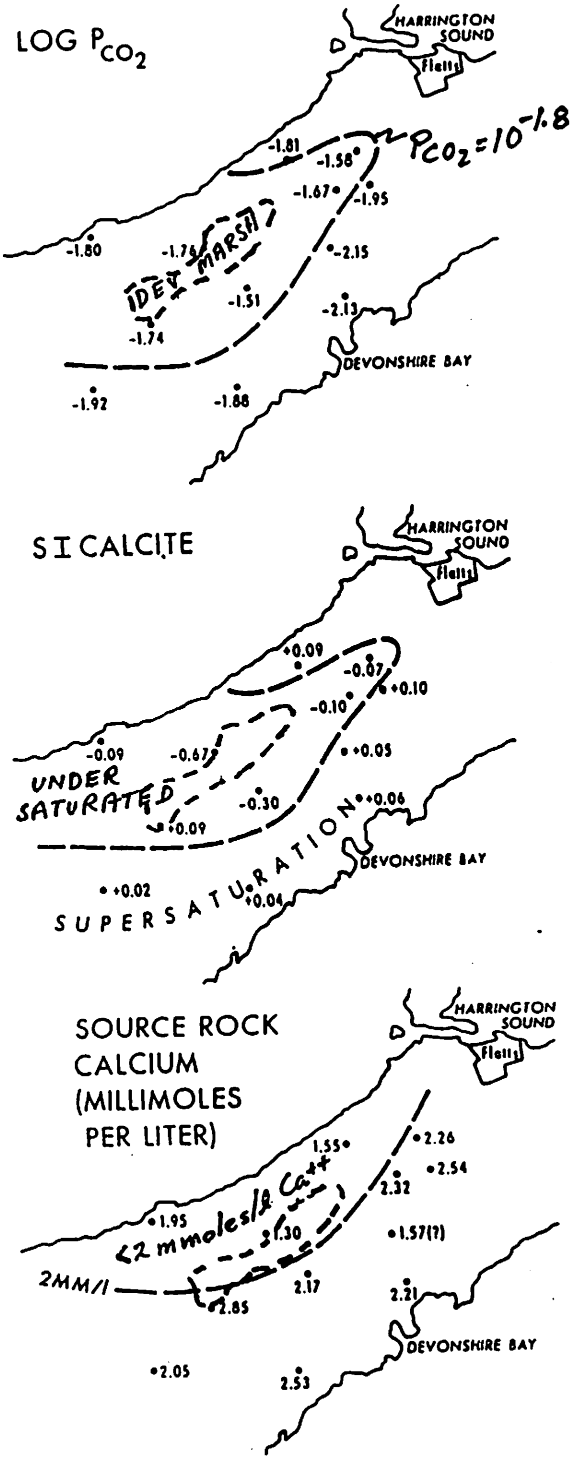

Fig. 7: Maps showing the variation in PCO_2, the saturation index for calcite (SI) and rock-derived Ca^{++} of the ground water in the vicinity of Devonshire Marsh, Bermuda (Plummer and others, 1976).

flank of an older ridge. This occurs during interglacial stages.

2. The undulating landscape is lowered, generally, because of dissolution by CO_2-enriched waters passing downward from active soils. This occurs on emergent dunes during both interglacial and glacial stages. Smart and Whitaker (1989) have shown in the Bahamas that biogenic CO_2 production in the soil is an important contributer to landscape dissolution. Vacher (1978) estimates that the rate of landscape lowering in Bermuda is about 5 m per 10^5 years from hydrogeochemical data in Plummer and others (1976). Local concentration of vadose flow on the dune flanks produces small dissolution pits, but the interdune depression deepens most rapidly because of focus of interflow (Vacher, 1978).

3. In a later interglacial stage, with the deepening of the depression and the rising sea level, the depression intersects the water table and becomes a marsh. Recharge of the fresh-water lens by CO_2-enriched water from the marsh (Plummer and others, 1976) results in phreatic dissolution of the depression margin, and the enlarged depression fills with peat.

4. With the following glacial stage, the water table drops below the peat-filled basin. The peat is removed by oxidation and leaching, and, in the process, the basin is deepened further by the downward-percolating vadose waters that scavange CO_2 from the oxidizing peat. Vadose dissolution, collapse of previosuly formed phreatic dissolution chambers, and scarp retreat deepen the depression. The collapse of phreatic voids has been documented by Mylroie (1984). The continued dissolutional lowering of the dune surface develops saddles within eolianite ridges bordering the depressions, so that some are vulnerable to marine flooding during the next interglacial stage of elevated sea level.

5. With the rise in sea level of the subsequent interglacial stage, the depressions again become fresh-water marshes, with peat deposition and depression enlargement if climatic conditions permit. If sea level rises high enough, or if dissolutional lowering and widening of the depressions are sufficient, the depressions may open to the sea and become marine sounds.

6. During the interglacial stages when the basins are inshore sounds, they are expanded laterally and become cliffed because of bioerosion as is documented by Neumann (1965) for Harrington Sound. In addition, Palmer and

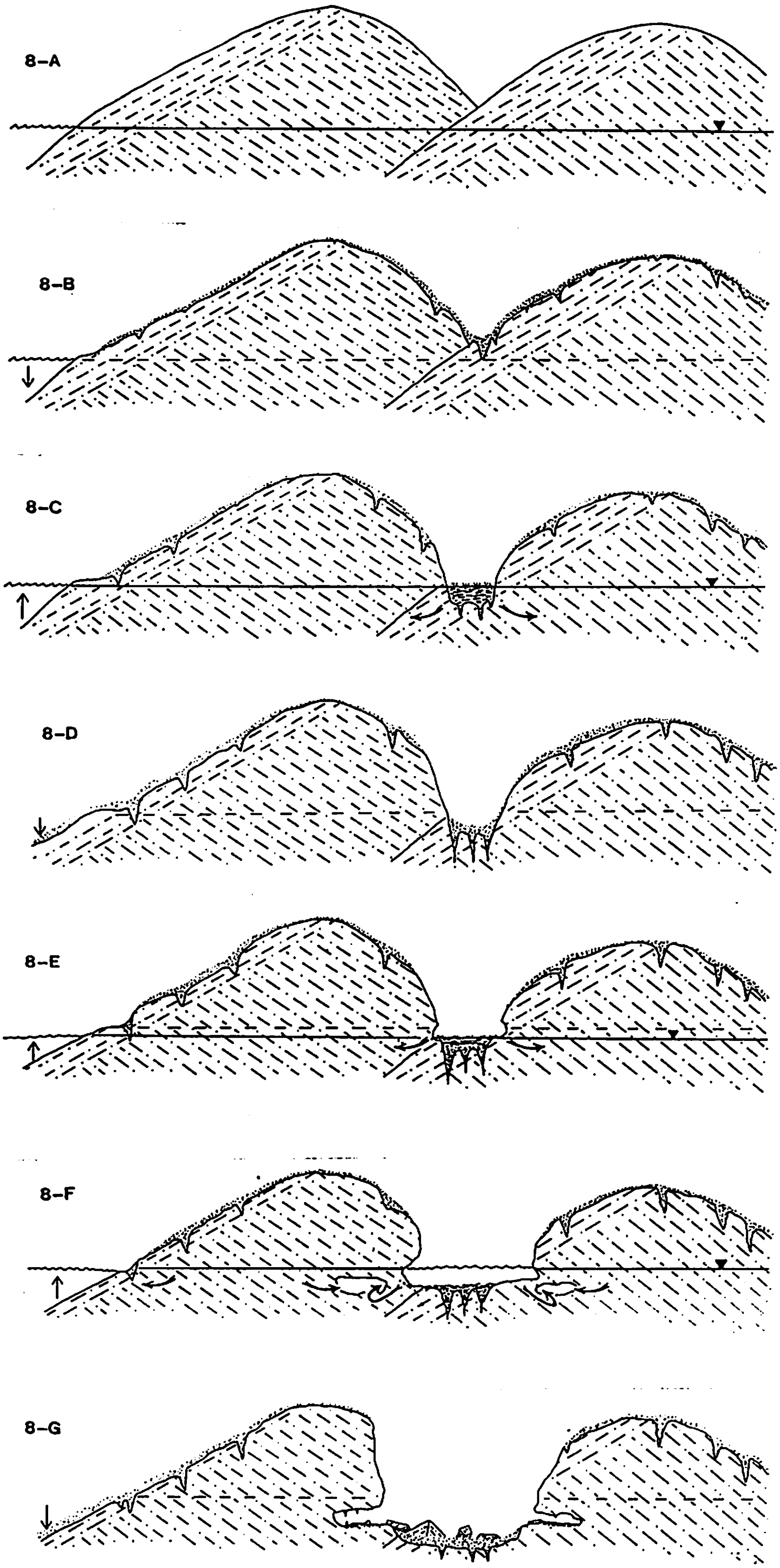

Fig. 8: Evolution of constructional topographic lows in eolianites under Bermudian climatic conditions. Dunes drawn are diagrammatic, the left-hand dune being deposited seaward and after the right-hand dune, as shown by their stratigraphic relationship. Horizontal dashed line is an arbitrary interglacial sea level position for reference purposes. The paleosol separating the dunes, as in figure 3, is eliminated here, as it is possible for the model to work given dunes deposited sequentially on the same interglacial sea-level event. The sequence presented here has ignored coastal processes and possible overstepping of the depressions by later eolianites. 8A: initial conditions; 8B: vadose landscape lowering; 8C: marsh development by intersection of depression by the fresh-water lens during interglacial sea level; 8D: accelerated vadose deepening during glacial low sea level caused by peat oxidation; 8E: re-occupation of the depression by fresh water during subsequent interglacial sea level; 8F: consequences of marine invasion of the depression; 8G: enlargement of the depression by scarp retreat, vadose processes and cave collapse during glacial low sea level. See text for a detailed discussion of this figure.

others (1977) have demonstrated enhanced dissolution in Bermuda from the mixing of small amounts of sea water with the fresh-water lens. By analogy with other areas (e.g., Back and others, 1979; Mylroie and Carew, 1988; Mylroie and Carew, 1990; Smart and Whitaker, 1989) such mixing-zone dissolution is probably significant in the phreatic zone of the limestones bordering the inshore basins. Enlargement of phreatic dissolution chambers is more rapid than other diagenetic processes (Vogel and others, 1990). Therefore, in the geomorphic evolution of Bermuda, there is a complete shift in the role of ground water from dissolution associated with fresh-water recharge to dissolution associated with brackish-water discharge.

7. Expansion and deepening of the depressions continues with additional glacial/interglacial cycles. During interglacial stages, the depressions are enlarged to basins by bioerosion and the cliffs are sapped by mixing-zone-related dissolution. With the falling sea levels in transition to glacial lowstands, marshes develop and peats are deposited in the deeper, closed-off portions within the sounds. During the glacial stages, these peats are leached, the deep basins are deepened further, and some of the caves made during earlier interglacial stages collapse.

The surface geology of the Bahamas is essentially the same as in Bermuda, with a few exceptions. Detailed studies of New Providence Island (Garret and Gould, 1984) and San Salvador Island (Carew and Mylroie, 1985) show that the Bahamas, like Bermuda, are dominated by eolianites. The Bahamas have an abundance of marine facies below 6 m elevation, and fossil reefs, which are rare on Bermuda, are present. Bermuda lies at about the northern climatic limit for carbonate islands. The Bermuda climate helps promote a large fresh-water lens, but limits sediment production in shallow platform waters. Thus Bermuda exhibits a "bullseye" arrangement of its eolianites, in which older eolianites are bounded seaward by progressively younger eolianites. In the Bahamas, carbonate sediment production appears to have been more prolific, resulting in islands in which there is a layer-cake geology of younger eolianites masking older ones beneath. The greater abundance of carbonate sediment in the Bahamas also makes longshore transport more of a factor, especially in modifying coastlines and sealing off lagoons from the open ocean, as has occurred in the Holocene (Teeter, 1985).

San Salvador Island contains many saline and hypersaline lakes (Fig. 2). These lakes are contained in basins that retain most of the original depositional morphology of the enclosing dunes. On San Salvador, only open coastlines or the restricted lagoons with marine connections (such as Pigeon Creek) contain rocky margins with cliffs. In the rare, small fresh-water ponds and blue holes on San Salvador, where the surface area of the water body is small, and the rock contains a fresh-water lens, the rocky margin of these small bodies is often cliffed. Thus in San Salvador, unlike Bermuda, the interior topographic lows have not expanded, and they are occupied by inland saline lakes, not reaches of an expanding lagoon.

EFFECT OF CLIMATE ON THE FRESH-WATER LENSES OF BERMUDA AND SOUTHERN BAHAMIAN ISLANDS

Wallis and Vacher (1990) point out a fundamental difference between the geometry of the fresh-water lenses in the islands of Bermuda and the geometry of fresh-water lenses in southern Bahamian islands. Wallis and Vacher (1990) discuss Great Exuma specifically, but the observations apply equally well to other dry, Bahamian islands such as San Salvador (Davis and Johnson, 1989) and Caicos Island (Wanless and Dravis, 1989).

In Bermuda, the Ghyben-Herzberg lens extends from shore to shore, as is shown in Figure 9 for the principal lens on the Main Island. On some parts of the Main Island, and in the smaller islands, the ground water of the lens is completely brackish. These higher-salinity ground waters are due to fresh-water/salt-water mixing in the vicinity of the interface. This mixing is from variations in sea level such as those due to tides and is greatest on the periphery of the various island masses. The crucial point is that the average configuration of the water table (and position of the interface, which is seen as the midline of the mixing zone) is such that the largest values are in the interior of the islands, and the values diminish monotonically toward the shorelines. Flow vectors are "centrifugal" in that they diverge from an interior maximum or axis. Across-island variations in the thickness of the lens and elevation of the water table reflect proximity of the shoreline and across-island variations in hydraulic conductivity.

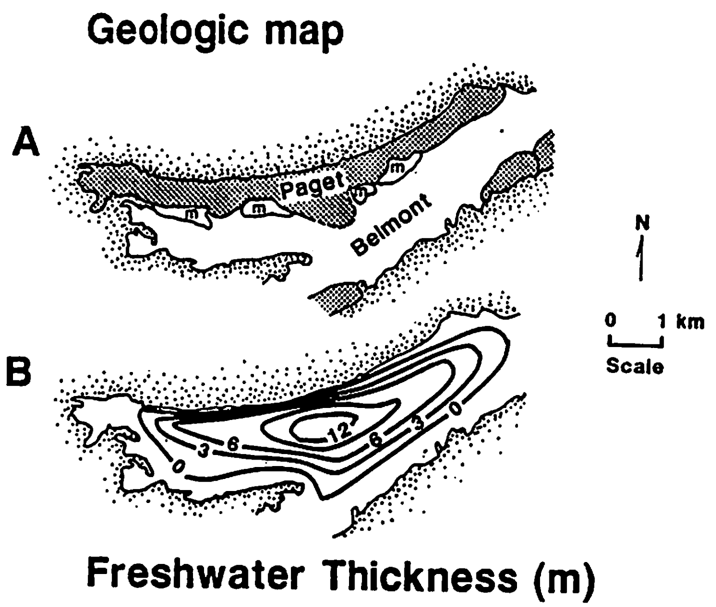

Fig. 9: Maps showing (A) the distribution of the Paget and Belmont aquifers in central Bermuda, (B) the thickness of the Ghyben-Herzberg lens in the same area (Vacher, 1974). The areas labled "m" in Figure 9A are marshes, the two eastern ones are Devonshire Marsh, the two western ones are Pembroke Marsh.

Specifically, as shown in Figure 9, the marshes have no significant effect on the average configuration of the lens.

Figure 10 shows the fundamentally different situation in Great Exmuma Island (Wallis and Vacher, 1990). The fresh-water lenses occur between the interior lakes and ponds. Within the map area of Figure 10, there are two fresh-water lenses. The major lens, in the southwestern part of the map area was mapped by Little and others (1976); it is in Pleistocene eolian limestones. The smaller lens along the eastern shoreline was recently mapped by Wallis (1990; Wallis and others, 1989); it is in a Holocene strandplain. These two lenses, together, clearly show that the dip of the water table and the rise of the interface are both toward the interior lakes and ponds in Great Exuma Island. The ground-water flow is centripetal in the vicinity of the marshes and ponds.

The same pattern occurs in San Salvador. Davis and Johnson (1989) show that the fresh-water lenses occur beneath the eolian ridges and discharge into the lakes that occur between the ridges. As at Great Exuma, and unlike Bermuda, a single lens does not extend across San Salvador; rather, there is a series of discrete lenses, and they are localized by topographic highs. Mylroie and Carew (1990) have shown that at past, higher interglacial sea levels, mixing-zone dissolution at the margin of these small lenses produced significant phreatic cave chambers.

The reason for the difference between Bermudian and southern Bahamian island hydrology is shown in Figure 11A, in which Great Exuma Island is taken as the southern Bahamas example. In Great Exuma, potential evapotranspiration greatly exceeds rainfall (by some 0.5 m/yr), so the interior lakes and ponds are sites of net ground-water loss. In Bermuda, potential evapotranspiration is about the same as, in fact a little less than, rainfall; therefore, the marshes do not effect a net extraction from the lens.

At both islands, there is positive recharge (0.4 m/yr and 0.2 m/yr for Bermuda and Great Exuma, respectively) in soil-covered or upland areas, meaning that in these areas, rainfall exceeds actual evapotranspiration. This 0.2-m/yr positive recharge in Great Exuma means that there is some tendency to build a fresh-water lens in that island. The 0.5-m/yr excess of

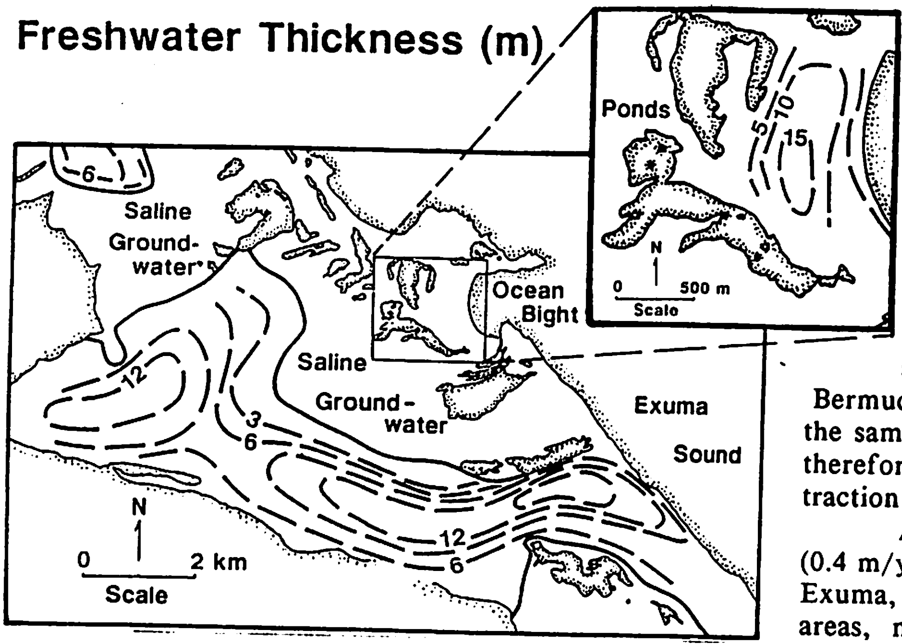

Fig. 10. Thickness of fresh-water lenses in northern Great Exuma Island, Bahamas (Wallis and Vacher, 1990). Individual lenses are separated by topographic lows occupied by saline to hypersaline lakes.

potential evapotranspiration over rainfall (Little and others, 1976), however, means that there is effectively negative recharge at the areas where water is continuously available, namely the lakes and ponds. As a result, The lakes and ponds have the same effect as a pumped well: they upcone the interface. The upconing can extend to sea level, resulting in zero lens, if the extraction is large enough or over a sufficiently large area. That this is so is seen from chemical data (McClain, 1990): the lakes, which are nontidal and hence not directly connected to the ocean, (a) are generally saltier than the nearby ground water, (b) are commonly hypersaline, and (c) bear isotopic signatures indicative of extensive evaporation. To the extent that the ponds and lakes can be considered shallow pumping wells, the pump is evaporation. Similar geochmical conditions were found on San Salvador Island (Davis and Johnson, 1989), where evapotranspiration exceeds precipitation 11 months of the year

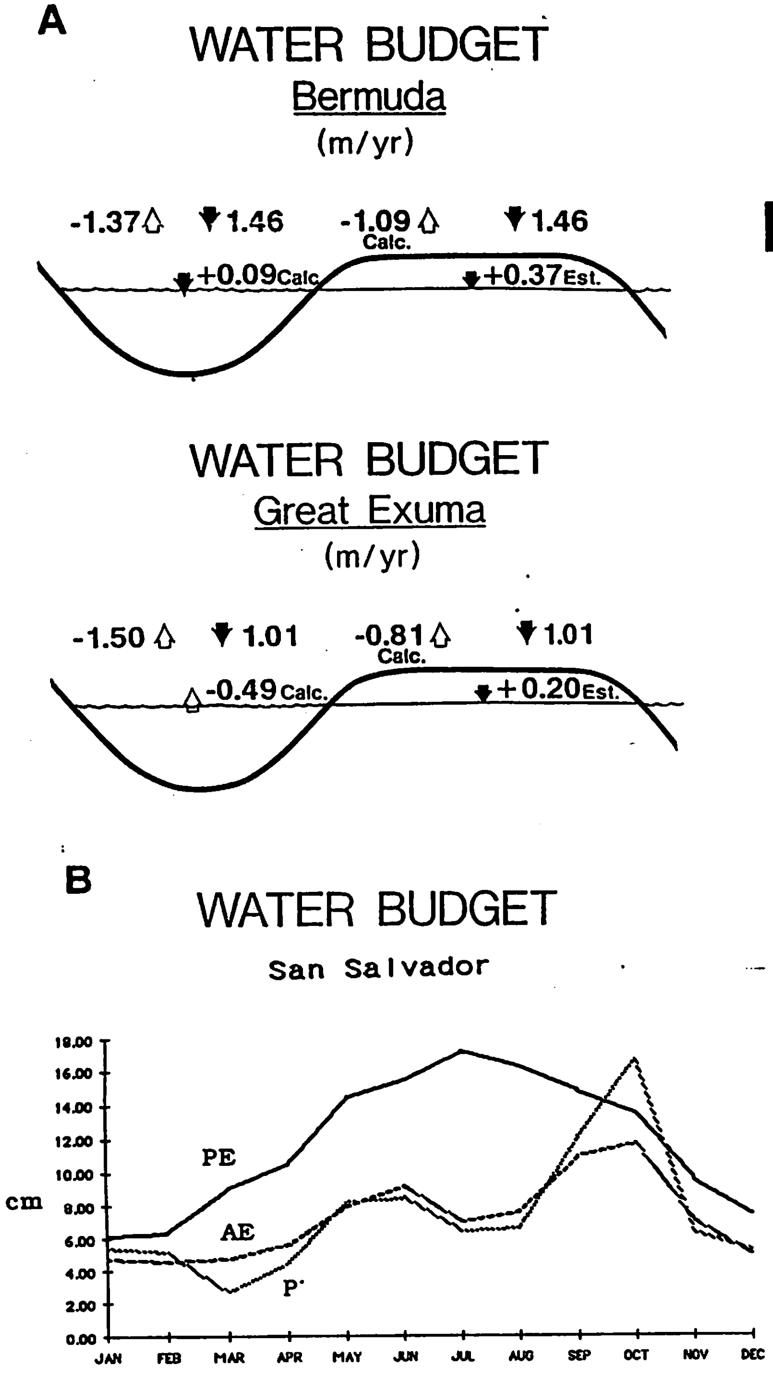

Fig. 11. Water budgets at (A) Exuma (Little and others, 1976; Wallis, 1990) and Bermuda (Vacher and Ayers, 1980), and at (B) San Salvador. PE = potential evapotranspiration, AE = actual evapotranspiration, P = precipitation (Balcerzak and others, 1990).

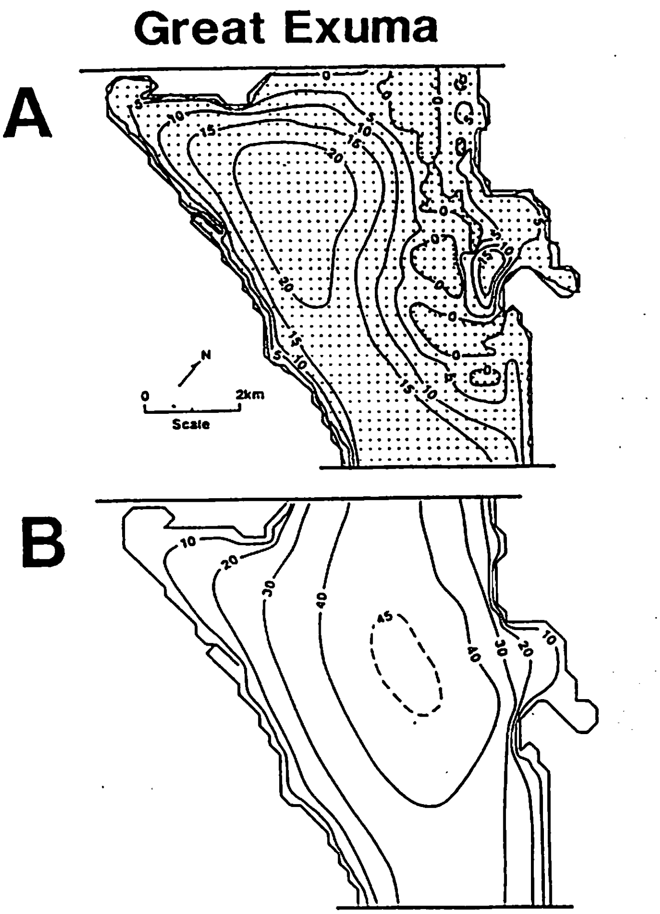

Fig. 12 Maps showing thickness of lens in northern Great Exuma from Dupuit-Ghyben-Herzberg finite-difference modelling (Wallis and Vacher, 1990). In (A), the topographic lows are given negative recharge, and the lenses are similar to those present in Great Exuma. In (B), the recharge at the topographic lows is set equal to that of the rest of the island. The difference between the two maps illustrates the difference between the presence and absence, respectively, of areas of strongly negative recharge in the interior of the island.

The conceptual model for the difference between the lenses of Bermuda and those of the southern Bahamas hinges on the fact that the interior submerged topographic lows of the southern Bahamas are sites of negative recharge, while the lows are neutral or sites of water excess in Bermuda. If Bermuda were in a climate like the southern Bahamas, the marshes would upcone the lens and fresh ground water would occur only beneath the eolian ridges. Alternatively, if Great Exuma and San Salvador were in a climate like Bermuda's, the lens would extend beyond the topographic control and cross these islands.

The latter contention was verified by Wallis and Vacher (1990) in a numerical-modeling experiment (Fig. 12). The experiment makes use of Dupuit-Ghyben-Herzberg analysis (Vacher, 1988) for flow in island lenses where the flow equations are solved by a finite-difference scheme like that developed by Fetter (1972) and adapted for spread-sheets by Stewart (1986). Figure 12A shows the prediction of the lens in the Great Exuma study area using a recharge of 0.2 m/yr in the upland areas, -0.5 m/yr at the ponds and lakes and -0.2 m/yr in the low-lying areas around the lakes, with a condition in the program that individual lake-node heads are set to zero if they became negative before convergence. Comparison of Figure 12A with Figure 10 shows that these parameters reproduce the observations in a general way. The important point to this paper is seen from comparison of Figure 12A with 12B, the latter showing the lens that would be present if the entire island received 0.2 m/yr of recharge. Figure 12B thus shows the effect of removing the evaporation-driven negative recharge at the submerged topographic lows. Clearly, the result is a lens and flow system like Bermuda's. The lens extends across the island, and ground-water flows directly from submerged topographic lows into

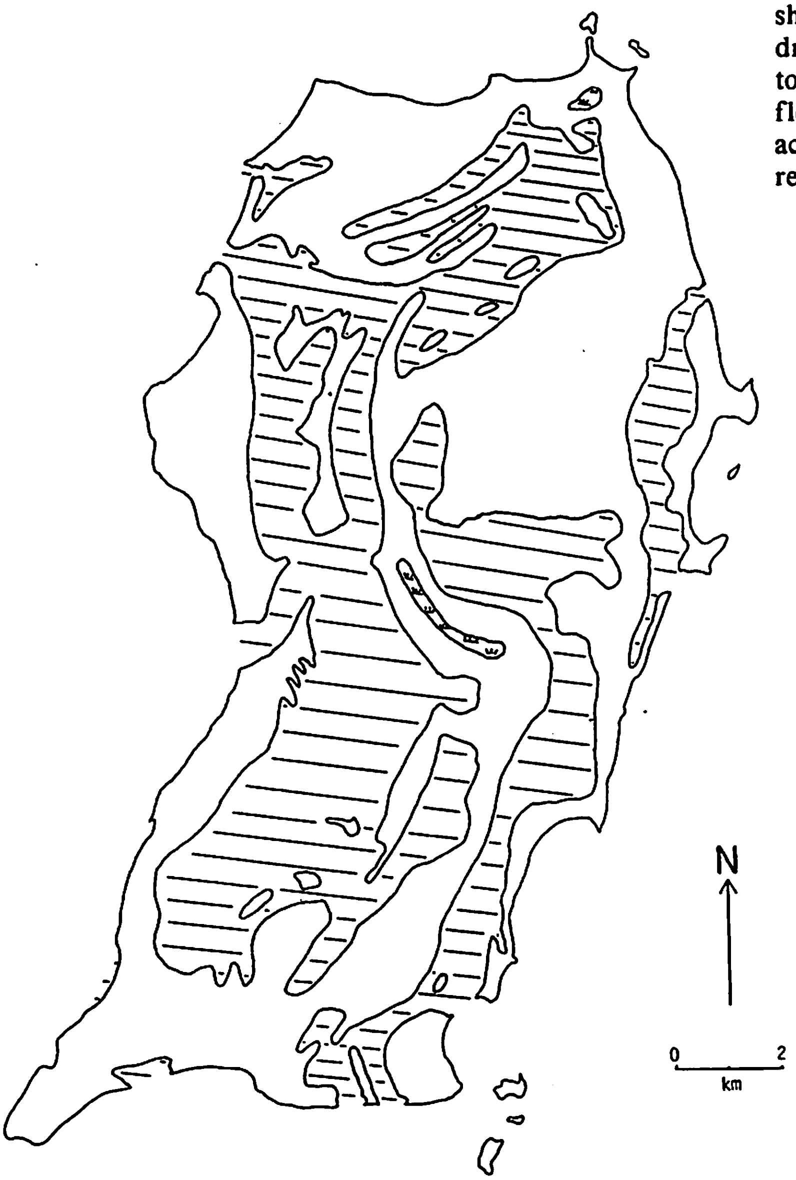

Fig. 13. Map of a hypothetical San Salvador Island at modern sea level assuming climatic conditions in the Quaternary similar to those operating today on Bermuda. Compare to Figure 2. The outer coastline and offshore cays have been held arbitrarily constant, except where breaching of the interior lows to the coast has occurred. Inland water bodies (lakes and sounds) are shown by diagonal line pattern. A minor lowering of the overall landscape by vadose dissolution, and the lateral retreat of lake shorelines under fresh water conditions has resulted in expansion of the lakes and their coalescence. All the original large water bodies now have one or more direct connections to the ocean. Only small water bodies trapped between high dune ridges, such as South Granny Lake and Reckley Hill Pond (see Figure 2), have avoided coalescence and connection to the sea. The isolated lakes are fresh and recharge the fresh-water lens, and the large coalesced water bodies are marine like the sounds of Bermuda. The resulting island looks similar to maps produced by raising sea level above modern elevations (Mylroie and Carew, 1990).

adjacent limestones of the saturated zone.

CONCLUSION: SUPPOSE SAN SALVADOR HAD A CLIMATE LIKE BERMUDA'S

If San Salvador or Great Exuma Island had a climate like Bermuda's, the interior ponds and lakes would not be hypersaline. Many of them would be fresh and become the sites of fresh-water marshes. These marshes would input water directly to a large fresh-water lens that would extend across the entire island. The water flowing from the marshes into the adjacent limestones would be aggressive from being charged with CO_2 in passage through the peat beneath the marsh. This ground water would be dissolving the limestones in the phreatic zone surrounding the presently submerged topographic lows. The flow system and hydrogeochemical processes would be like those in the vicinity of Devonshire Marsh, Bermuda.

If San Salvador had a climate like that of Bermuda's, then during one of the next interglacial highstands it would look something like the speculative outline map of Figure 13. What are now (in today's arid San Salvador) shallow, salty lakes, would be deeper, widened basins -- widened because of sapping related to dissolution by horizontally flowing CO_2-charged waters during the earlier highstands, and deepened because of the dissolution by downward-flowing vadose waters that removed the peat during intervening glacial-stage lowstands. Most of these deepened and widened basins would be submerged by seawater during the new highstand and would thereby be converted to inland reaches and sounds as shown in Figure 13. These inshore sounds would be widened even further because of mixing-zone-related dissolution within the rock of the rocky shoreline and bioerosion from the marine side of the shoreline. New sand bodies would be accreted around the external shoreline, and these would close off new topographic lows that, with ongoing sea-level changes, would evolve into a new generation of marshes and inshore sounds.

The difference between Figure 13 and Figure 2 illustrates our view of the effect of climate on the geomorphology of islands composed largely of Pleistocene eolianite. Where fresh water is abundant, as in Bermuda (Fig. 1) of the speculative San Salvador of our Figure 13, depositionally formed topographic lows undergo an evolution that results in an extensive interior shoreline. Where fresh water is scarce, as in San Salvador (Fig. 2), the topographic lows without a marine connection retain their depositional configuration. Where small ponds occur in the fresh-water lens of San Salvador, their low surface area retards evaporation and fresh-water dissolution commonly produces a cliffed margin.

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