

FRINGING REEFS, ENCLOSING BAYS, AND SALT PONDS OF ST. JOHN, VIRGIN ISLANDS

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CARIBBEAN REEF STRUCTURE and zonation have been the subject of a number of papers in the last few decades, but little attention has been given to closure of embayments by encroaching fringing reefs and subsequent creation of salt ponds and coastal swampland. Within the rugged coastal topography of the Northern Virgin Islands, and specifically of St. John where fringing coral reef development is common, can be found classic stages in bay closure which seem to illustrate a full sequence of events, and suggest further avenues of research to clarify the processes involved.

The island of St. John lies along the northern boundary of the Caribbean Sea at 18°20'N, 64°45'W. It is a part of the geographically related and topographically similar group of islands immediately east of Puerto Rico called the Northern Virgin Islands. These islands—St. Thomas, St. John, Tortola, Virgin Gorda, and a host of lesser islets—are extensively faulted uplifted masses of volcanic rock characterized by irregular coastlines and rugged slopes rising steeply to elevations of 450 meters. St. John, which exhibits a drowned shoreline typical of the group, is indented by a virtually continuous series of small, often parallel-sided bays (see map). Weathering and transport of materials from the upper slopes to the coastal valleys has been extensive, although the actual depth of alluvium is relatively shallow (3-8 meters) owing to the small scale of the islands and their watersheds. Annual rainfall in the present and recent past is on the order of 100-120 centimeters; but in a geologic time frame, St. John, like most of its Caribbean neighbors, has been subjected to many hurricanes and stationary weather systems which have exerted severe stresses on both land and shoreline. Such storms may dump 25-35 centimeters of rain on the land in a few hours, and cause even the smallest watersheds to flood. This periodic flushing carries upland silt, gravel, and even large boulders to the coast, and often breaks through natural barriers to the sea. In the last 250 years some twenty major hurricanes have been recorded in the Northern Virgin Islands, the last one in the 1932 season.

St. John was under intensive agriculture in cotton and sugar cane from about the year 1700 up to the early 1900's, during which time the land was extensively though periodically cleared from the coast almost to the crest of the island. Soil loss appears to have been significant under these conditions, leading to a generally poorer capacity to retain water, a lowered water table, and eventual failure of perennial streams.

The Northern Virgin Islands (unlike the politically related but geologically distinct island of St. Croix to the south) are surrounded by an extensive insular shelf. This flat plateau, which grades out gently to a depth of 30-50 meters at a well-defined drop-off 3-10 kilometers offshore, was presumably derived from upland erosion during a Pleistocene low sea level stillstand. Some living patch reefs and a remarkable series of drowned reef ridges have been located on the southern boundary of the shelf off St. Thomas and its neighbor St. John.

Our understanding of the sea level history of St. John is complicated by the interaction of two processes: *eustatic* sea level fluctuations which occur when large volumes of the earth's surface water are frozen in continental glaciers; and *tectonic* movements of the island platform which may raise or lower the shoreline with respect to the ocean's surface. Most coastal areas of the world are still recovering slowly from the last Pleistocene eustatic lowering. The several earthquakes and hundreds of minor tremors which occur annually throughout the Caribbean are evidence that the sea floor and island arc are still undergoing tectonic alteration. Cemented accumulations of sand, pebbles, and volcanic cobbles, interpreted as beachrock formed at or near sea level, have been discovered at several different depths on the submerged platform surrounding St. John, each probably indicative of a low stillstand. Correlation of these deposits with the drowned reef ridges and known eustatic changes within the Atlantic-Caribbean basin may answer questions concerning the origin of St. John's coastline.

Live fringing coral reef development is common along the present shoreline of St. John, where reef platforms typi-

cally extend 50-200 meters offshore, producing a shallow back reef flat beneath only 0.5-1.5 meters of water. Although local coral species diversity does not approach Indo-Pacific standards, some thirty species of hermatypic corals may be easily found on these and deeper reefs. The dominant reef crest form is *Acropora palmata* (elkhorn coral) joined on the steep windward reef face by encrusting or head-forming species of *Diploria* (brain corals). *Montastrea* and *Siderastrea* (star corals), and in protected sites by *Agaricia* (lettuce coral) and *Acropora cervicornis* (staghorn coral).

A conspicuous feature of the coastal geography of St. John are some 25 shallow salt ponds, which occur at the heads of present bays. Less commonly, ponds occur as narrow strips immediately inland of linear shorelines. The barriers which separate these ponds from the sea are usually loose and porous aggregations of storm-raised coral rubble and sand, with minor amounts of terrestrial sediment. Depending upon the degree of consolidation of this barrier, the ponds, which lie at or slightly below sea level, are influenced by tidal changes in the adjacent bays. Mean tidal ranges in the Virgin Islands are only about 25-30 centimeters, and the water level in most salt ponds varies only a fraction of this amount during a given cycle.

Except where man or recent floods have opened channels, these ponds do not maintain direct circulation with the sea, and conditions of poor mixing, high wind evaporation, and high temperatures lead seasonally to salinities close to or exceeding saturation. In periods of heavy rainfall these ponds rapidly fill with runoff and become brackish or drinkably fresh. During floods, or perhaps under storm wave attack, the barriers may be breached and a temporary channel cut, leading to drainage and transitional periods where marine fauna may enter the ponds. These salt ponds are ideally located to act as natural sediment traps for eroded fine material, which is effectively settled out as the runoff is gradually percolated through the barrier beach to the sea over the weeks following a flood. This provides a significant buffer system to the offshore biota, since the rapid

Southside Pond, on the southeastern tip
of the island, may have been created in a rather short
time by a hurricane-raised barrier beach with
little contribution from encroaching fringing reefs.
(Area shown here is within rectangle on chart, page 43)



National Ocean Survey one inch = one thousand feet

Geologists and "catastrophists" have debated the causes of such geologic phenomena for a long time. Here, if it wasn't Noah's Flood it might have been a hurricane. . . .

injection of fresh, silt-laden water on adjacent fringing reefs may cause temporary or long-term setbacks in coral growth. Salt ponds play a useful role in the animal and human ecology of the island: when a sea connection is closed, landlocked snook and tarpon may be easily caught, an extensive sheltered habitat for sea- and shorebird nesting is available, and other wildlife may feed in the pond or even drink from it. Precipitated sea salt is traditionally collected during dry seasons by Virgin Island residents for the year's domestic needs.

The historical sequence by which salt ponds have formed in the Virgin Islands seems relatively straightforward, although little mention has been made in the scientific literature. St. John provides examples of various stages in the apparent sequence of development: shallow fringing reefs extending from opposing bay headlands gradually coalesce to form a continuous barrier across the bay, followed by consolidation of the barrier and gradual isolation of the pond from tidal and infiltration effects. The sequence is modified by and dependent upon extreme storm wave conditions which accompany hurricanes or other major storms. During such storms, waves of 3-8 meters may effectively tear loose and move shoreward large volumes of reef material, including heavy uprooted heads and chunks of the underlying reef basement. This shoreward transport tends to rapidly raise the reef crest or sand barrier. eventual colonization by hardy terrestrial vegetation and consolidation into a less permeable barrier follow. One of the last stages in bay closure seems to be a shallow embayment with a channel remaining open, as at John's Folly Bay where most of the water forced in over the reef crest by wave action is returned to the sea through a single deep channel. Although the additional circulation through this channel may favor coral growth, there appears to be a point at which (as in the classic spur and groove systems of many coral reefs) the channel is self-scouring, and tends to slow down further closure. Perhaps it is at this stage that a single extreme hurricane event is finally successful in effecting closure. In certain cases, no evidence of former reef development is visible. It is likely that such salt ponds were closed off by storm

effects alone. At the close of the last century many prominent geologists were engaged in debate with "catastrophists" who believed that observed geological phenomena were caused by specific historical events, such as Noah's Flood. Today a measure of catastrophism (albeit radically different from that of the earlier believers) is returning among sedimentologists, many of whom believe that the geological record is composed in large part of deposits laid down during singular major events: dust storms, hurricanes, turbidity currents, volcanic eruptions, and, in some cases, even floods. It is not inconceivable that a single hurricane might create an isolated salt pond overnight from a bay that was previously open to the sea.

The sequence immediately following establishment of a barrier is not well studied, but is probably related to the present condition of the spectacular fringing reef at Lagoon Point in Coral Bay. Here, a reef crest is already well-developed, and storm-raised coral rubble islets along its edge are being colonized by terrestrial vegetation, including black mangrove (*Avicennia nitida*) and sea purslane (*Sesuvium portulacastrum*). Shoreward of the reef crest, which is already raised to within a few centimeters of sea level, an extensive reef flat populated by turtle grass, mat-forming colonial anemones, and calcareous algae has developed. Further inshore, a slightly deeper lateral lagoon system drains off water driven in across the reef crest and flats by wind waves.

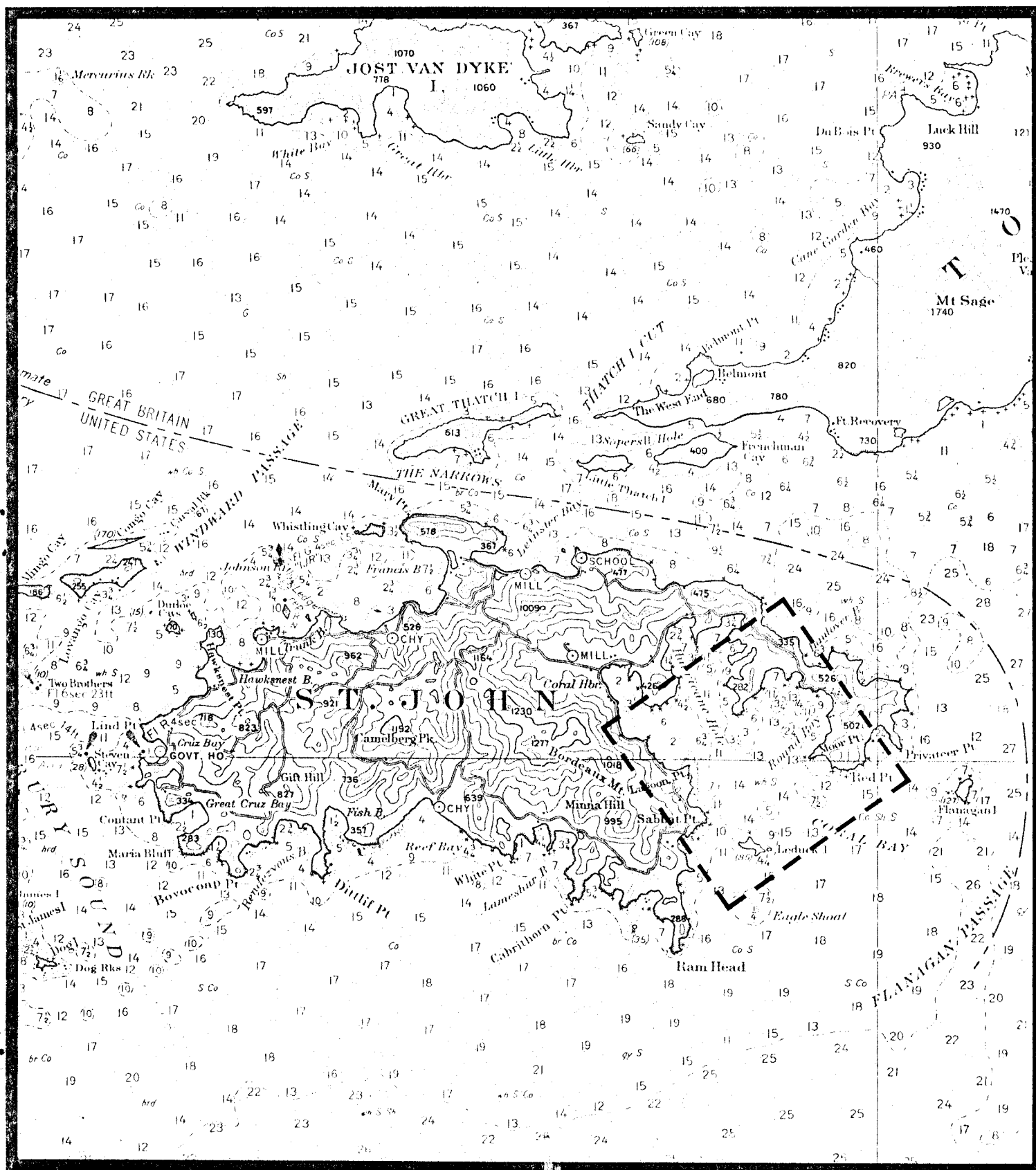
Early in its development, Lagoon Point reef was apparently responsible for the closure of a minor embayment now isolated as a small salt pond, separated from the nearshore lagoon by a 1-2-meter-high ridge of sand and coral rubble. The southern end of the main reef structure exhibits the characteristics of the first stage of salt pond development: the seaward edge of Friis Bay is formed by the near coalescence of the reefs on both sides of the bay, and another small pond has already been formed behind the southern or lower arm of the bay's fringing reef. If further reef development or storm waves complete the barrier across Friis Bay, radical salinity fluctuations would kill off the marine biota and accumulations of fine sediment would

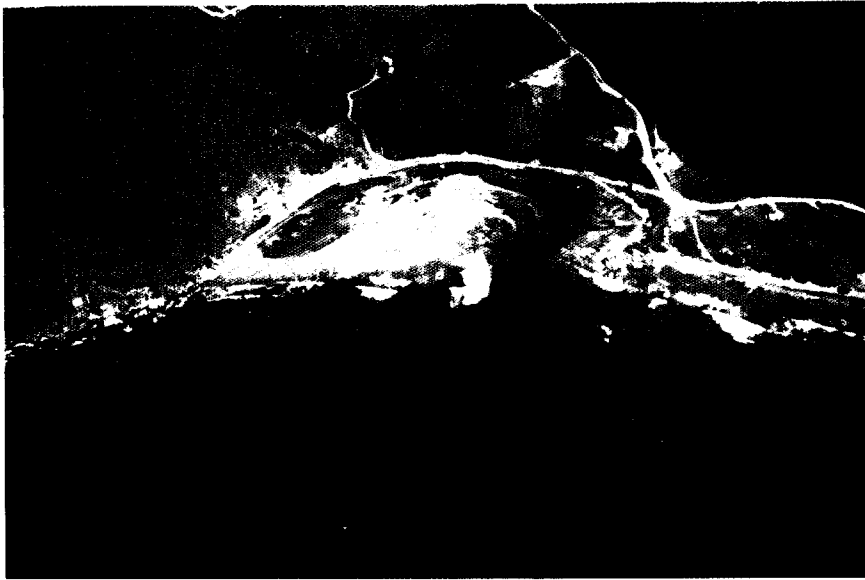
eventually cover the earlier coral foundation of the reef.

The evolution of dry land from coastal salt ponds is also poorly understood. If the rate at which sediment fills the pond exceeds the rate at which the adjacent seaward barriers are being raised (by storm waves or sea level fluctuations) the ponds would eventually fill to above sea level, producing flat dry land. More common is the situation at Brown or Reef bays on St. John where consolidation of the barrier through soil formation and a heavy vegetation cover have apparently prohibited much percolation of seawater into the adjacent pond. Certain trees and shrubs which can tolerate brackish water have colonized the former pond site at Brown Bay only with partial success. The dry, sparsely vegetated coastal swamp thus formed gives the appearance of being in constant stress, with a high brackish water table and only marginally healthy vegetation. At Reef Bay much more extensive tree colonization has occurred up until a recent time when either through hurricane winds, excessive flooding, or disease most trees in the former pond site were killed simultaneously. Since active sugar plantations existed near both these sites in the nineteenth century there is a possibility that some artificial drainage of the ponds was undertaken for insect control, altering or accelerating the natural sequence.

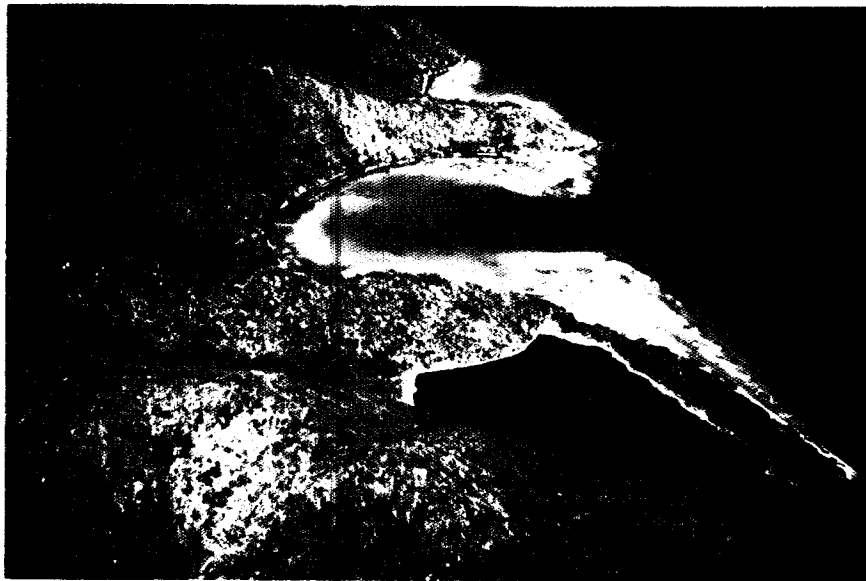
Most of the information summarized here is based upon extensive qualitative observation of the bays, reefs, and ponds of St. John over a three-year span, and on inspection of aerial photographs. It has not yet been logistically possible to core the beach barriers, nor to determine if in fact the sub-bottom structures of the ponds represent earlier back reef environments. An empirical test of the importance of hurricane waves in final bay closure will inevitably be provided when St. John's current run of good weather fortune runs out. The detailed photography and observation now under way by the National Park Service, the National Ocean Survey, and other research interests in the Virgin Islands should provide the baseline information needed to assess long-term evolution of these fascinating coastal land forms, and reaffirm their importance in the transitional ecosystems dividing land and sea. ■

The steep topography, irregular coastline, and shallow insular shelf of St. John are evident on this National Ocean Survey (USC&GS) chart (part of Chart 905, "Virgin Islands—Virgin Gorda to St. Thomas and St. Croix." Soundings in fathoms; heights in feet). The broken-line rectangle is the portion shown in the aerial photograph on page 41.





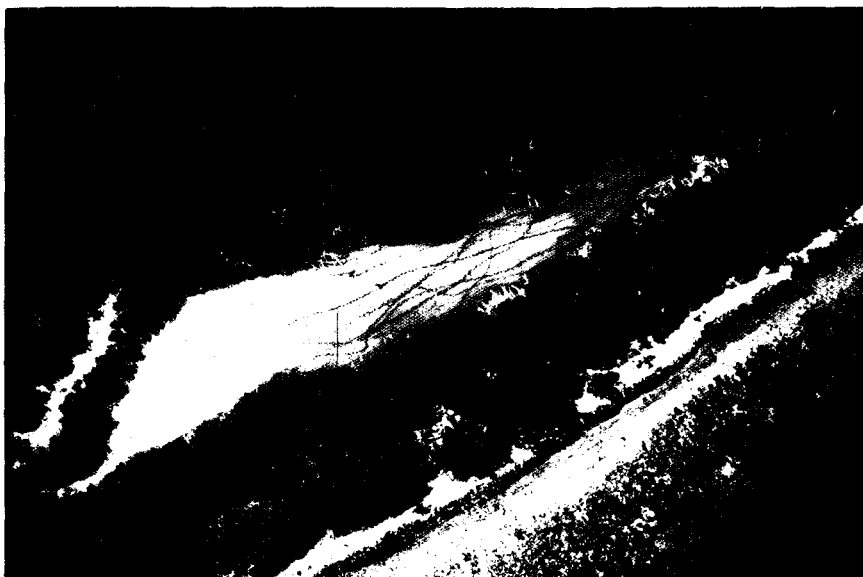
Various stages of bay closure are evident in these two photographs from eastern St. John. Along the fully exposed shore at John's Folly (above), where strong windward wave action approaches from the southeast, an asymmetrical basin has resulted as the reef crest proliferates inward, and back reef debris gradually fills the bay. Dark areas at the bottom of the photograph are turtle grass beds, clearly visible at 10-15 meter depths.



At Newfound Bay, a fully isolated salt pond has already developed behind a consolidated reef barrier. Adjacent to the pond, a nearly symmetrical basin with a partially closed entrance represents a second, incipient pond. The symmetry, and a lack of coarser reef sediments filling the back reef, is probably related to the bay's more leeward exposure, and a straight-on wave energy approach.



Southside Pond (above), on a highly exposed eastern tip, is one of the deepest salt ponds on St. John, which may indicate that its barrier berm developed very rapidly under the stress of hurricane storms. The surrounding watershed is also restricted, suggesting that relatively little sediment has been available to fill in the pond.



Another class of salt pond occurs along linear shorelines behind a storm-raised coral rubble and rock berm. During dry periods pond water evaporates, leaving crystalline salt deposits and soft muddy sediments, here criss-crossed by the tracks of feral donkeys.