COMPARISON OF MODERN SILICICLASTIC AND SKELETAL CARBONATE BEACH FEATURES--EDISTO, SOUTH CAROLINA (1972), AND SAN SALVADOR ISLAND, BAHAMAS (1984)

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ABSTRACT--This paper emphasizes study of skeletal carbonate beaches, examined 11 to 16 March 1984 on the windward and leeward sides of the modern carbonate platform island of San Salvador, Bahamas. The beaches there are separated from deep ocean waters by shallow lagoons (with associated reef baffles) that surround the entire island. The geometry, anatomy (sedimentary structures), texture, and composition of a siliciclastic beach that fronted on the Atlantic Ocean at Edisto Beach, South Carolina, during the period 21 to 25 June 1972 is compared with similar features of skeletal carbonate beaches located at four widely separated sites on San Salvador Island.

Edisto Beach fronts on the Atlantic Ocean and is in Edisto State Park, South Carolina, approximately 97 km (by road) southwest of Charleston, South Carolina. This beach may be considered as a typical, predominantly siliciclastic (quartz grain-rich) beach situated along the southeastern coast of the United States. Periodically, during any given year, northeast storms and southeast hurricanes remove previously formed beach structures and cause these beaches to be in an almost constant state of flux between deposition and erosion.

During the period of 21 to 25 June 1972, studies were made of well-developed transitory beach morphologic features and sedimentary structures such as thin-bedded beachface deposits composed of coarse-grained shell hash and quartz grains (range in grain size from fine sand to fine pebbles) that dip seaward at an angle of <10 degrees; beach ridge deposits (thin-bedded) that dip landward or runnelward at angles of up to 30 degrees and are composed largely of coarse-grained quartz and shell hash as well as rippled runnel deposits of muddy quartz silt and sand. The ripple crests are generally perpendicular to beach ridge trends (Fig. 1). More permanent beach area features include: landward of runnels are shallow, trough crossbedded generally fine-grained, quartz-grain-rich, wind-formed dunes stabilized by trees and grasses; tidal marshes composed of clay-rich, organic muck covered with marsh grass; and stormwashover deposits (into the tidal marshes) composed largely of coarse-grained clastic quartz and shell hash. Tidal channels scour beach deposits as well as tidal marshes (Fig. 1).

Skeletal carbonate beaches have formed around the landward periphery of a platform carbonate (largely wind-deposited bedrock) island of San Salvador, Bahamas (Fig. 2). Further, San Salvador is completely surrounded by a shallow marine platform, or shelf, that locally extends seaward for as much as 1.6 km (1.0 mile, Fig. 3). Coral reefs populate both the seaward margin (barrier reefs) and locally some nearshore areas of this platform. These reefs serve as baffles to seawater energy. Marine organisms that secrete hard parts such as corals, gastropods, pelecypods, foraminifera, and encrusting and stalked algae may be found on this marine platform, and their fragmental hard parts serve as the source material for skeletal carbonate beach sands on San Salvador. Obviously, these hard parts are fragmented largely during storms or times of high wave energy (spring tides and strong winds) as well as by the "mill" at the beach toe.

Comparison of siliciclastic Edisto Beach morphology and sedimentary structures with San Salvador skeletal carbonate beach deposits shows that the Edisto beachface (shoreface or foreshore), beach ridge, runnel, and dune deposits are well developed (Fig. 1). San Salvador beaches display well-developed, laminated, generally sand-sized foreshore deposits, but beach ridge, runnel, and dune structures are poorly developed or may not be present at all.

The purpose of this study is to compare modern siliciclastic and skeletal carbonate beach morphology, sedimentary structures, texture, and composition. Hopefully, these data will enable recognition of ancient beach deposits.

MATERIALS AND METHODS

Four skeletal carbonate beach sites in San Salvador were trenched (Fig. 3). Site 1 was south of Columbus Cross on the leeward or west-central side; site 2 was Grotto Cove near the southwestern end; site 3 was Rice Bay on the northeast coast; and site 4 was Fortune Hill Settlement on the east-central, windward side.

RESULTS AND DISCUSSION

Site 1, Beach South of Columbus Cross--A trench, 7.62 m long and 0.60 m deep, was dug on 12 March 1984 approximately 49 m south of the Cross Monument to Christopher Columbus on the west-central or leeward side of San Salvador. Only seaward dipping, laminated beachface (foreshore) units were observed in this trench whose landward portion bottomed in limestone bedrock (Fig. 4). Thus, a beach ridge, runnel, and dune system was not present here.

A diagram of the trench wall (Fig. 4) shows that the dip of foreshore laminations ranges from 5 degrees in the lower part of the trench to 7 degrees in the upper part. This observation indicates a steepening of the beach face as foreshore laminations aggraded. Laminations in this

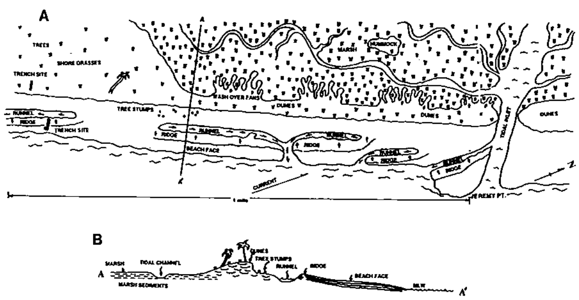

FIG. 1. A) Plan view of Edisto Beach, South Carolina, 21 -25 June 1972. B) Cross-section of beach and tidal marsh structures.

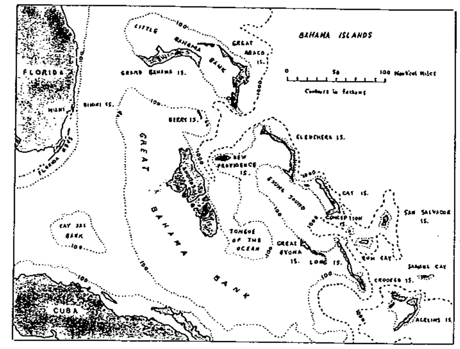

FIG. 2. Generalized map of Bahama Islands.

trench range from 0.02 to 0.12 m (0.05 to 0.40 feet) in thickness and from 0 to 3 phi in grain size. Grain-size arrangement within lamination thickness is cyclic.

Swash marks, accentuated by sea grass, and bubble pits (visible after backwash passed) were noted on the surface of this relatively flat beach. Seaward, at the toe of this beach, there is a beach mill where shells are fragmented to finer sizes. Seaward of the mill is a beach step approximately 0.30 m high.

A shallow lagoon (up to 9.14 m deep) seaward of this beach is floored by a carbonate rock platform that extends as much as 1.61 km offshore. Barrier reefs fringe the seaward edge of this platform, and patch reefs are scattered over its surface. These reefs serve as a baffle to seawater energy.

Site 2, Grotto Cove Beach--Seaward of the beach at Grotto Cove, a shallow lagoon floored by a carbonate rock platform extends over 0.80 km offshore. Barrier reefs are situated along the seaward edge of this platform, and patch reefs dot the platform surface.

Figure 5 shows an en enchelon arrangement of patch reefs offshore of Grotto Cove Beach. This reef arrangement seemingly causes a refraction of wave fronts which likely are responsible for forming a notch (grotto) at water level in the modern limestone bedrock east of the beach.

The beach at Grotto Cove is steep and is both cuspate and scalloped, possibly the result of refracted wave fronts impinging the beach at a high angle (Fig. 5). On the foreshore, or beachface, sea grass accentuated swash marks. Also, ephemeral rhomboidal ripple marks were present on the lower foreshore after backwash (ebb flow) had passed. Here, there is an active beach "mill" with an associated 0.30- to 0.61-m beach step.

A 12.19-m long beach trench that averaged 0.61 m deep was dug on 13 March 1984 along the "nose" of a beach cusp (Fig. 5). Wind-formed dunes, 0.61 m high, stabilized by grasses are situated landward of this trench.

Figure 6 shows the distribution of beach foreshore laminations in the Grotto Cove beach trench. Note that, near the trench top, there is an "unconformity" indicating two different periods of beach formation. The older beach foreshore sequence is relatively thick and ranges between 4- and 7-degrees dip (seaward) from bottom to top. Newer beach foreshore laminations form a thin veneer and have an average dip of 10 degrees. Presumably, beach aggradation causes an increase in dip of laminated foreshore deposits.

In the landward portion of this trench, the laminations range from a horizontal 0-degree dip to a 2-degrees landward dip (Fig. 6). This situation likely represents infilling of a shallow runnel associated with the older beach.

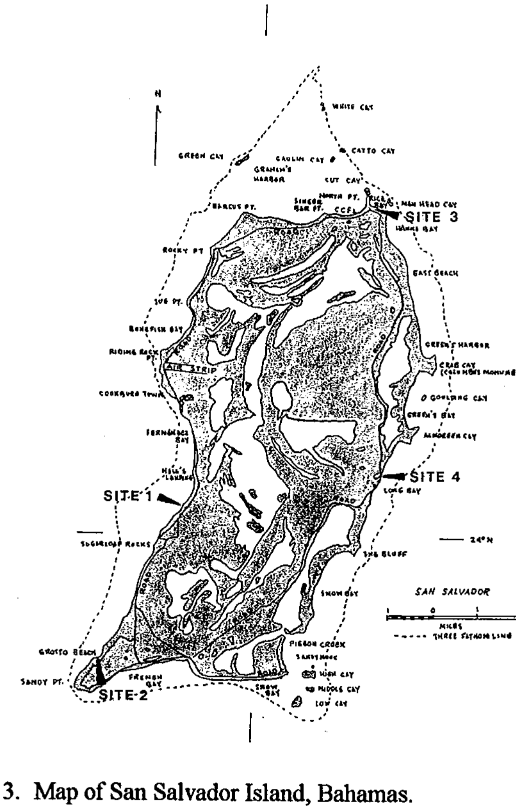

FIG. 3. Map of San Salvador Island, Bahamas.

Figure 7 depicts two measured sections in the Grotto Cove beach. See Fig. 6 for the location of these sections in the trench. Lamination thickness in the lower, or older, beach sequence ranges 0.003 to 0.076 m (0.01 t0 0.25 foot), and grain size ranges from 1 to 3 phi. Newer beach laminations range from 0.015 to 0.030 m (0.05 to 0.10 foot), and grain size ranges from 1 to 3 phi. The grain-size distribution in laminations in the Grotto Cove Beach are not as clearly cyclic in their arrangement as are similar features in the beach at site 1 near Columbus Cross.

Site 3, Rice Bay Beach--Figure 8 diagrams the geometry of coral patch reefs, seagrass patches, ripples, and megaripples on a portion of the shallow seafloor directly in front (seaward) of the beach on Rice Bay

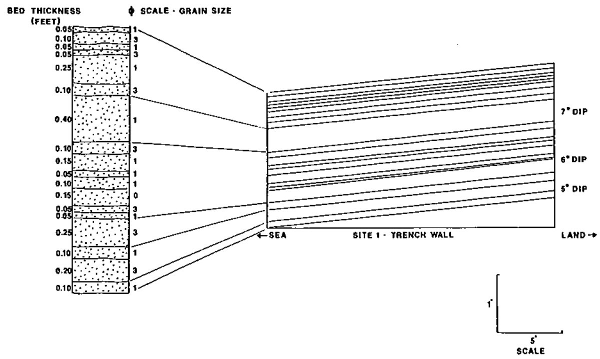

FIG. 4. Beach trench south of Columbus Cross.

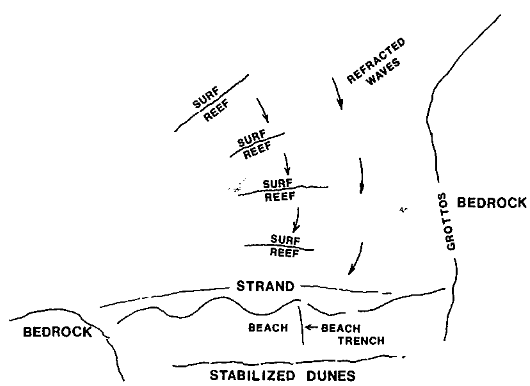

FIG. 5. Diagram of Grotto Cove.

in front of a Coast Guard Station. Here, there are two crudely cresent-shaped (concave landward) coral reefs. The one nearest shore has its seaward edge approximately 27.43 m from the strand line, and the outer one is situated so that its seaward edge ranges between 76.20 and 91.44 m off shore. The outermost reef is cut through by a channel, and, on the landward side of this outermost reef, a 6.10-m wide channel shows megaripples (amplitude circa 7.62 cm and wave length circa 50.8 cm on the seafloor). These bedforms are composed of very coarse skeletal carbonate grains.

Between the two reefs (Fig. 8), the approximate shape of a relatively thick growth of seagrass has been mapped. Here, seawater depth is approximately 7.62 m. On the seafloor, both landward and seaward of the thick seagrass growth, there are scattered seagrass growths associated with rippled (2.54-cm amplitude and 5.08- to 15.24-cm wave length) skeletal carbonate sand-sized grains.

On the northeast coast of San Salvador Island (site 3, Fig. 3), on 15 March 1984, a 6.10-m long trench was opened in Rice Bay Beach. This low-lying beach is concave, with respect to shoreline configuration, and seaward there is a shallow platform that extends out to the Atlantic Ocean for a distance of over 0.80 km. On the seaward edge of this platform, an erosional rocky promontory of lithified limestone bedrock forms a barrier between open ocean water and Rice Bay. In areas on the platform's seaward edge, where the rock promotory is absent, there are barrier coral reefs that form a baffle to open ocean water energy.

Landward of Rice Bay Beach, there is a continuous low ridge of wind-deposited dunes that are stabilized by grasses. Clumps of seagrass litter much of the upper beach and perhaps mark the presence of a very shallow runnel.

Figure 9 shows laminated units in the trench wall at Rice Bay. The seaward end of this trench bottomed in watery sand at a 0.61-m depth, whereas, the landward end was 0.67 m deep. In the lower and upper parts of the trench wall, there are two shallow (0.06 to 0.15 m) poorly-developed backshore ridge-runnel deposits marked by buried clumps of seagrass and landward-dipping laminations. The lower ridge-runnel lamination is 5 degrees, and the upper dip is 0 degrees.

Seaward-dipping foreshore laminations in this trench range in dip from 3 to 4 degrees near the bottom to 8 degrees near the top. This observation attests to the fact that, as beach foreshore laminations aggrade in a vertical sense, their degree of dip increases.

Two measured sections which record bed, or lamination, thickness and within lamination grain size, from the trench wall in Rice Bay Beach are given on Fig. 10. Ridge-runnel lamination thickness ranges from 0.012 to 0.152 m (0.04 to 0.50 foot), and the range in grain size is from 1 to 4 phi. Foreshore laminations are partially cyclic, and range in thickness from 0.009 to 0.016 m (0.03 to 0.54 foot), and the range in grain size is from 0 to 4 phi.

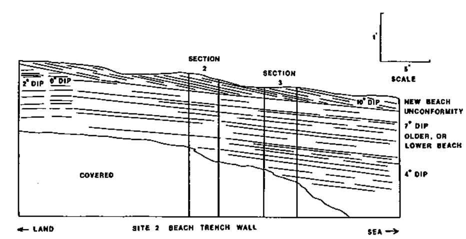

FIG. 6. Beach trench on Grotto Cove beach.

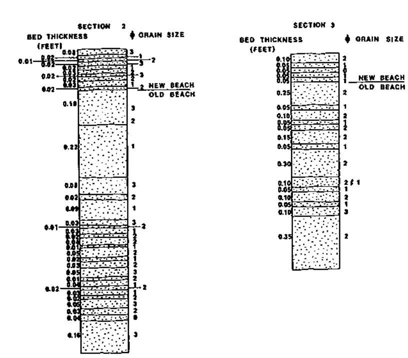

FIG. 7. Grotto Beach trench measured sections.

In section 1, grains range largely from medium- (2 phi) to coarse-grained (1 phi). Foreshore grain-size range at Rice Bay is similar to that at Grotto Cove Beach (site 2), but grain size is a bit coarser than at Columbus Cross Beach (site 1).

On Rice Bay Beach, a deposit of beach rock has formed in beach foreshore laminations and extends eastward from the beach in front of the Coast Guard Station (unconsolidated, easily-trenched beach material) toward the easternmost extent of Rice Bay. It was also noted here

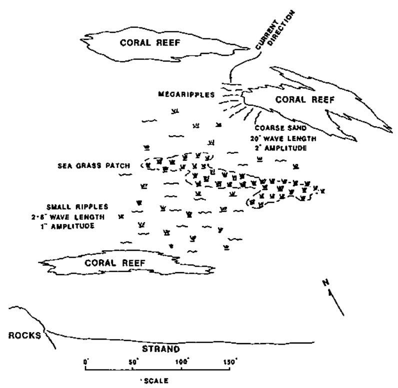

FIG. 8. Rice Bay nearshore map seaward of beach.

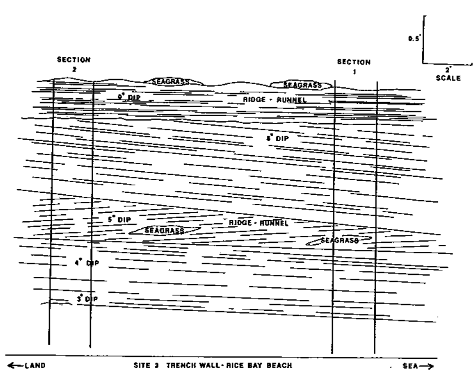

FIG. 9. Beach trench on Rice Bay beach.

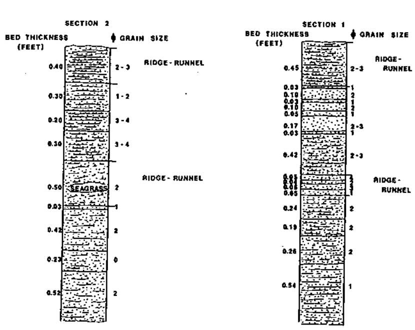

FIG. 10. Two measured sections from Rice Bay beach trench.

that, where beach rock is exposed along the strand line, the efficiency of the beach mill in pulverizing skeletal carbonate material is somewhat diminished.

Bain (1985) investigated beach rock formation on the beach at French Bay which is located at the south end of San Salvador Island. This area is separated from the open Atlantic Ocean by a shallow carbonate platform. With the work of Moore (1973) and Manor (1975) to guide him, Bain (1985) concluded that penecontemporaneously formed beach rock has the same texture and composition, dip, and sedimentary structure as overlying, or adjacent, beach foreshore deposits. Further, Bain (1985) emphasizes that, for beach rock to form, it is necessary to have skeletal carbonate rock beach sand situated between salt water and meteoric water-saturated beach ridge or dune deposits. Evidently, meteoric water must spend enough time in carbonate dune or ridge sand to enable carbonate material to go into solution in response to either the pH or carbon-dioxide content of the meteoric water. When carbonate-rich water moves through beach foreshore laminated, skeletal carbonate sand, carbonate cementation takes palce, and beach rock forms. The cement is either high magnesium calcite or aragonite.

Exhumed beach rock is another noteworthy feature pointed out by Bain (1985). It is important to realize that beach rock forms beneath the beach foreshore surface or subtidal sediment. Therefore, where exposed rock is observed, it must be realized that beach rock has been exposed by erosion.

It is interesting to note that beach rock has not formed at site 1 (Columbus Cross Beach) because no beach ridge or dune deposits are present. Also, site 2 (Grotto Cove Beach) is a very wide, steep beach with requisite dune deposits, but tidal fluctuation is not large enough to enable carbonate-charged meteoric waters to migrate to and cement beach foreshore deposits. However, the Rice Bay Beach (site 3) is a relatively flat, narrow beach with sufficient tidal fluctuation and associated beach ridge and dune deposits to facilitate the carbonate cementation process of forming beach rock.

Site 4, Fortune Hill Settlement Beach--On 16 March 1984, a beach trench 5.49 m long was opened on the eastern (windward) shore of San Salvador at a point south of the causeway at Fortune Hill Settlement, due east of the Salt Pond. This relatively narrow, flat beach faces the open Atlantic Ocean; however, there is a shallow carbonate platform that extends seaward for over 0.80 km. Barrier coral reefs are located on the seaward edge of this carbonate platform. Landward of the beach is a continuous ridge formed of wind-deposited dunes that are now stabilized by vegetation. Wave action has cut a notch along the base of this unconsolidated sand dune deposit (similar to the notch cut in the siliciclastic dune structures at Edisto Beach, Fig. 1). The upper beach is littered with clumps of seagrass which may mark the location of a shallow runnel. Limestone bedrock crops out over much of this beach area so much so that the entire beach area along this coastline may be considered as only locally sandy. Conditions here are such that the beach rock-forming process is not operative.

Figure 11 shows the distribution of laminations in the trench wall of Fortune Hill Settlement Beach. The seaward end of this trench was 0.30 m deep, and the landward end, 0.79 m deep. Much of this trench bottomed in watery sand.

The locations of measured sections 1 and 2 are also given on Fig. 11. Note that much of the trench wall shows seaward-dipping laminations. In section 2 (seaward part of trench), the dip angle increases upward slightly from 3 to 4 degrees. In section 1 (landward of trench) near the base of the trench, there are landward-dipping laminations that have a 7-degree dip. This is likely part of a beach ridge that dipped landward and enabled filling of a runnel. In section 1, the seaward-dipping laminations show a slight upward increase in dip angle (3 to 4 degrees).

Figure 12 indicates two measured sections in the Fortune Hill Settlement beach trench that record lamination thickness and within-lamination grain size of foreshore and beach-ridge deposits. Foreshore laminations range in thickness from 0.006 to 0.061 m (0.02 to 0.20 foot) and in grain size from 1 to 3 phi (fine to coarse sand). There is an active beach mill here as well as a beach step of 0.305 to 0.610 m. Grain-size distribution on this beach is similar to that of Rice Bay and Grotto Cove, but grain size is a bit coarser than at Columbus Cross (leeward side of San Salvador).

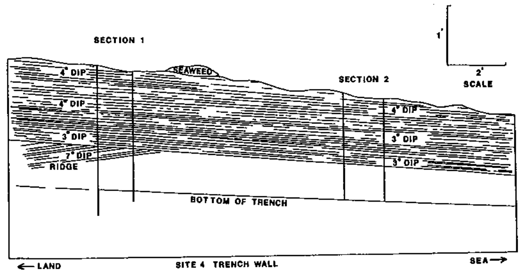

FIG. 11. Beach trench in Fortune Hill Settlement beach.

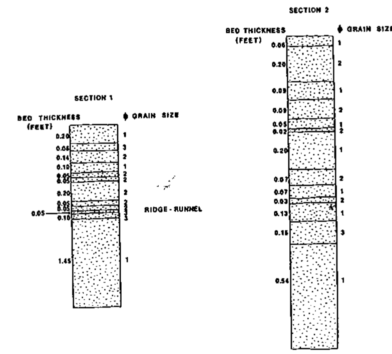

FIG. 12. Two measured sections from Fortune Hill Settlement beach trench.

CONCLUSIONS

It is likely that skeletal carbonate beach deposits at San Salvador are derived from the skeletal hard parts of marine life forms that populate shallow carbonate platforms which surround San Salvador and extend seaward as much as 1.67 km. Cursory mapping of the shallow seafloor near beach trenches at sites 2 and 3 indicates a wide range in current flow direction as well as intensity of current flow.

Presumably, storm activity, high energy currents, spring tides, scavengers, and others facilitate breakup of the hard parts of marine organisms. These fragments then pass through many avenues of sedimentation across the shelf and arrive at the mill at a beach toe, where largely sand-sized skeletal grains are deposited and reworked on the beach by swash and backwash of waves during each tidal cycle. THe beach mill grain comminution process will be diminished should beach rock be exposed in the beach foreshore area.

Reineck and Singh (1980) state that beach morphology and grain-size distribution are strongly controlled by wave activity and that a given beach is in dynamic equilibrium with existing hydrographic conditions. Therefore, it is suggested that the cyclic, or partially cyclic, coarse- and fine-grained grain distributions within laminations may be explained by cyclic tidal increases and decreases (spring and neap tides) interrupted from time to time by storm activity.

Visual inspection of grain-size distribution data on San Salvador carbonate beach deposits reveals that the Grotto Cave (leeward side), Rice Bay, and Fortune Hill Settlement beach sands (windward side) have a similar grain-size distribution, and all are a bit coarser than Columbus Cross beach sands (leeward side) accumulated in a relatively low sea-water energy area.

Further, the shallow, broad carbonate platform that surrounds San Salvador Island with its barrier reefs formed on the outer edge of the platform as well as coral patch reefs that dot the platform; likely, all act as a baffle to very high energy waves from the open Atlantic Ocean. In other words, if San Salvador had no "protective" shelf with reefs, its sediment supply would greatly diminished, and, if its beaches were in direct contact with the open ocean, such sediment that would be found on beaches would contain a considerable amount of granule- and pebble-sized grains.

The siliciclastic beach features on Edisto Beach include well-developed, very coarse-grained beachface (foreshore) and beach ridge layers as well as well-formed runnel and dune deposits. In contrast, because of relatively low water energy, the skeletal carbonate beaches on San Salvador are dominantly sand-sized with well-formed, laminated foreshore deposits, but beach-ridge and runnel deposits are better developed on the windward side (Atlantic Ocean side) and poorly developed or not present on the leeward side of the island.

Also, it is well known that siliciclastic beach deposits, like Edisto Beach, are transient features in that, during stormy periods, the entire beach is removed only to be completely rebuilt during relatively calm periods. In line with this previous statement, inasmuch as beaches of San Salvador were studied for only 5 days in March 1984, there is little sense of beach depositional history. It is possible that the beaches of San Salvador have been in place for years in their "protected" environment. However, should a major hurricane strike San Salvador, even these beaches may be removed and later rebuilt.

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