A TEACHER'S GUIDE
TO
THE DEPOSITIONAL ENVIRONMENTS
ON
SAN SALVADOR ISLAND, BAHAMAS

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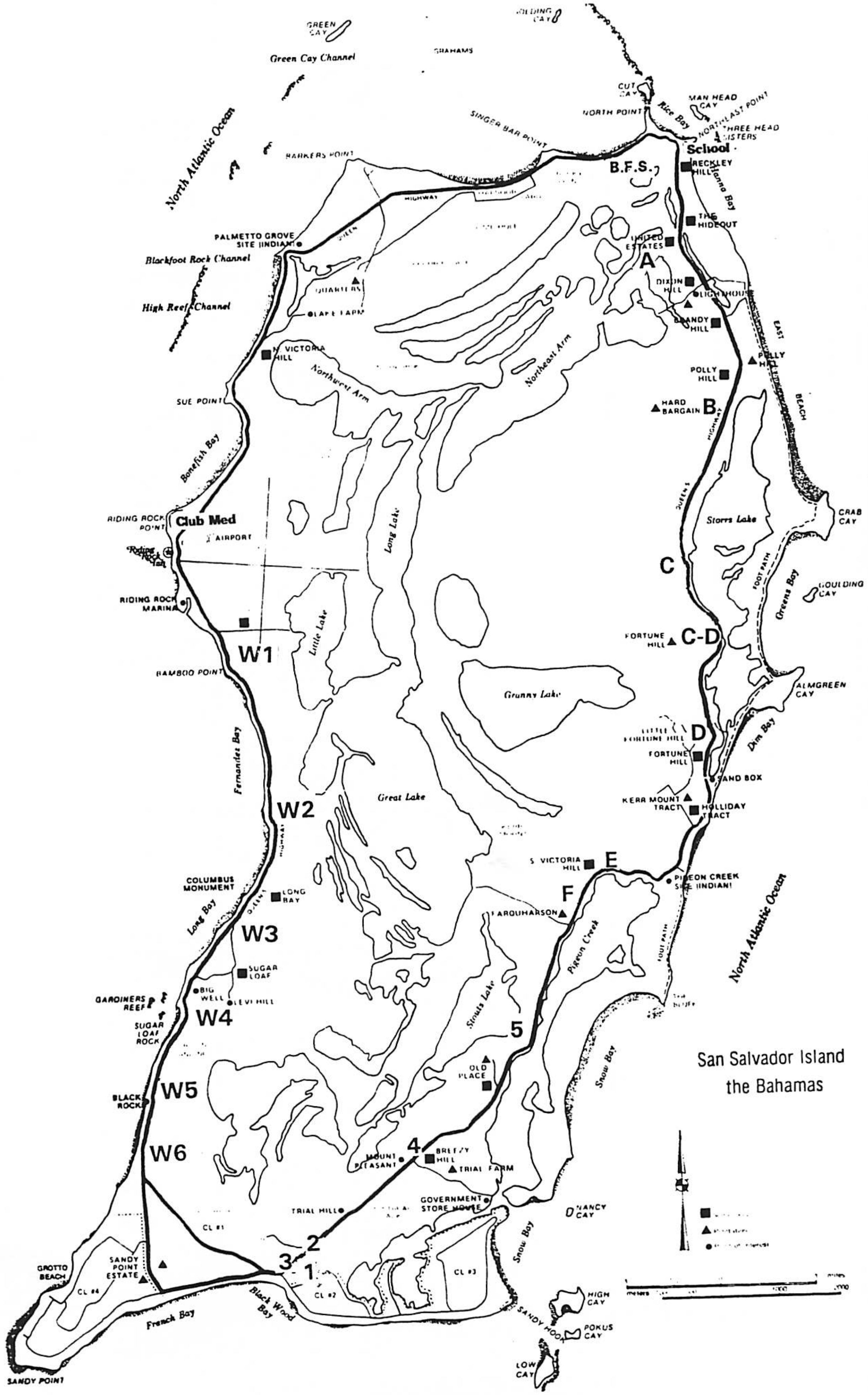
Foreword

My first visit to San Salvador was at the head of a line of geology students whom I had brought down to study "Marine Geology". Everything I saw was new to me. Fortunately, a biologist who had been there before, took me aside and briefed me of places of possible interest to a geologist. Weekends found me rushing to possible lithotopes, scouting them out for the next week's class-visit.

I have never forgotten those feelings of terror and dismay. If only, I thought, there were some kind of a guide book for faculty so that I could get some idea about places to visit and possible exercises once there. Now that my last visit to the island is upon me, I decided that perhaps there are still some geologists who haven't seen the island that are contemplating bringing a class to study the sedimentary environments of San Salvador.

With that in mind I have put together this guide book. I hope it will be a useful reference for: places to visit, exercises to attempt, techniques for data collection, and books to bring along. The Field Station at San Salvador is one of my very favorite places and I hope that this guide will help make it the same for you.

INDEX MAP TO SAN SALVADOR ISLAND, BAHAMAS



Chapter One
RECENT SEDIMENTARY ENVIRONMENTS ON SAN SALVADOR

Preface

I believe San Salvador is an ideal place to teach sedimentary environmental analysis. It possesses a wide variety of recent and "fossil" carbonate lithotopes (all that is missing are oolite shoals and extensive tidal flats). Its lithology is restricted to a single component (carbonate) which greatly simplifies analyses. It is close enough for fairly easy and relatively inexpensive visits. San Salvador has a low population density, especially along the shoreline, so that access to lithotopes is easy. Finally, the Field Station offers the logistical support and research facilities necessary for such an instructional program.

You might like to begin with the study of the beach lithotope. In the first place, it's a familiar environment, even to those from the heartland. It allows the student to concentrate on the techniques of the analysis without having to worry about a new lithotope at the same time. Secondly, beaches are easy to get to. No need to get into mask, snorkel, and fins nor to struggle bringing the gear. Finally, it's also the easiest to analyze. No problems with breaking waves, or drifting away from your observation position Collecting samples or data, even making notes, is straight forward.

THE BEACH ENVIRONMENT

Introduction:

San Salvador offers a variety of beaches and beach forms for introductory classes. They range from boulder beaches to those formed with very fine, muddy-sand. I have grouped them by energy levels. I have further identified accretionary, neutral, and erosional types. The thread connecting all of the beach studies is their relationship with the energy levels of the waves that produced, modified, and destroyed them. I have tried to make this connection via the relationship of beach slope, and sediment texture to wave energy. The beach slope is pretty obviously related to wave height/energy. The textural connection is less obvious because of the limited range in sediment size available to the waves. Nevertheless, comparisons of histograms of various beaches documents the relationship of texture to wave energy.

Although my course is directed at the study of as many lithotopes as possible, beaches inevitably become the most common environment visited. This is because study and data collection on beaches is easier, but also because much can be learned by the comparison of several similar lithotopes. For one thing, the student is made aware of the wide variety of conditions and facies can develop in a single lithotopic category. Once that point is made it can be extended to the reefs, lagoons, and other sedimentary environments.

North Point and Cut Cay Beach (a low-energy beach)[1]

North Point is easily accessed from the Field Station. Access to Cut Cay Beach, at its northern terminus, however, is much more complicated. Recent slump collapses of the cliffs along the west and north terminus of North Point have eliminated any easy access to the shore from the North Point cliffs. Presently, the only way to reach Cut cay is to wade along the leeward shore of North Point and across the causeway that separates it from North Point. This method of approach should only be attempted at low tide.

Some time should be allowed for discussing the geomorphology of North Point and the sedimentary structures exposed on the ocean-side and top of the peninsula, as well as solutional features and the energy contrasts between the windward and leeward sides of the point.

At the top of the ridge, which forms the peninsula, the seaward face of the cliffs exposes low-angle cross bedding of divergent orientations. Also exposed are a series of semi-circular re-entrants along the shore, one with a beach developed at the strand line. This re-entrant is an excellent place to observe the cross-bedding of the cliff-rock and to discuss the controls of waves and currents on beach development, and the origins of the re-entrants. Beaches are absent along the seaward side of this peninsula except in the re-entrants where they receive partial protection from wave and current action. A beach is also developed at the eastward curve in the coastline where the high school is located (Rice Bay beach). It has formed there because the long-shore currents sweep the sand down the point and deposit it there as they are forced to turn east by the coastline.

Where the cross-bedding is exposed on the top of the ridge, a series of vertically oriented intersecting surfaces which project above the bedding plane surfaces give the appearance of resistant desiccation crack fillings. However, the lack of clay in these well sorted sands and their undoubted eolian origins preclude such a possibility. They are fillings of collapse-jointing which resulted from the solutional removal of supporting strata below. Other evidence for extensive solutional activity on the peninsula include: the semicircular cliffs on both sides of the point (which appear to be exposed sink-holes), the hummocky surface of the ridge, and the sugary solutional-residuum found on the walls of the sink holes.

On the seaward side, North Point is also an excellent example of a high-energy eroding shoreline. Despite the baffling effects of the coral reefs, which are developed very close to the shore, the wave-energy level is high, even during calm seas. Large rock fragments transported to near the top of the cliff on the seaward side, document wave transport during storms.

The contrasting energy level on the sheltered, leeward side of the peninsula is quite striking. The cliffs on this side are obviously due to collapse rather than wave erosion. In fact, beach development is widespread on the leeward side.

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[1]For further information see: Diehl, *et al*, 1988, 27-28; White & Curran, 1985, 73-94; White & Curran, 1989, 17-22; White & White, 1991, 235-247.

The best evidence for low energy levels is Cut Cay beach tucked into the leeward side of the tip of this island just north of North Point. The beach is a small crescent, narrowly confined by lithified dune-rock cliffs on three sides, and makes an ideal mapping project as well as being one of the few low-energy beaches available for study. The beach is very flat and consists of fine to very-fine, muddy-sands. Directly offshore is a narrow, rippled, unstable-sand foreshore and, seaward of that, a well-developed *Syringodium* and *Thallassia* meadow has developed in still, very shallow water. This meadow has a much better faunal representation than that off the Field Station beach. However, because of the shallowness of the water and the high mud content, even minor agitation clouds the water and reduces visibility. It is therefore advisable to enter the water at the extreme southern edge of the beach and wade out to the meadow. I recommend that you line up your students at about 4ft. intervals and have them snorkel through the meadow in traverses which parallel the shore.

A short swim northward around the point brings you into the strong surf action typical of the rocky shoreline exposed along the east side of the Cay. Here some high-energy coral types (*Acropora palmata* and *Acropora cervicornis*) are sparsely developed (see palisades reefs later in this chapter).

It seems advisable to visit the North Point area in the first week of work, but after Field Station Beach has been covered. The outcrops along the top of the ridge expose cross-bedding of various orientations. After the Field Station Beach visit, the students should observe that the cross-bedding in the sedimentary rock is different from that at the beach. A discussion of the beds including their divergent orientations, excellent sorting, and lack of fossils should suggest an eolian origin. If not, it should be proposed at this point.

North Point is a good place to begin a discussion of solutional effects on the carbonates of the island. Attention should be called to the possible origins of the crescent shaped cliffs, the hummocky topography, the natural arch on the windward side of the peninsula, and the oval re-entrants between the cliff top and the strand line on the leeward side (biscuit-board topography). After the class gets down to sea level at the end of the peninsula, the students can make a closer examination of these re-entrants observing their "smooth" surface, the sugary sediments coating their surfaces, and the linear cavities which link the re-entrants to the cliff surface. The presence of the inlet separating North Point from Cut Cay may also be attributed to solution and collapse.

East Beach (a low-energy, accreting beach)[2]

East Beach is reached by a roadway-trail which starts in United Estates (nearly opposite the lighthouse road) and crosses the salt pond and a series of dune ridges to the eastern edge of the island. It is one of the longest beaches on the island stretching for nearly four miles from Hanna Bay to Crab Cay. Despite its windward orientation, it is a low energy development. The apparent paradox is explained by the fact that the windward direction on San Salvador

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[2] For further information see: Diehl, *et al*, 1988, 29.

(southeasterly), is the direction from which the gentlest winds blow. Storm winds are westerly and northwesterly. Further, the beach is protected by a barrier reef about a half-mile off shore. Patch reefs are also present occurring close to the shoreline. The profile of this beach is closest to the "classic" berm-toped form so widely portrayed in textbooks, but rarely seen on San Salvador.

I would recommend a stop at the lighthouse either before or after the visit to East Beach. It is an excellent vantage point for observing the arcuate configuration of the ridges and intervening crescent-shaped lakes.

On the way to the beach, the trail passes through some farm fields and past an old concrete covered well. If time allows you might want to study the well and test the salinity of the water. Carefully lower a small collecting bottle into the well to gather a sample at the very top of the water. Test this for salinity, then gather a sample from water a foot or two below the surface, if possible. The high porosities in the carbonates of the island produce a close linkage between sea levels of the open ocean and the saline water table of the island. Indeed, tidal level changes can be monitored in the wells. The fresh water lens floats on this marine wedge.

Beyond the well is the crest of the ridge which is some distance from the ocean. From this vantage a series of 4 progressively lower ridges, paralleling the first can be observed. As you approach the ocean the ridges give way to a series of low sand dunes which parallel the ridges and the strand line.

The beach itself is broad and flat. It is assumed that the prevailing winds have generated a northward long-shore current which supplies this beach with sand eroded from the headlands of Crab Cay. Whatever the source, the sands are accumulating along East Beach and the shoreline is accreting. This is documented by the series of progressively lower eolian dunes behind the beach, and the burial of patch reefs by encroaching beach sediments.

The beach sand is medium grained, silty-sand consisting of reworked dune sand, shell debris, and ooids. It is one of the three beaches on the island, that I am aware of, which has a red component in the sand. I attribute it to finely ground red, encrusting foraminifera, *Homotremra rubrum* fragments (presumably derived from the reefs) which protect this shore. Although shell fragments are a component of the sand, few complete shells are found. If you are lucky, you may find a *Spirula*.

From the shoreline you can see the dark outlines of several patch reefs which range from 3-50 yards off the beach. I would recommend a visit to the off shore reefs first. The water is slightly turbid, but clear enough to see the unstable sand bottom. Oscillation ripples are well displayed here as are "tadpole nest" interference types near the reefs where waves and currents are refracted around these obstacles. The seaward reefs stand in 20-30 feet of water and have a few live corals on display. Algae of all types are well established on the reefs, and *Goniolithion* is abundant on their tops. I make a point of the *Goniolithion* in preparation for a visit to a "fossil" reef at Grotto Beach (see chapter three). As you progress shoreward, the live corals disappear and the reefs are essentially dead, except for the algae which cover them. It appears that siltation and the increasingly turbid water are responsible for the coral demise. The "dead" reefs nearest the shore are being buried by the accreting beach.

Field-Station Beach (a moderate energy, eroding beach)[3]

The transitory nature of beaches is well illustrated by the Field Station Beach. During the years of my observation, it has waxed and waned and the sandy and rocky portions have migrated back and forth along the strand line.

At the present time, the beach is receding. In fact, it has never regained its former configuration since the January storm of 1977. However, depending on the season, it may be sandy along most of the shoreline, or may consist of an abbreviated sandy beach with significant stretches of beach-rock defending a receded sandy beach. At the present time the sandy portions have retreated behind fossil beach-rock (exposed at low tide) from the boat ramp, at the west edge of the beach, to the curve, about midway to the concrete dock. from there to the dock there is a continuous sandy beach.

Directly in front of the "T-building", beach-rock, ripped up from the shallow onshore area and the beach and eolian blocks from the rocky-shore behind, are stacked in an imbricate fashion. Sand, shells, and smaller rock fragments fill the interstices. Fossil analogs of this type of deposit can be seen along the old sea cliff at Sandy Point and a Grotto Beach (see chapter three). It is a good place to discuss imbrication as an adjustment to wave or current action and the use of this sedimentary structure to determine current direction or the direction to the strand line.

The beach-rock defending the sandy portions is host to a variety of algae, mussels, snails, and crabs. In fact, fossil crab burrows can be seen along this outcrop.

The beach sediment is coarse-grained sand, consisting of reworked beach-rock sand, algal fragments, ooids, pellets, and shell debris.

The higher wave energies here have produced a steeper profile than those at Cut Cay and East Beach. Typical of beaches in the eroding phase is a pronounced "step" just in front of the strand line. Immediately off shore is a wide unstable-sand zone with well developed oscillation ripples. Beyond the rippled zone is an extensive *Thallassia* and algal meadow.

Since this is the closest water to the Field Station, it is the ideal place to introduce the course, demonstrate various measurement and sampling techniques, and check out the students' snorkeling skills. The bedding characteristics of the beach can be displayed by digging an "L-shaped" trench to expose their strike and dip. Since there are many outcrops of beach-rock

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[3]For further information see: Diehl, *et al*, 1988, 22-24; Armstrong & Miller, 1988, 23-32.

along this shoreline, it is easy to elicit a comparison of the beach sediment with the bedrock. It is also a good time to introduce under water sampling of sediment and biologic remains. Student teams can collect from the beach, from the unstable sand area adjacent to the beach, and from the stabilized sand area of the *Thalassia* meadow.

The textural contrasts of the beach-unstable sand areas with that of the *Thalassia* meadow, should highlight the importance of plants as organic baffles and sediment traps. The role of plants as sediment contributors may also be documented. Many of the particles in the sample will be fragments from *Halimeda* and *Penicillus*, major sediment contributors. This can be easily shown by dipping still-green fragments of either form in clorox, then comparing the bleached remains with the coarser sediment.

Sandy Point Beach (a high energy beach)[4]

Sandy Point Beach is located on the southwest tip of San Salvador. Here the prevailing winds, wave refraction around the tip of the island, and deep water immediately offshore combine to produce one of the most consistently high-energy beaches on the island. Depending on the season or storm conditions, the beach is accreting or eroding. The result of this cycle is an arcuate series of beach-faces and alternating water-filled troughs, which parallel the shoreline. Coral reefs had developed in the deep water offshore, and the accreting beach has killed and partially buried them. These reefs still shelter a diverse biota, including very large fish.

The high-energy waves have produced some of the steepest beach faces on San Salvador. The active beach face has a rather atypical convex-upward profile, developed by waves which sweep around the point and spill over the beach berm. Here the deep, calcium-rich water becomes supersaturated at the surface, and deposits a transparent "frosting" on the beach sediment. The bedrock cliffs behind and adjoining the beach offer exposures of present-day cavern development, as well as some fossil analogs of beach, dune deposits, and sink fillings.

It is probably most efficient to make this an "all-day" trip, combining this beach-study and the study of solutional effects on the ancient carbonates behind the beach (see chapter three).

This beach offers an opportunity to "exercise" all the teams. The beach-profile team has the most challenging task. Indeed, new techniques have to be developed because when the crews drop below the berms of the next "beach" they loose sight of the ocean and have to use a brunton or some other leveling-device to shoot a horizontal line. This is also the longest profile.

The sediment samplers usually notice the "frosty" nature of the grains, but if they don't, you may wish to call it to their attention and ask them to explain it.

The biota-collectors will find a whole new fauna.

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[4]For further information see: Diehl, *et al*, 1988, 34-35.

Generally, the wave-heights alert the students to the high energy level of this beach. Nevertheless, I would suggest a word of caution to anyone who is not a strong swimmer. Students have had the wind knocked out of them when they were dumped on the beach-face by the surf. I also had a student have his face-mask torn off and lost in the surf zone. Swim fins are routinely lost at this beach.

I would suggest a walk along the bed-rock cliff that backs this beach. It displays all kinds of evidence of solution, past and present. There are hundreds of small solutional-channel ways linking the rock face with the top of the outcrop. There are also solutional-collapse blocks re-cemented in filled cavities. It is possible to climb this low cliff and explore solutional activities there, but the crest of the hill behind the beach can be reached by truck and offers a much more diverse and more easily accessible view of solutional activities (see chapter three).

Rocky Point Beach (an intermittent, high energy, eroding beach)[5]

The Rocky Point Beach is the steepest beach on the north end of the island. It owes its high inclination to storms with their north-northwesterly winds and surf. Its high angle coincides with the texture of the beach sediments (medium-coarse). The biota is also different than that of the Field Station Beach, partially because of its proximity to deep water and also because of the higher energy regime here. It is located at the big turn of the road north of North Victoria Hill settlement. At this point the road cuts between the beach and a small inland lake. This stop includes two beaches: Rocky Point and Sand Dollar Beach, around the point to the south. The Rocky Point itself displays some of the best "palm-root" structures on the island (see chapter three.

The walk from the truck to either beach passes through an area of sandy soil which is brush and palm tree covered. It is probably an exact analog to the ancient palm root lithofacies exposed on the tip of the point. It might be instructive to discuss this similarity either before or after the inspection of the palm-root lithofacies.

The apparent paradox of a high energy beach (as indicated by the beach-face slope) on the leeward side of the island may serve as a opportunity to introduce the role of "catastrophe" in the formation of deposits. During severe storms, which bear winds from the west, the highly inclined beach is formed and remains long after, since the normal wave regime lacks the energy to modify most of the beach face. The beach-face steepness extends into the water so that it becomes waist deep within a couple of meters of the strand line, in contrast with most beaches on the island.

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[5]For further information see: Diehl, *et al*, 1988, 29-31.

Sand Dollar Beach (an intermittent, high energy, eroding beach)[6]

Sand Dollar Beach lies adjacent to Rocky Point Beach, and is separated from it by Rocky Point. Like Rocky Point Beach, it has a steep profile, but usually only a moderate to low surf. It is oriented in a more north-south direction in contrast with the east-west configuration of Rocky Point Beach but it also lies in the northwest, storm quadrant of the island. Like Rocky Point Beach, its steep face is attributable to periodic storms which form a profile that more seasonable seas can't modify. The beach face is perhaps even narrower, but the off-shore conditions are quite different. The slope below the strand line is much gentler, leading to an extensive unstable-sand on-shore lithotope, covered by oscillation-ripples (see shallow-water, near shore lithotopes).

Singer Beach (a storm built deposit)[7]

Singer Beach is reached by hiking westward along the shoreline from the paleosol development of the Dump Beach (see Patch Reefs). It represents a very-high energy beach of "catastrophic" origin. It developed over a two-day period in January of 1977. Another storm, apparently since my visit in 1992, has reworked and cleaned up the old shore face which had become overgrown with vegetation. It consists of boulder size blocks of beach rock and other large fragments picked up from the offshore and deposited by storm-waves about two meters above the normal high-tide strand line. Despite the textural contrast with other beaches on the island, it corresponds morphologically and displays a nice, concave-upward beach face, a berm, and a beach back. The imbrication of the large rock fragments is well displayed.

This is an excellent area to study the textural contrasts of beach materials and to reinforce beach morphology. It is also a great place to present an exercise in paleoenvironmental reconstruction.

THE SHALLOW NEARSHORE ENVIRONMENT

Introduction:

The nearshore (on-shore) environment is defined as bordered on the landward side by the low tide shoreline, and on the seaward side by the breaker line. I limit the definition further to the "shallow"-nearshore which typically extends about half the distance to the breaker line. This lithotope is below wave base during calm-sea intervals, but is subject to reworking by storm waves. San Salvador has a variety of such lithotopes which can be further distinguished on the nature of the water bottom interface. I have described three such bottoms: the rocky bottom, the unstable-sand bottom, and the stabilized-sand bottom.

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[6]For further information see: Diehl, *et al*, 1988, 29-31.

[7]For further information see: Diehl, *et al*, 1988, 24-25.

Bonefish Bay (a rocky bottom)[8]

Bonefish Bay, is found on the northwest quadrant of San Salvador between Sue Point and Club Med. My investigations were limited to the northern portion of this bay.

Just offshore from a sandy beach, the bottom consists of beachrock diagenized to varying thicknesses, a hard ground. Close to the shore it is extensively bored and hosts a large number of sea urchins that nestle into these cavities. The bay has a gentle slope so that the water is shallow for a good distance. During low tide, crossing the chinoid zone is a challenge and it is best to wait for higher water which would allow the investigator to float over this zone and into the deeper portions of the bay.

My last visit to this beach was in 1980. At that time the water was very turbid and the bedrock displayed mostly algae, some encrusting dead coral mounds. There were only a few widely scattered live corals (*Siderastrea*). Near shore *Diademas* inhabited the pocketed bedrock surface. The bay was near lifeless.

At the present time the bedrock surface is being re-populated by scattered patches of coelenterates, sponges, and algae. *Goniolithion* is especially abundant and luxuriant. In some places the colonies are 2 feet in diameter and it seems to be the dominant biotic element in the "patches". The sponges are diverse as are the gorganacea. The coelenterates, though healthy, are less abundant and consist mostly of species of *Porites*. There are a few *Diploria* species and, of course, *Siderastrea*.

There are a few circular wave-cut depressions that have penetrated the weathered portions of the bedrock and expose cross-bedding. In the deeper water, rippled unstable sand hosts sand dollars.

Sand Dollar Beach (a mostly unstable-sand environment)[9]

Sand Dollar Beach is situated south of Rocky Point and extends between the point and the New World Museum to the south. The beach face is comparable to the Rocky Point Beach, and probably wouldn't be visited if it weren't for the presence of a well developed, unstable sand bottom offshore. Apparently Rocky Point shields this area enough to allow accumulation of sand, but the energy levels are too high to permit sediment stabilization. Over the past few years, however, a *Thalassia-Syringodium* meadow is beginning to establish itself. If development continues, the area will take on the character of the offshore portion of the Field Station Beach.

This offshore area is host to both sand dollars and sea biscuits, whose tests are sometimes present in large numbers. Unfortunately, this is known to most visitors and is highly collected.

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[8]For further information see: Diehl, *et al*, 1988, 31.

[9]For further information see: Diehl, *et al*, 1988, 29-31.

It is apparently the unstable-sand habitat that these echinoderms favor. That part of the shallow foreshore not yet stabilized by the spreading meadow is characterized by the presence of loose sand formed into oscillation ripples. And, because they form in a higher energy regime than that of Field Station or East Beach, they are larger. During times of calm seawater, visibility is excellent and the ripples can be seen for 30 meters or more. Unfortunately, being on the western side of the island, these waters are prone to high seas and turbidity during and shortly after storms.

It is an excellent place to observe the comparative sorting in offshore lithotopes as compared with the beach face, and as a contrast with the sorting and biota found in stabilized sand environments.

Field Station Beach (a stabilized-sand environment)[10]

Offshore of Field Station Beach, beyond the unstable sand area, a well developed *Thalassia* meadow extends for most of the length of Grahams Harbor.

In contrast with the fairly well sorted sediment found off Sand Dollar Beach, the materials found off Field Station Beach are very poorly sorted. This can be attributed to two things. The wave and current baffling effects of the *Thalassia* and the abundant algae found there reduce the winnowing action and help to trap fine sediment. Secondly, the largest fragments found in this lithotope are produced by the organisms that inhabit it. Echinoderm tests and Mollusc shells make up some of the coarsest materials, but *Halimea* flakes make up a considerable fraction of the bio-sediment found there.

A strong case for vegetative origin and trapping of sediment can be made here. Especially when contrasted with beach-face sorting.

A comparison of the shells collected at Bonefish Bay, Sand Dollar Beach, and Field Station Beach should demonstrate contrasts in biologic activity and relative faunal diversity in these three lithotopes.

THE LAGOON-TIDAL FLAT ENVIRONMENT[11]

Introduction:

Perhaps the most unique geologic feature of San Salvador is its tidal lagoon, Pigeon

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[10]For further information see: Diehl, *et al*, 1988, 22-24.

[11]For further information see: Anderson & Boardman, 1987; Anderson & Boardman, 1988, 7-22; Colby & Boardman, 1988, 95-106; Diehl, *et al*, 1988, 37-38; Mitchell, 1986, 215-230; Teeter, 1985, 147-160; Teeter, 1989, 43-46; Teeter & Thalman, 1984, 177-186.

Creek. It extends about three and a half miles north of its inlet and for nearly two miles east and south of it, with a maximum width of approximately three-quarters of a mile at high tide. It lies between two ancient dune complexes along the southeast edge of the island, and empties into the ocean through a channel about 100 meters wide. Because of the large volume of water transferred during tidal changes, strong currents develop near the mouth of the lagoon. This phenomenon makes Pigeon Creek the one place on the island where water-current action and the features produced by currents, available for study. The strong ebb-flow has produced a very large subaqueous delta which is building out into Snow Bay.

Because of its linear configuration, the headward portions of the lagoon are not completely flushed during tidal exchanges. This is a rare feature in the Bahamas. The result is an occasionally developing salinity gradient from the mouth of the lagoon up to its terminus. A great deal of additional research on the lagoon could be tied to: seasonal changes and possible reversals in salinity gradient, the salinity effects on other biota, and volumetric studies of the exchanges themselves, and the development of the sub-aqueous delta produced at its mouth.

The tidal flat lithotope is limited to the edges of Pigeon Creek especially in its upstream portion.

Pigeon Creek Inlet

The Pigeon Creek inlet is reached by turning south off the old "Queen's Highway" just east of the Belmont Church and taking the coastal road to its end. Standing at the mouth of the lagoon the large, white subaqueous, ebb-delta stands out in contrast to the green-thalassia-floored bay. The delta consists of a series of arcuate dunes, about one meter high, with their foreset beds dipping toward the bay. The dunes are covered with current ripples. The dune complex is isolated from either bank by channels near both shores. Up stream of the mouth, on the east side of the lagoon, a shoal has developed. Mangroves have anchored and grow there, accelerating deposition. This organic baffle has been augmented by a dense *Thalassia* meadow, which hosts a variety of organisms including *Chione cancellata* and *Callianassa*, whose mounds dot the grassy flat. The vertical sequence produced by this prograding delta is; a *Thalassia* meadow overlain by tabular cross-beds of the delta which is, in turn, overlain by a second *Thalassia* meadow. This same sequence is displayed in the ancient sediments of the Pigeon Creek Quarry (see chapter 3, Ancient Analogs, Quarry E.).

The mouth of Pigeon Creek is an ideal place on San Salvador to observe current action and its effects. It is best to time your arrival to coincide with slack water at either high or low tide. At this time it is relatively easy to swim out over the delta complex and observe the developing and coalescing dunes.

At slack-tide you can determine the last current direction based on the orientation of the current ripples which cover the dunes. It is also possible to swim to one of the front dunes of the delta complex and observe the orientation and inclination of the forset beds. As the delta grows this becomes more and more of a challenge. From this point at the seaward edge of the delta, you can point out the *Thalassia* meadow which has developed in this part of Snow Bay.

If time permits, I would recommend a trip up the east side of the channel, retracing our traverse over the sub-aqueous dunes, and investigate the vigorous growth of the *Thalassia* meadow which has developed upstream of the delta complex. The textural contrast with the clean well-sorted sands of the channel and the muddy-poorly sorted sediment of the meadow document the effectiveness of the grass as an organic baffle.

A close examination of the *Thalassia* meadow is rewarding. The *Thalassia* is encrusted with algae and forams, which are being eaten by snails. The substrate hosts *Callianassa* and *Chione cancellata*, which are regular inhabitants of such meadows. If slack water continues, or if the tide is beginning to rise, you can use it to carry your class across the lagoon in a northwest direction to the well-developed mangrove thicket along the opposite shore. The proproots of these large mangroves serve as shelter to a variety of fish and other organisms. The traverse across the lagoon allows a reconnaissance of the channel with its shoals and depressions. The floor is veneered by a sediment lag consisting of larger shells and shell fragments. The water in the lagoon tends to be murky and is often inhabited by barracuda and sharks. So an advanced warning might be in order.

When the tide begins to change, the gradual transformation of the ripples as they become reoriented with respect to the current reversal can be observed. The relationship of the current to the ripple form is forcefully reinforced by this simple demonstration. At this time, swimming against the current is not too difficult, but as the exchange progresses the current strength increases and swimming can become a problem. A short swim along the shoreline near the house at the inlet mouth reveals several pockets with nice coral and sponge developments. These corals are healthy, if diminutive, and display a wide variety of species.

<u>Northern Terminus of Pigeon Creek</u>

Because of road conditions, I would recommend a visit this part of the island only once. The occasion of this visit may be a combined island geology and island culture and history tour.

About three-quarters of a mile east of South Victoria Hill the road makes a sharp turn to the west and passes between a pond and the northern terminus of Pigeon Creek. A concrete pier and several conch middens in the lagoon mark the location. The color contrast between the red-brown of the pond and the blue-green of the lagoon is striking. Because of the expanse of the lagoon at this location, it often confused with the ocean. A salinity measurement is helpful here. I suggest measuring the salinity of the pond and then the lagoon. Generally the pond has the highest salinity, sometimes 10-20 parts/thousand higher than normal marine salinity. Pigeon Creek is lower, but still up to 10 ppt higher than normal marine salinity. The road continues along the western edge of the lagoon, but easy access to the water is limited by mangrove and brush thickets and mud flats. I suggest that you make at least two stops along the way toward the mouth of the lagoon to take salinity readings. These also represent opportunities to investigate the tidal flats on San Salvador.

The last stop is about a mile north of the inlet because it is too complicated to get to the mouth from the north. Nevertheless, the salinity is at or near 35 parts/thousand and the trend is noted. An examination of an island map might make an explanation of the salinity gradient easier.

REEFS

Introduction:

The island of San Salvador is an excellent place for reef investigation. This is because it is nearly completely ringed by these features. There are two major types; the off-shore reefs which include barriers and deeper-water patch-reef complexes, and the near-shore patch reefs. Their abundance and variety offer many opportunities for study. A second benefit of their wide distribution is that no matter which way the wind is blowing, there are some reefs in the lee of the island available for study.

The barrier-type reefs, which fringe the island, are mostly well off shore. Further, the high-energy conditions of this lithotope make it a "challenging" environment which is best investigated by those equipped with SCUBA and operating out of boats. I have listed North Point as a possible place for land observation of this lithotope from a distance. I have also included the Telephone Pole off-shore patch-reef complex, which is suitable for a quick visit if your students are good swimmers.

The near-shore patch reefs may be observed in a number of places including; Dump Reef, East Beach and French Bay. They are easily reached from land and afford opportunities for observation, mapping, and study. They also display a spectrum of growth activity and vigor which invites a comparative study.

PALISADES AND OFF-SHORE REEFS

Kissling (1980) used the term "palisades" to describe the linear bulwark of linear coral reefs which rings the island. It is a complex ecosystem of high-energy loving forms and those which find quieter conditions in their proximities. His research spanned several years on San Salvador and resulted in many publications describing palisade-reef morphology and composition. He, and others, also described a fossil palisades-reef complex near Cockburn Town (1980) (see chapter three).

The reef palisades can be visited nearly everywhere around the island. Most, however, are far offshore. A near-shore occurrence can be found adjacent to High and Low Cays off Pigeon Creek in Snow Bay. However visits to either island requires boats.

<u>North Point</u>

For those of us that are relatively shore-bound, this lithotope can be viewed from the cliffs on the east edge of the North Point peninsula. It is a short walk from the Field Station. This area also displays eolian dune development and extensive solutional activity. The reef complex is developed on the eastern side of North Point. Unfortunately, near vertical cliffs prevent close approach from the ridge top. However, observation from this distance still allows an appreciation of the high-energy levels of this lithotope and coral fragments washed to the ridge top (a testimony to storm-wave energy) enables the students to identify the species present. This area is best to visit in late afternoon when the sun is behind the viewers and water-surface reflection is minimized.

Cut Cay[12]

A swim around the point of Cut Cay will bring you in contact with the fringes of such a complex. This is not recommended for anyone who is not strong swimmer, however. The water deepens quickly and the swimmer is often greeted by large waves that break between the island and rock pinnacles. *Acropora palmata* and *Acropora cervicornis* can be seen just around the point.

Fernandez Bay[13]

Telephone Pole Reef complex is situated in Fernandez Bay, south of Cockburn Town. The reefs, which make it up, are about 100-200 meters offshore in about 20 ft of water. It can be spotted by sighting seaward along two offset telephone poles, that are located near an unused structure. From the shore it resembles a series of dark shadows. It contains thickets of *Acropora cervicornis,* and *Montastrea* mounds. The reef is also note-worthy because some of the *Montastrea* mounds are inhabited by comatulid crinoids.

I have only made two visits to telephone pole reef, and never with a class, because it is a long distance off shore in fairly deep water. I would recommend the use of boats for those interested in reconnaissance of this area.

PATCH REEFS

Patch reefs include a broad spectrum of reef forms ranging from a few closely associated single colonies, to pillar-like developments 5-15 meters wide, to extensive communities tens of meters in diameter. They tend to be subcircular in outline and on San Salvador, best developed close to the shoreline.

Several researchers have made extensive studies of these and the barrier system on the island. My investigations have been of a much more limited nature. This is because of the

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[12]For further information see: Diehl, *et al*, 1988, 27-28.

[13]For directions on locating reefs and further information on them see: Diehl, *et al*, 1988, 31-33.

logistical complications of patch-reef study and the limited time available to examine the other lithotopes. For those with limited time or for those uncomfortable in deep water or long distances from shore, I find Dump Reef and the patch reefs off East Beach are sufficient.

Swimming around the reefs is always an adventure. Wave action invariably washes you into the reef and pushing off with your bare hands can be painful if you happen to be next to *Millepora*, sea urchins, and other sharp or stinging objects. For that reason, I would encourage any person planning a patch-reef visit to bring a pair of gloves. I generally buy the white cotton ones with the black nylon dots on the fingers and palm.

Dump Reef[14]

Dump reef is a common stop for many biology and geology classes. One reason for its popularity is its ready accessibility. It can be reached by walking west from the Field Station entrance for about a quarter mile. On the seaward side of the road a trail has been cut and maintained by the Field Station which leads to the "dump" and the "Dump Reef" beyond.

The reef complex consists of two major reef clusters which begin very near the strand line and project out into Graham's Harbor for nearly 50 meters. The size of these reefs indicates a time of great coral activity in the past. At the present time much of the reef is dead, supporting a luxuriant growth of algae and a few diverse coral types (*Acropora cervicornis, A. palmata, Porites sp., Siderastrea radians*, etc.). Also present is a healthy crop of *Millepora*. The coralline algae *Goniolithion* is well displayed along the tops of parts of the reef. This same distribution of *Goniolithion* is also displayed on the patch reefs off East Beach and the fossil analog on Grotto Beach (chapter three). A variety of fish add color and interest to the reef complex for the students.

The second reason for Dump Reef's popularity, and what makes the trip worthwhile (for me at least) is the relative ease with which I can visit these few coral specimens and talk to my class about what they are seeing while in the water. Generally the sea-state is very low. This allows one to hover over a specific specimen relatively easy and make sure that the whole class gets a chance to see it. The operational word is "relative". Swimming and instructing are two nearly mutually exclusive activities. This is especially true in the case of patch reef instruction. All of the patch reefs that I have visited on San Salvador are within the surf zone so that each wave that strikes you is a wave of translation. I have been "translated" into or across the tops of reefs more times that I would like to count. The process is generally painful and certainly not one to encourage one to tarry over a particular specimen for discussion. It is usually "see and flee" on the patch reefs. This makes instruction of what to see and do while visiting reefs of some importance and the relative calm around Dump Reef is the ideal training ground. Unfortunately, entry and exit from the water at Dump Reef is difficult. One must cross a stretch of slippery and jagged beach rock before reaching a sandy bottom. Except for the most agile, I would recommend that students wade across the bed rock, then sit and put on fins and mask.

[14]For further information see: Diehl, *et al*, 1988, 24-25.

A visit to the Dump Reef also allows an examination of one of the unconformities present on the island. On San Salvador, unconformities are marked by a well developed "red" zone. At Dump Reef the red zone, clastic fragments cemented by red cement, and a "palm-root" zone all are testimony to a zone of weathering which interrupted sedimentation here. Because this unconformity is very near sea level the surface is algae covered and is being intensively bio-eroded by all manner of algal grazers. After the student's exposure to the "yellow, black, and white" zones on North Point, this is an excellent opportunity to reinforce the role of biota in limestone erosion. The tidal pools developed on the bedrock surface are hosts to chitons, limpets, and other rocky-substrate inhabitors.

East Beach Patch Reefs[15]

The patch reefs off East Beach, are perhaps the easiest to access. Entering the water is easy on the flat sandy, low-surf beach. A short swim brings you to the reefs. In fact, one can wade to the closest reefs along this shoreline. However, the reefs with the most life present are those about 25-50 meters offshore. The swim to these structures allows a perusal of the sandy seafloor which is covered with oscillation, ladder, and tadpole-nest ripples. Unfortunately the fine-textured sediment is generally suspended in the water on even very calm days so visibility is limited. These reefs display somewhat stunted examples of *Acropora palmata, A. cerviornis, Siderastrea radians, Diploria sp.*, etc., and a wide variety of typical non-coralline reef inhabitants: sponges, sea whips, algae, lobsters, and fish.

INLAND LAKES[16]

Introduction:

The inland lakes on San Salvador cover about half of the island. Most are arcuate in plan, filling the depressions between eolian-dune highlands. Some have formed in sink holes. Because of extensive solutional activities, the lakes are all probably linked to the surrounding ocean and many respond to tidal changes. Indeed, tidal "fountains" have been observed in some of the lakes. However, the linkage is too weak to maintain normal marine salinities. During Spring storms, the rain-dilution lowers their salinity to the "brackish" range. During the dry season, salinities soar to hypersaline concentrations. (50-76 ppm). These lakes represent an environment where algae, diatoms (which, I am told are responsible for the red-brown color of the lakes), and certain molluscan species can survive and even flourish. The lakes are an excellent place to study "restricted" faunas, and algal-salt crust formation. They might also be suitable for dolomitization studies.

Salinity checks of the lakes during my stays (January-February) universally indicate

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[15]For further information see: Diehl, *et al*, 1988, 29.

[16]For further information see: Diehl, *et al*, 1988, 40-41; Teeter, 1989, 35-40.

hypersalinity levels. With the exception of salinity study visits, I have only investigated the north arm of Great Lake and Little Lake.

Great Lake

The drive out to the lake gives an opportunity to drive past several smaller ponds where salinity measurements can be taken. It also represents an opportunity for observation of red and black mangroves and their contrasting root-holdfast systems, (pneumatophores). The north arm of Great Lake can be reached by a trail that begins at the observation tower at the end of the road leading east from just south of the Riding Rock Inn. The observation "tower" offers a good chance to see the distribution and configuration of the lakes, if not already seen from the light house. The hike down from the tower is steep, narrow, and rocky. It is also a good place to see the development of the thin terra-rosa soil which is common the island and to compare it with the "red-zones" seen in the ancient rocks.

The entrance to the lake from the trail end is narrow and not well suited for observation by a group of students. Further, it doesn't offer an opportunity to observe "beach" features and the restricted fauna which is present here. Therefore, I suggest you have your class traverse about 50 meters of salt-crust to the low-water shell-beach developed offshore. On the way to the beach, desiccation cracks developed in the algal-salt crust can be observed. This trip is a challenge, because the crust won't support a person and every one breaks through to about 12 inches of bottom muck. The bedrock bottom is very irregular and jagged so walking barefoot is not recommended. Hard-soled booties are best for this traverse because tennies tend to be sucked off by the sediments.

Since this traverse is difficult and the lake shoreline is essentially flat, neither a profile or map seems necessary. A biota collection., however, is extremely interesting and rewarding. The beach consists entirely of mollusc shells. The fauna is limited to two species: a clam (*Anomalocardia ? cuneimeris*), and a snail *(Batillaria sp.)*. This restricted fauna may lead to a discussion of the concept of the relationship of salinity to species diversity. The concept can be demonstrated by a salinity measurement.

The crescent-shaped shell-beach is apparently the low-water strand line, while the point of entry onto the crust is the high water shoreline. It would appear that the lowering of the lake level, related to the dry season, results in such high levels of salinity marked by the extensive mortality of even these salt-tolerant forms, and producing the shell beach.

Little Lake[17]

Little Lake can be reached by continuing east down the main street of Cockburn Town. There are some very narrow road cuts in the limestone along this route, so it should not be taken

[17]For further information see: Teeter, 1983; Sanger & Teeter, 1982; Bowman & Teeter, 1982.

with a truck. The road ends at a small pier and a boat house.

The water here is generally very frothy and the shoreline a mixture of mud and lower concentrations of the mollusca described above. Although this represents an easy access to the lakes, I feel that it does not display the restricted fauna or the lake level changes which are so obvious at the Great Lake.

ROCKY SHORELINES

Introduction:

Although not a depositional environment, the rocky shoreline is an important environment to visit. It is the host of many organisms and the source of much sediment. On San Salvador, rocky shorelines display the effects of wave erosion, solution, and biological attack. In the rock record, they may be indicated as unconformities or hardgrounds. They occur at many places on San Salvador. I will describe them at only three places. North Point, where they display cross bedding, extensive solutional activity, and the "classic" yellow, black, and white zones. Rocky Point, where the color zones are present, as well as the fossilized remains of a "palm forest". And Dump Reef, where "palm roots" and a red-marked unconformity are displayed.

North Point[18]

North Point is an erosional remnant of an eolian dune complex. The western edge, close to the mainland, is mostly sediment and vegetatively covered. The eastern, seaward, side is mostly steep cliffs. Along this side there are several semicircular re-entrants, formed by the collapse of sink-holes. These display low- to moderate-angled cross-bedding. Direct access to the sea is limited until about half way out on the peninsula, but several overlooks make remote observation possible.

A grounded propane tanker rests, in part, on a well developed coral reef. The reef lies a few yards offshore on the ocean side and runs for most of the length of the peninsula. When the light is right, the brightly colored parrot fish can be seen working through the corals.

About half way out a sea-arch is observable and a little way further a swale leads to several ledges at sea level. Here the yellow, black, and white zones are clearly visible.

The yellow color is limited to that portion of the shoreline which is within the tidal range, and is wetted at least once daily. The yellow represents healthy growing algae. The back zone directly above is also algal-coated, but the algae is dormant because they are only wetted during times of storms and high seas. Above the black zone the white zone is free of algae, and hence white. Close inspection reveals the pocked and pitted surface of the yellow

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[18]For further information see: White & Curran, 1985, 73-94; White & Curran, 1989, 17-22; White & White, 1991, 235-247.

and black zones, as well as the mollusca which are responsible, in part, for the irregular surface. Folk (1973) recognized the boring effects of algae and fungi on limestone and referred to such riddled terrain as "phytokarst".

Chitons are found in abundance in the yellow zone, as are the snails, *Nerites* and *Tectarius*. In the sands and rocks on the cliffs above, the ground snail *Cerion* is abundant, especially in "shell exchange areas" where hermit crabs bring their old shells while searching for a new one with a better fit.

One of the best exposures of the "yellow", "black" and "white" zones is displayed on the cliffs of the leeward side of the peninsula near its southern terminus.

Rocky Point

Rocky Point offers a second display of the yellow, black, and white zones and a chance to verify the relationship of the colors with the presence of algae, the mollusca listed above, and the jaded rock outcrops produced by bioerosion.

Rocky Point also exhibits a nice collection of "palm-root" molds. They are red-colored, bowl-shaped structures with a complex of branching and connecting rock-tubes beneath them. There are two theories as to their formation: 1-These formed at a time when the area was soil-covered and a grove of palms grew there. The acids of the palm-roots partially dissolved the carbonate soils and some of the dissolved carbonate precipitated close-by to form basins around the root butt and tube-like sheaths as around the small rootlets (rhizocretions). Since a new generation of palm grove is present above the outcrop it is often possible to see an uprooted palm to observe the "elephant-foot" shape of the root butt so it can be compared with the fossil root-molds. These areas are generally red to red-yellow in color because of the iron which was concentrated during the solutional removal of the carbonate. This same color is much in evidence in the soils present on the island (latosoils). 2-These are the resistant remnants of solution depressions, whose exterior matrix has eroded away. Many of these contain limestone breccia similar to the breccia found associated with solution depressions. The rhizocretions are likewise the resistant remnants of the root systems associated with the depressions' development.

Dump Reef

The rocky shoreline adjacent to Dump Reef also displays palm-root molds. It is also a good place to observe an unconformity which coincides with the root-zone. The red stained carbonate is solutionally smoothed and pockets of dark-red carbonate chips in a red-carbonate matrix can be found at this horizon. This is also a good place to observe the bioeroders in action, since many of the depressions in the rocks form tidal pools with abundant mollusca in place and doing their thing.

CAVES AND SINKHOLE DEVELOPMENTS[19]

Introduction:

I have included sink holes as depositional environments despite their erosional origins, because they are also sites of sediment accumulation. Mylroie (Gerace, 1983) has described the caves and karst development which is widespread on the island.

For my purposes, both solution and deposition features are best displayed at Sandy Point. Sink hole investigation may be a part of a day-long trip to Sandy Point and Grotto Beaches. This is one lithotope where the recent environment and fossil analogs can be found juxtaposed.

Should you desire to include a caving experience, I would suggest a visit to Lighthouse Cave. It is close to the Field Station and has a relatively easy access. Further, it is possible to walk through a portion of this cave in a loop that returns to the entrance area. Experienced spelunkers will find it to be an extensive system, worthy of an extended visit.

North Point and Cut Cay

Sink holes and a serrated cliff line, produced by erosion and collapse of sinks are well exposed here. The hummocky surface of the peninsula is due, in part, to solutional collapse. The eolian cross-bedding is cut by vertical fracture fillings which resemble desiccation-crack fillings, but are solution-produced fractures that have been mended by subsequent precipitation of carbonate. These fillings are more durable than the friable dune bedforms and stand in relief. By descending from the ridge top at the cut which separates North Point from Cut Cay, one can observe lateral exposures of many sink holes. Their walls are mostly covered with a sugary, friable sandy coating which obscures the original bedding. Vertical conduits extend from these large cavities to the surface and some of the crack fillings extend to the surface as well. These sink hole exposures are large (30-50 feet in diameter) and very much rounded in outline.

Sandy Point[20]

The road cuts leading to the top of the Sandy Point expose a series of sink holes and fillings formed in an eolianite. They are one to two feet in diameter and of various lengths. Some display a finely-laminated rim formed by the precipitation of iron-stained calcium carbonate and an indurated filling of latosol and limestone breccia blocks. Some are recent and contain loose red-soil and plant debris.

Just behind the beach and extending along the southern edge of the island is a low cliff

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[19]For further information see: Gerace, 1983, 67-96.

[20]For further information see: Carew & Mylroie, 1985, 11-62; Carew & Mylroie, 1989, 7-16; Gerace, 1983, 67-96.

formed by fossil beach rock. It displays numerous solution pits, chimneys, and small caves. Also present are relics of ancient solutional activity, and are small cavities filled with indurated collapse breccia. These old sink holes do not display the obvious cavity rimming and red coloration like the sink fillings observed at the top of Sandy Point. Here it is sometimes difficult to delineate the sinks, but the observation of beach-rock blocks with their bedding planes oriented in a wide variety of attitudes should alert the students to collapse phenomena.

At the crest, the surface consists of nearly bare limestones with a very sparse cover of brush where a series of open sink holes is displayed. Some are small vertical conduits a few inches across; others are large enough to contain mature trees. Indeed, some of the solution activity has been accelerated by the presence of the tree roots (Lambert, 1992). Some of these sinks contain collapse blocks and soil which has washed into the depressions.

Light House Cave[21]

From the light house at United Estates, a trail leads about a quarter mile down to a large cave system. Access is by ladder to the bottom of a sink hole. From there, the cave winds extensively. It displays some typical cave formations: stalactites curtains, etc. Because of its low elevation the main level of the cave is partially filled with water at high tide and it contains wet passages even at low tide. Visitors to this cave should dress for a wet trip and carry flash lights.

Eolian Environments

To my knowledge, there is no truly eolian lithotope on San Salvador. The closest thing to it is the region behind East Beach were a few low, semi-stabilized back-beach dunes have developed. Behind them are a series of larger eolian dunes which have been stabilized for years and are now utilized as farm fields. Unfortunately, the bioturbation of plants and humans have thoroughly disrupted the original bedding, and a soil horizon has developed, so all original texture is lost. Perhaps deep pits might uncover both aspects of the dunes, but I don't believe this has been attempted.

It is unfortunate that this lithotope is lacking because of the wide extent of fossil eolian deposits on San Salvador. Indeed, the "heart" of the island consists of eolian deposits that can be visited in several places (see chapter three).

[21]For further information see Mylroie and Carew, 1994.

Chapter Two

SEDIMENTARY ENVIRONMENTAL ANALYSIS ON SAN SALVADOR

Preface

An important step in environmental analysis instruction is a "plan of attack" which will maximize exposure to the various lithotopes for time spent at the Field Station. This guide is designed to help this procedure by describing some of the examples of the various environments present on the island. The instructor can then design an itinerary which best fits the goals of the course. It is hoped that the equipment lists will expedite the planning process and also serve as a reminder when packing for the visit.

Aside from the normal snorkeling gear, there are a few items of equipment that are necessary for data gathering. The equipment list is dictated by the type of research the team is undertaking. For that reason I have listed five exercises and the equipment and techniques recommended for the determination of each.

Environmental (Lithotope) description
Beach-profiling
Beach-mapping
Sand-sampling and analysis
Biota-collection and analysis

DATA GATHERING TECHNIQUES

Introduction:

The following techniques have grown out of thirty years of data gathering at near-shore marine environments. They were copied, learned, and modified from a variety of sources. It may be that the following techniques are already known to you or that you know much better ways of gathering the data. This chapter, then, is for those few who are innocent of lithotopic study, and need some help in getting started. They are not fancy but they have this in common: they are relatively inexpensive and are easy to learn and apply.

Environmental description

In an ideal world, the environmental description should be a succinct, complete depiction of the lithotope in terms of its physical, biological, and lithological characteristics. For practical purposes, however, only a partial description is possible.

I have found it to be useful for the students to make the suggestions for possibilities.

This generally opens a discussion of the "controls" of a lithotope and which are important. For students, it is better to keep the list short and simple. I have included a check-list, (Appendix A, Plate 1), to aid in this process.

The following parameters are routinely obtained or measured by my students:

wind direction and velocity
wave height
current direction and velocity
tidal range
water and air temperature
salinity
turbidity
bottom material and conditions

For best results, it seems appropriate to organize the students into four teams: to 1) profile the beach, 2) map the beach, 3) sample the sediments, and 4) sample the biota. Each team (three to four members), after learning its task, is responsible for gathering the requisite equipment, performing the data collection and later reducing its data and making a presentation of the results to the other teams in our afternoon laboratory-discussion sessions. By rotating the team membership, each student learns all the techniques required.

Wind Measurement

Equipment

Anemometer
Compass
Data sheet (Appendix A, Plate 1)
Clip board

There are several hand-held anemometers on the market. I have tried most types that I am acquainted with from the "pith-ball" (Dwyer portable wind meter, $13.50) to a three-cup anemometer. I have found that the pith-ball device, which measures wind velocity by how high the ball is drawn up the tube by the wind blowing over the top, is generally unsatisfactory. High humidities, static electricity, and grit seem to freeze the ball somewhere in the tube. Even when freed, you can never be sure that its movement is not restricted in some way. Further, they tend to give widely divergent readings when a series is taken.

The Davis instrument company offers a wide range of wind-measuring devices. A wand-type device called the "wind wizard" ($35.75) is relatively inexpensive and gives fairly consistent readings. It has three scales; miles/hour, meters/second, and the Beaufort scale. This, by the way, is a nice way to introduce the Beaufort scale should you be so inclined.(Appendix A, Plate 5)

A three-cup "BT-anemometer" by Sims ($138.00) is a much more accurate device. It is also much more expensive. It gives readings in miles/hour and knots. The relatively large size of the instrument, plus the necessity of assembling the cups every time it is used or carrying it around assembled, made it less attractive than my personal favorite, the Davis "Turbometer" ($125.00) wind-speed indicator. It consists of a four-bladed fan-like vane, in a plastic housing. It is much smaller than all the other instruments (about the size of a king- size package of cigarettes), which makes it very handy to carry into the field. It is also very accurate and gives consistent readings. It has three scales; miles/hour, meters/second, and knots. It does require 3-AAA batteries.

On San Salvador the prevailing wind is 120°. This is the wind of fair weather. If you are lucky all of your observations will be from this direction. Such winds produce quiet seas. Winds from the West and North are usually accompanied by storms. If possible, I would recommend that beach-data you gather under good-weather conditions be compared with that produced by stormy conditions. Beach steepening under stormy conditions, is a nice way to illustrate the effects of higher energy levels on beaches. It also demonstrates the effects of "catastrophes" on the sedimentary record.

<u>Procedure</u>

I was taught that the best method of determination of wind direction was to turn my face until both cheeks felt the wind equally, then take a bearing with a compass. I generally use an underwater compass for the purpose, but any type will do. Remember winds are named for the direction from which they blow.

Once the direction has been determined, the next step is to hold your wind-measuring device, of whatever type, into the wind at arms length. Take the reading and either note it yourself or dictate it to the party recorder. The traditional notation is "winds of ___ (kts, Mph, M/S) at____degrees".

Wave Height

<u>Equipment</u>

Leveling rod
Data sheet (Plate 1, Appendix A)
Clip board

Wave-height measurements are essential if one is emphasizing the effects of wave heights on beach-slopes. A direct correlation between wave-height and beach slope can be demonstrated.

An additional measure can be made on the beach at this point: the wash-area, or beach face; which is the distance between the strand line and the highest current swash-mark. These data should be considered along with the wave height and beach-slope figures.

Procedure

Wave-height determinations can be made using one of the beach-leveling rods. A volunteer measures a distance of 1-2 rod-lengths (@ 1.5meters each) from the stand line into the surf-zone. (The distance is controlled by the water depth. It is best to stand in water about knee deep, or less). He/she, holds the rod at arms length and faces the shore. The rod should be oriented so that the rod-reader on the shore can observe the centimeter markings and determine the lowest and highest water levels of at least 5 waves. The rod-holder must be aware of and compensate for undercutting and settling of the rod while in the surf zone. This can be accomplished by gently raising the rod above the bottom for a short period and gently replacing it after each reading. It should be emphasized that this exercise is to determine relative wave-heights at the various beach lithotopes and it is, therefore, not necessary to determine the heights of waves off shore.

An alternative method is for the rod-reader to move into the surf zone between the rod and the strandline. This will allow readings that cannot be made from the shore.

Neither of these techniques is recommended for shorelines with high or breaking waves (eg. Sandy Point).

Tidal Range Determination

Equipment

Data sheet (Appendix A., Plate 1.)
Clip board
Leveling rods
Markers

The tidal range on San Salvador is under two meters. The observed range, of course, varies with the lunar cycle. If you plan to spend ten or more days on the island, you might want to consider a tidal-range determination experiment.

Procedure

The easy way to determine this range is by the use of a tide-watch or tide-table and make your observations at the times indicated. Lacking either of these aids or wanting to develop the range by experiment, dictates repeated visits to the beach.

Start at as near to the high-tide line as possible and work down to the low-tide level.

I recommend that the observer use a fairly large rock as a low-tide marker, selecting and marking one side as the swash-line indicator. As the tide drops, the observer moves the rock to keep up with the swash-line. I suggest a heavy rock just in case the tide turns before the last observation. Baring a strong surf, the rock will remain in place as witness to the approximate low tide.

Once the range has been established, a profiling team can measure the tidal range in the same way as a beach profile is determined.

Water and Air Temperature Measurement

Equipment

Thermometer
Data sheet (Appendix A., Plate 1.)
Clip board

Metal thermometer cases are particularly prone to corrosion and sometimes "freeze" so that the thermometer can't be removed for use. Plastic cases are best, if they are available. I would not recommend using a liquid thermometer without a case. They have a habit of breaking in your pack and are difficult to replace on San Salvador, especially on short notice.

Procedure

Take out your thermometer as soon as you arrive at the lithotope and hang it on a stick in the shade so that it can begin to equilibrate to the ambient temperature. This normally takes only a few minutes. By the time that temperature comes up in the environmental analysis, the thermometer is ready to read. After air-temperature is measured and recorded a volunteer can wade into the water and submerge the thermometer for a minute or two and then report the reading to the recorder. If it is an armored thermometer remove it from its case before immersing it in sea-water. If the case is metal, be sure that someone rinses the thermometer (and especially the case) with fresh water each day.

Salinity Measurement

Equipment

Salinometer-refractometer
Eye dropper
Distilled water (I collect it as drippings from the Field Station air conditioner)
Data sheet (Appendix A., Plate 1,)
Clip board

Salinity measurements can add a significant dimension to environmental analysis on San Salvador, especially if is to be considered as a factor in faunal diversity (see Inland Lakes, and

Pigeon Creek). If you have a salinometer, an experiment, at the Field Station Beach, in the determination of "normal marine salinity" might be a good way to begin. This base-line figure can be used in comparison with data collected at the inland lakes and Pigeon Creek.

Salinity measurements at the inland lakes demonstrate brackish or hypersaline conditions, depending on the season. I find a series of readings along the length of Pigeon Creek especially instructive. Pigeon Creek is one of the few tidal lagoons in the Bahamas long enough to develop a salinity gradient from its mouth to its head.

Procedure

The first step is to calibrate the instrument. This is done by lifting up the daylight plate, placing a couple of drops of distilled water on the prism surface, and gently closing the daylight plate. Next, look through the eyepiece and observe the line produced by the junction of a light-blue and a dark-blue field. This line should be at the base of the scale. If it is not, use your thumb nail to turn the adjustment screw just behind the daylight plate-hinge until the line is at "0". The instrument should be calibrated each time it is used unless a series of readings are to be made within a few minutes.

After calibration, use the eye-dropper to flush the prism face with some of the water to be measured, and take a reading.

After all the measurements have been taken and recorded, again flush the prism with distilled water.

Beach Profile Data Collection

Equipment

Leveling rods
Data sheet (Appendix A., Plate 2.)
Clip board

Beach profiling is the only method that I know of which will present an undistorted cross-sectional view of a beach. The tools for this are "beach-leveling rods". I have never seen such items for sale, so I come to San Salvador prepared to make some when I arrived. They consist of two, 1.5 meter lengths of wood or metal that can be written on with a marker pen. My first "rods" were made from aluminum, window-screen framing-material, found at the Field Station. It is essential that they be wide enough that a series of 10cm. markings can be made and marked. The graduations should begin at the top.

Measure down 10 centimeters and make a horizontal line with a magic marker. Label this "10 cm". Continue down the rod to the bottom. Do the same thing with the second rod.

The determination of the end of the profile depends on the specific reason for the profile. If you want to compare beach slopes, texture, and wave energy, for example, you might want to stop at the strand line. For other reasons you may wish to stop at the "step", just off-shore. Sometimes you may want to extend the profile into the surf zone. When the water gets about knee deep, however, it becomes difficult to "hold station" and the wave surge tends to undermine the rods quickly.

Procedure

The profiling team ideally consists of 3 members; two rod-holder-readers, and one data collector. In a pinch, one of the levelers can also record the data. The profiling process begins at the "top" of the beach where the rod-reader positions his/her rod vertically and stands behind it looking directly toward the ocean. The second rod-holder uses his/her rod as a horizontal measuring device and marks off a horizontal distance of 1.5 meters (one rod-length) down the beach-face (make sure this distance is measured in the horizontal and not by simply laying the rod on the sloping beach surface).

The data collector stands behind the rod-reader and makes sure that the rod-holder has positioned his/her rod in a direct line from the first rod to the beach. It should be perpendicular to the shoreline to get maximum slope. Once the second point has been determined, "turning point-1" (TP-1), the rod- holder orients his/her rod vertically.

The rod-reader crouches behind his/her rod and sights past the first rod to the top of the second and lines it up to the horizon.

Unless the beach is perfectly flat (highly unlikely), the rod-reader's eye will be some distance down his/her rod. This distance is read from the first rod. (interpolations are made between the 10cm markings) This first reading "called TP 1, is called to the data collector and recorded on a beach- profile form as D.E. (difference in elevation).

The cumulative (Cum) difference in elevation from the top of the beach to the base of the profile is calculated by subtracting each D.E. from the previous cumulative measurement for the entire profile. The horizontal distance (Dist) between TP's is also recorded. Typically, this is 1.5 meters, but with rapid drops, or rises in the beach profile or the desire to include a specific data point in the survey, the distance can be "broken" to any desired length. When the distance is broken, or any other significant departure from the profile program is undertaken, it should be noted in the "remarks" column.

The profile crew is responsible for the production of the profile in the afternoon laboratory and presenting its data to the rest of the class during the discussion period that follows the laboratory session (Appendix A, Plate 3).

Beach Profile Construction

Equipment

Profile construction forms (Appendix A., Plate 3.)
Scale
Profile data sheets
Drafting pencil and eraser

The data collected at the beach is used to construct an undistorted cross-section of the beach. As such, it can be directly compared with other such profiles. When beach profiles are compared with wave height a strong case can be made for the direct correlation between wave energy and beach slope. It is also instructive to compare beach slope and the texture of the beach sediment. Because of limited provenance, the textural range is small. Nevertheless a texture/beach slope relationship can be demonstrated when a comparison is made between low, moderate, and high-energy beaches.

Therefore, the slope of the beach face can alert the students to the possible textural make-up of the beach sediment, or a textural analysis of beach sediment can allow the prediction of the beach slope.

Procedure

Rotate the profile forms so that their widest edge is horizontal. Refer to the data sheets and plot the highest point on the construction form in the upper left hand corner. The scale can be expanded or contracted to fit the specific needs of the profile. Typically, I use 1 inch equals 1 meter. Plot the starting point of the profile in the upper left hand corner of the sheet (unless you anticipate that the profile will rise from the initial point). Mark off the first distance along the horizontal line at the top and measure down the "cumulative" distance to plot the second point. Continue in the same fashion to plot all data points. When the edge of the plotting form is reached, slip a second sheet under the first. After all the data points have been plotted, connect them with a light line to indicate the beach profile. Make sure to plot the position of sampling sites along the profile.

Beach Map Data Collection

In some lithotope analyses, a map is necessary to either document a specific feature or spatial relationship, or to explain why some phenomena was experienced. The ocean environment is not one conducive to most mapping techniques, eg., plane-table mapping or the use of transits. I have found that using marine sextants to measure horizontal angles is an easy and relatively accurate method to produce useful maps.

Honest-to-goodness sextants are very expensive, but the plastic "Davis" Mark-3 sextants, obtainable from most marine supply stores are less than $30.00. They can be read to two seconds of arc, are light, fairly tough, and don't rust. The mirrors will corrode after a couple of seasons if you don't remember to wash them off with fresh water after every day in the field. It is also recommended that you re-align the mirrors every morning.

Sextant Orientation and Operation

Equipment

- 2 sextants
- "Flag"
- Measuring tape
- Compass
- Data sheet (Appendix A., Plate 4.)
- Clip board

The sextant should be in the right hand, with all 4 fingers looped through the bracket on the back of the instrument that runs from behind the index mirror down to intersect the other handle at a "T" intersection. The sextant is then rotated to the horizontal plane. Make sure that the colored filters are swung out of the line of sight of both the index mirror and eye piece.

Horizontal angles are measured by rotating the sextant until the "target" is centered above the horizon mirror and turning the index arm with the thumb and first finger of the left hand until the opposite end of the baseline can be seen directly below it in the horizon mirror.

When measuring horizontal angles, the viewer should always make sure that his/her left-most object is seen through the eye piece directly above the horizon mirror.

To determine the horizontal angle, turn the instrument face toward you and read the scale. The angle equals the numbers read from the arc opposite the "0^o" on the index arm. You can read to two-minutes of arc by using the vernier scale, but since you can't plot anywhere close to that, you needn't bother to teach them how to read it. I recommend that each student gets a chance to take and read at least a half-dozen horizontal angle measurements.

Procedure

The first step is the construction of a base-line. If a beach is to be mapped, it is recommended that the base line run parallel to the beach some distance above the strand-line. The length of the base-line is optional, but it should be at least twice as long as the distance to any point that is to be mapped from the base-line. I do not recommend the use of metal tapes to measure the base-line. I have marked a 30 meter piece of line for this purpose. It doesn't rust or take up much room. Begin by selecting and marking one end of the baseline (a stick is good) and extending the tape down the beach. If two or more tape-lengths are required, it is essential that a person stand at the first end and sight past the first and succeeding turning points to the end of the tape to make sure that the projected base-line is straight. After the base-line has been laid out and marked at both ends, the bearing of this line should be recorded.

The mapping-team ideally consists of 4 members. Two instrument-operators, one recorder, and one flag-bearer. One instrument-operator is stationed at each end of the base-line. The recorder is stationed slightly behind the baseline about halfway between each end. The flag-bearer (typically the party chief) proceeds to the first data point. Once there he/she identifies it as data-point 1 and places the flag, or him/herself over the data point as a target. The instrument-operators stand directly over the base-line ends and measure the horizontal angle between the opposite end of the base line and the data point. Each instrument operator relays his/her horizontal angle to the recorder, who fills out the data sheet (Appendix A, Plate 4.) being careful to indicate which end of the baseline each angle is read from. The data should be grouped in sets of two shots for each data point, one from each end of the baseline. It is advisable to label the ends of the baseline as "A" and "B" and to record the shots from each in the appropriate column on the data sheet.

It is recommended that mapping data be collected in the following manner: The flag bearer situates the flag or him/herself over the data point. He/she indicates his/her readiness by waving the flag or calling out to the recorder. The recorder enters the "Station number" in the first column of the map data sheet and informs all members of this number. This serves as a check of any miss numbering by any member of the team. If they are agreed that the number stated is correct, each instrument operator measures the horizontal angle between the new station and the opposite end of the base line. Each operator reads the angle to the recorder, who enters it and notes from which end of the baseline the angle was read. If a depth is also required the flag-bearer measures it and relays this information to the recorder. The recorder then fills in the remarks column by indicating the nature of the station; eg. shot along strand line, rock along shore, sampling point, etc.

Since the map is produced later in the laboratory, it is essential that any possible ambiguities be removed while in the field. If mapping is to be undertaken on both sides of the base line, it is essential that each side be indicated as E, W, N, S, or + , - for each set of shots.

If some specific object (like a reef) is to be mapped, it is best to center the object with respect to the end-points of the baseline. The best positioning occurs when the two lines of sight intersect at nearly 90°. Although it is desirable that all data points are confined within the area between the baseline ends, data can be obtained from positions beyond these points. The horizontal angle from the end closest to the data point will be larger, sometimes much-larger, than 90° so it can't be determined from a single sextant reading.

The "shot" must be doubled or tripled. This is done by measuring the angle from the base line to some point between it and the desired data-point. This angle is called out and recorded as a "doubled" or "tripled" angle. The sextant is then shifted to this point and the angle between it and the desired point is measured. The two (or three) angle segments are then added to produce the complete angle.

The most difficult part of the Procedure, is the location of the flag-holder through the sextants. This can be helped by adding surveyor's tape or a bright piece of cloth to the flag or flag-holder. The flag-holder should stand behind the flag while shots are being made. If the shots are fairly long, or surf noises make communication difficult, the flag-holder should keep his/her eye on the recorder. As soon as both angles are recorded, the recorder wave his/her hands over head as a signal to move to the next data point. Likewise, the data recorder watches the flag-holder. When he/she takes up a position on a data point he/she waves the flag and then places it over the point. When this is observed the data recorder or either instrument reader notifies the rest of the crew so that the new readings can be taken.

This team is also responsible for the construction of the map and a presentation of its significance during the laboratory session devoted to this particular project.

Beach Map Construction

Equipment

- Mapping paper (generally, 8½" X 11" bond paper)
- Engineer's scale
- Protractor
- Straight-edge 12" or longer
- Data sheets
- Drafting pencil and eraser
- Dissecting needle

The data collected at the lithotope is reduced to a map in the laboratory. Once constructed, it offers a perspective of the lithotope that may not have been possible in the field. The map is important because it documents the relative positions of all recorded data points. Students are often surprised that their data can actually be used to produce an image which resembles the site. In addition, the map and profile of a beach become the basis for comparison with other such lithotopes and are helpful in integrating and explaining sediment textures and structures.

Procedure

Select a scale which will allow the completed map to be constructed on 8½" X 11" sheet of paper. For special projects you may wish to use a larger sheet or several 8½" X 11" sheets overlapped.

Draft in the measured baseline, again making sure that it is so placed that all the data points can be plotted. This is often a trial-and-error procedure and sometimes it is simpler to draw the line in an arbitrary fashion and then slip additional sheets under the first one to get all the data points in. If additional sheets are used, be sure to tape them together or mark their margins so that any relative movement is prevented.

After the baseline is constructed the end points are located with pin pricks. I have found a dissecting needle useful for this process. These pin-pricks are the loci of all rays measured in the field. Each data point is measured by the protractor from the base line and plotted as a tick. A ray is drawn from the loci through the tick. Keep these lines very light and as short as possible. The angle to the data point from the second station is then plotted and the line produced through its loci at the other end of the baseline and the protractor-tick should intersect the first. This point should be marked by a pencil, given its appropriate number and the rays to it erased. This procedure continues until all the data points have been plotted. If the data points marked a shoreline or some other feature, they should then be connected by a light pencil line to define it. Once the data points have been plotted, distances to any of them can be determined by simply scaling them off the map. Be sure refer to the remarks on the data sheets while constructing the map so that sample collection points and other miscellaneous data are noted. If a really polished presentation is required, the original data points may be marked with ink and a second sheet of paper placed over the first so that the points can traced through. This strategy can also make up for a misplaced base line. This finished map need not have the data points labelled, but they should be shown to indicate data point coverage of the area.

The finished map should include: a title, a north arrow, a scale, a legend if symbols are used, a date, and the authors' names.

Sediment Collection

Equipment

Sample bags
Marking pen
100ml graduated beaker

In the final analysis, the sediment, with the sedimentary structures and organisms it contains, is the sole reason for the lithotopic study. Our understanding of "fossil" lithofacies, is often based on and understanding of modern day lithotopes and their accumulated sediments. These sediments, when fossilized, may be the sole basis for a lithotopic reconstruction. For this reason, the sampling team should be careful to note any and all features associated with the sediment.

This team is also responsible for the textural analysis of the sample, the production of a histogram, and presentation of this data and the team's conclusions as to the significance of the data in the afternoon laboratory- discussion session.

Procedure

The sample collection team is also responsible for the observation and notation of sedimentary structures observed at the lithotope. Therefore, before a sample(s) is/are collected a survey of the lithotope should be undertaken.

If the lithotope is a beach, I recommend lining up the team members across the width of the beach and walking its length, together. One team member should be assigned as data-recorder and note any feature observed by the team. Once the survey is completed the sampling strategy should be developed. For beaches, again, a single sample usually suffices. It is nice if it can be taken at one of the TP's of the profile traverse. Then it can be noted by the profile recorder. Each sample is to be numbered and the number recorded by the profile crew and the sample-collection crew. The sample is obtained by twisting the 100ml beaker into the sediment at the collection point. Be sure that at least 100ml is collected.

If the lithotope is underwater, a similar survey is done by floating the length of the lithotope. Underwater sampling is slightly more complicated because of the weightless condition of the sampler. I recommend that the sampler dive to the bottom and scrape up a sample with the beaker, while a second member holds an opened sample bag. Transferring the collected sample into the collection bag, without loosing sediment isn't easy. It is sometimes easiest to simple drop the beaker into the plastic bag and quickly close it before the sediment washes out. When sampling in grassy areas, it takes repeated efforts to obtain the 100ml.

Sediment Analysis

Equipment (textural analysis)

graduated beaker (100ml)
sieve set
wash bottles
funnel
graduated cylinders (100ml)
data sheet

The analysis of the collected sediments can take a variety of directions. Textural analysis is the most common approach. Another goal may be a survey of the nature of the grains (lumps, ooids, pellets, biological fragments). A textural analysis is generally undertaken to determine the carrying capacity (energy) or sorting efficiency of the medium. A component analysis may uncover the provenance of the grains, or the relative importance of the various sediment contributors, (molluscs, algae, etc.)

The sieves required for a textural analysis can be obtained from a variety of sources. Hubbard produces a set of 6½ inch sieves graduated from 2.0mm (ϕ-1) to 0.62mm (ϕ4) plus a lid and pan. The sieves are plastic with metal screens, which are light weight and corrosion resistant. Because the sediments collected are always at least damp, wherever they are collected, the constituent grains always tend to stick together. For that reason wet-sieving is recommended.

A medium powered microscope is required if a component analysis is to be undertaken. A small sample is spread out on a petri dish and scanned by the microscope operator. Grains are sorted by component-type (lumps, oolites, shell fragments), and placed in separate compartments for subsequent counting and/or further study. Care should be taken to insure that the scanned portion is representative of the total sample. After the component census the data are entered on the data sheet (Appendix A, Plate 8)

Procedure

Each sieve of the nest is inspected for cleanliness and defects. They are then nested, in order, with the coarsest at the top and the pan at the bottom. One hundred milliliters of the collected sediment is placed in the top of the sieve nest. The sample is washed through the nest using the wash bottles filled with fresh water. The use of salt water will result in screen corrosion. The accumulating water levels in each sieve must be monitored to make sure that water- and sediment-flow is maintained. Special care must be taken to insure that the pan does not become completely filled. As the pan approaches fullness, the team must carefully lift the sieve nest from the pan. The best method is to have one member hold the pan while another carefully lifts the nest free. If the set continues to drain, it must be held over the pan to catch any sample that may be filtering through. The pan is then carefully tilted so as to drain most of the water, but not to loose any accumulated sediment. The nest is then reconfigured and the washing continues. When it appears that the sorting has been completed, each sieve is removed, in turn, and its contents are washed into a graduated cylinder.

The best procedure for this is to turn the sieve nearly vertically, being careful not to spill the sediment, and gently wash all the grains to the bottom using a wash bottle from behind the sieve. Then place the sieve on the funnel which is inserted into one of the graduated cylinders and continue to wash from behind until all the sediment has been transferred to the graduate. If the graduate fills with water before all the sediment is transferred, stop the procedure and carefully drain a portion of the water from the graduate, then continue the transfer process.

It is best to have graduates for all the sieves in the nest. If so, you can align them in sieve-size order and produce a histogram directly. If not, allow the sediment to settle in the graduate, and read the ml marking at the top of the sample. If the washed-sample was 100ml, then the percentage of each size-grade can be read directly as a percentage of the original sample. After each fraction is measured, it is dumped and the graduate washed clean and drained for the next fraction. The data is added to the data sheet (Appendix A, Plate 6) as volume percent. As a rough check on procedure, the percentages are accumulated in the right hand column and, ideally add up to 100%. It is more common for the figures to be over or under by 10% or so. If the cumulative percent is over the 10% figure, you may wish to re-do the procedure. Often, excessive material is lost during the water draining procedure of either the pan or sieves in the nest.

The volume percent data are used to generate the histogram at the bottom of the data sheet. The histogram makes a textural comparison with other samples easy. It also presents visual information on such things as relative sorting, and the extent of size-grade distribution.

sorting index

3 size-grades or less	=	good sorting
4-6 size grades	=	fair sorting
> 7 size-grades	=	poor sorting

By using the cumulative percent data, a cumulative curve can be superimposed over the histogram. For this curve, the data points should be entered on the right-hand side of each size-grade column. Once the points are plotted, they may be connected by a smooth curve to produce the cumulative cure

Biota-collection

Equipment

Collecting bags
Marking pen
Notebook or data sheet

It is assumed that specific lithotopes should have specific biota. With this in mind, the researcher must determine which organisms are lithotope specific (if any) and which are ubiquitous. How this may be accomplished has been a continuing problem for me. Originally, I collected and identified every dead organism found in any lithotope. This meant a lot of work in identification and with very long faunal lists it became very difficult to isolate specific forms as lithotope specific. It occurred to me that a better way of picking out the "facies-fossils" would be to sample the lithotope and determine which species were most abundant. I have finally come to the method of only identifying the three or four most abundant species. Some forms are indeed ubiquitous, but some work out to be fairly useful as facies-fossils. (Appendix A, Plate 7.)

Any new or interesting live specimen is to be announced to the other teams so that all can observe the form. After observation it is to be returned to its habitat.

All the specimens are collected in a numbered plastic bag to be analyzed in the laboratory session.

This team is also responsible for the identification of the collected biota, the production of tags for each species which include: the name, collecting site, and lithotope identification. They are expected to present their results to the other teams in the laboratory-discussion session.

Procedure

The team members, equipped with collecting bags, should form a line at one edge of the sampling site and traverse the site in parallel paths. Collect only dead specimens that are complete enough to ensure proper identification. Collect all the specimens that you see unless numbers or volume become problems. In that instance, collect specimens in a ratio that reflects their relative field abundance. At the end of the traverse, bag and identify the sample by number and enter the number, location, and lithotope in your notebook. If the site includes more than one lithotope, biologic samples should be collected from each and so indicated.

Analysis of the biota sample

Equipment

Reference books
Hand lens
Data sheet (Appendix A, Plate 7.)
Identification Labels (Appendix A, Plate 10.)

Procedure

During the laboratory session, the sample is sorted by species and each population counted. The team then selects 1-3 specimens of the 3-4 most abundant, "indicator", species collected and identifies them. Each identified specimen is provided with an identification label which includes its name, collection site, and a specific location in the lithotope if it is significant. The team members that identified the specimens should also be included on the label. If it appears that any form may be unique to that lithotope, this should also be indicated on the name card. Those forms which are considered as ubiquitous, should also be so indicated.

If a form can't be identified it should not be thrown away, but labeled as unidentified and placed with the other identified forms. Subsequent teams may be able to identify it.

Chapter Three
SELECTED ANCIENT ANALOGS

Introduction

One of the many benefits to the study of sedimentary environments on San Salvador, is the availability of "fossilized" lithotopes, similar to the recent settings on the island. This makes possible comparisons between the two and verification or refutation of predicted lithologic responses or characteristics to specific lithotopes.

These ancient analogs are exposed either naturally in cliffs or in the quarries opened in the course of building the road that rings the island. Adams (in Gerace, 1983) has listed these quarries and given a brief interpretation of each. I have listed these and a few favorite places of my own.

A tour of these ancient analogs seems appropriate sometime near the end of the Field Station stay. At that time, lessons learned in the present lithotopes can be applied in deciphering these lithofacies.

Beach Facies[1]

Beach-rock is displayed extensively around the island. In fact, the western, or storm facing, side of the island is mostly fringed by beach-rock facies, at sea level. The juxtaposition of the beach-rock and the sand accumulated on the beaches offers a handy comparison.

Bonefish Bay

Bonefish Bay offers excellent exposures of beach-rock at the shoreline. In fact there is little modern beach and only sparse sand deposits to cover the ancient

Field Station Beach

Beach rock is exposed as scattered outcrops along the receding beach that extends from the Field Station front to the east towards the concrete pier. It can also be observed along the shore line of Field Station Beach and along the low cliffs to the west of the Station. Overlying this facies, to the west of the station, are exposures of eolian strata of varying thickness.

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[1]For further information see: Bain, 1985, 63-72, 121-128; Bain, 1988, 33-44; Bain, 1989, 23-26, 41-42; Curran & White, 1986, 243-?

Quarries "W2", "W3", "W4"

These quarries, along the SW side of the island, have all been interpreted as exposing beach facies.

Shallow-water, Nearshore

Barker's Point

Barker's Point is an interesting lithotope. It consists of an eroding beach backed by low, cliff-like shore. A large limestone erosional remnant forms the island portion of a diminutive tombolo. Surf action makes it difficult to get into the water, but if you want it is best to arrive at low tide and enter on the east side of the point. The is an excellent patch-reef development around the point.

Of even more interest, however, is the lithofacies displayed on the shore. It consists of poorly-sorted sand containing fossilized conchs, *Strombus gigas*. Given the texture and the enclosed biota, I have interpreted it as an example of a shallow-water, nearshore facies. Please note, collection of any of these conchs is prohibited.

Quarries "W1" and "W5"

The rock exposed at quarry "W1" has been interpreted as a shallow-water, marine deposit. There have been reports of fossilized burrows in this exposure. Quarry "W5" has also been described as exposing shallow-water sediments.

Sub-aqueous Delta[2]

Quarry "E"

The Pigeon Creek quarry is one of the most interesting exposures on the island. It includes a variety of lithofacies and sedimentary structures and abundant fossils, making an interpretation more multidimensional and hence, more interesting. It also contains abundant evidence of solutional activity. In order to make the most of "E", the students should have previously visited the sub-aqueous delta forming at the mouth of Pigeon Creek. This quarry displays the ancient analog of the depositional succession now developing there.

The subaqueous-delta succession is exposed along the quarry face closest to the road. Near the floor of the quarry, are flat-lying, bioturbated, poorly-sorted, fossiliferous beds which correspond to the basal *Thalassia*-meadow lithotope. It is complete, with abundant *Chione* remains typical of this environment. Overlying this unit is a tabular cross-bedded sequence

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[2] For further information see: Teeter, 1985, 147-160; Teeter, 1989, 43-?; Teeter & Thalman, 1984, 177-186.

about one meter in thickness, which corresponds to the progradational dunes of the delta complex. Above the cross-beds is a repetition of the *Thalassia*-meadow unit, similar to the one presently encroaching on the advancing delta facies. These upper beds also contain extensive *Ophiomorpha* burrow-fillings, the fossilized equivalents of the *Callianassa* burrows now forming. Some of the *Ophiomorpha* burrows penetrate through to the cross-bedded "deltaic" sands beneath.

Also present at this quarry, are a variety of "fossil' solution-cavities, complete with depositional rims, collapse breccia fillings, and red-carbonate cements. These are displayed on several of the boulders which remain on the quarry floor.

Reefs

There are several excellent exposures of reef-facies on the island. Perhaps the most spectacular is that displayed near the old dock in Cockburn Town. This complex was described by Kissling (1980) as a Pleistocene, fringing reef.

Cockburn Town Reef[3]

Kissling (19980) describes three distinct facies. "*Acropora palmata* palisades, *Acropora cervicornis* thickets, and massive coral patches dominated by *Montastrea, Diploria, Siderastrea,* and *Porites*". He, and his colleagues, worked out the stratigraphy of the exposure and described the reef complex in terms of; biological components, sediments, and general morphology.

The Cockburn Town reef is exposed along the cut made to the old dock in Cockburn Town. However, recent construction has covered this exposure. The best access is now along the south edge of a new tank-farm fence across the road from the Cockburn Town Post Office. The tank farm is fenced off short of the shoreline, allowing access to the reef. The exposure near the SW fence corner is nearly flat and consists of the top of the reef with the encroaching beach facies landward. Further north, the beach facies is absent and the reef stands in relief like a beach wall, exposing its top and flanks. This allows a three-dimensional exposure of the reef and the back-reef talus. This exposure offers a splendid opportunity for reef mapping, faunal cataloging, and diversity studies.

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[3]For further information see: Curran & White, 1984, 71-96; Curran & White, 1985, 95-120; Curran & White, 1989, 27-34; White, Kurkjy, Curran, 1984, 53-70.

Grotto Beach, patch reef[4]

The cliffs exposed at the eastern edge of the beach display a buried patch reef. The reef itself forms the base of the outcrop, and consists of *Diploria* fragments (mostly in growth position) surrounded by cavities filled with calcarenite. Overlying the corals is a thicket of the calcareous algae, *Goniolithion*. Above the *Goniolithion* zone and around the sides of the exposed reef are uniformly dipping, well bedded calcarenites interpreted as beach facies. This exposure is strikingly analogous to those patch-reefs being buried at East Beach.

Quarry "A", a reef-lee facies

Quarry "A", north of Dixon Hill, exposes a coarsely mixed sand and gravel lithology, together with scattered fragments of *Diploria*. It is interpreted as a reef-lee deposit.

Quarry "C-D", a reef-lee facies

Quarry "C-D" was excavated on the west side of the road about half-way between quarries "C" and "D". Like quarry "A, the exposure consists of coarsely mixed sand and gravel and contains *Diploria* fragments. It is also interpreted as a reef-lee deposit. Both are probably analogous to conditions current in the leeward area of "Telephone Pole" or "Snapshot" reefs.

Caves and Sink Holes

Sandy Point[5]

As stated earlier, the area around Sandy Point is ideal to investigate both ancient and modern cave and sink hole development. Perhaps the best exposures of the ancient features are found on the top of Sandy Point, and reached via the road system there. In fact, some of the road cuts expose excellent examples of collapse-filled sinks.

Eolian Deposits

The eolian environment appears to have been dominant during island formation. Indeed, the core of the island consists of eolian deposits. Early workers, as a matter of fact, considered many of these islands to consist entirely of eolian dunes which presumably coalesced to form large, island-sized accumulations during low sea stands during the Pleistocene.

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[4]For further information see: Carew & Mylroie, 1985, 11-62; Stowers, Mylroie, & Carew, 1988, 323-330.

[5]For further information see: Carew & Mylroie, 1985, 11-62; Carew & Mylroie, 1989, 7-16; Gerace, 1983, 67-96.

North Point and Cut Cay[6]

North Point has excellent exposures of Pleistocene eolian dunes. Cross-bedding of various attitudes and orientations are observable nearly the entire length of the peninsula. The constituents are very well sorted (predominantly oolitic) sands.

Watlings Quarry[7]

Probably the greatest thickness of eolian deposits are exposed at Watlings Quarry, just east of Watling's Castle. The exposure here is about 40 feet high. The dunes here consist almost entirely of very well sorted, fine grain ooliths

Road Quarry Exposures

Many of the quarries, opened to supply materials for the peripheral road, were cut into eolian deposits. On the east side of the island, quarries "B" and "C" expose what appear to have been eolian deposits. Quarry "B" sediments consist of ooliths, fecal pellets, and foraminiferal fragments. Quarry "C" deposits are also a mixture of oolids and biological debris of one sort of another. Near the south end of the island, Quarries 1-5 (from near Pigeon Creek to French Bay) all appear to have been cut into eolianites.

Quarry "W6", along the southwestern edge of the island, has been described as exposing eolianites.

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[6]For further information see: White & Curran, 1985, 73-94; White & Curran, 1989, 17-22; White & White, 1991, 235-?

[7]For further information see: Bain, 1985, 129-132.

Appendix A
Data Collection and Description Forms

Plate 1.

Environmental Analysis Data

Location: Date:

I. Lithotope type:

A. Configuration

B. Peculiarities of lithotope

II. Physical and Chemical Parameters

A. Weather Conditions

Air Temperature: _____ Barometer ____.___

Winds _______ @ ____ Clouds, Precipitation ________________

B. Water Conditions

Wave height/sea state:__________ Water Temperature: _______

Currents:_________@_____ Water Clarity/Turbidity:__________

Salinity: ________‰

C. Bottom Conditions

Substrate: _________________

Lithology: _________________

Texture: _______________

III. Biological Parameters

A. Biosurvey:

B. Bottom vegetation:

Type:____________________

Amount: ________%

Plate 2.

Beach Profile Data

Location

T.P	Dist.	D.E.	Cum	Remarks

Location

T.P.	Dist	D.E.	Cum	Remarks

Plate 3.

BEACH PROFILE PLOTTING FORM

Mapping Data Form

Date: Location:

Station	Bearings		Depth	Remarks
	"A" end	"B" end		

THE BEAUFORT SCALE OF WIND FORCE

This scale was modified from one devised by Sir Francis Beaufort in 1805
The strength of the wind is indicated by numbers from 0 to 12

Beaufort Number	**Specifications for use on land**	**Miles per hour**	**Terms used in U. S. Weather Bureau forcasts**
0	Calm; smoke rises vertically	Less than 1	Light
1	Direction of wind shown by smoke drift, but not by wind vanes	1-3	Light
2	Wind felt on face; leaves rustle; ordinary vane moved by wind	4-7	Gentle
3	Leave and small twigs in constant motion; wind extends light flag	8-12	Gentle
4	Raises dust and loose paper; small branches are moved	13-18	Moderate
5	Small trees in leaf begin to sway; crested wavelets form on inland waters	19-24	Fresh
6	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty	25-31	Strong
7	Whole trees in motion; inconvenience felt in walking against wind	32-38	Strong
8	Breaks twigs off trees; Generally impedes progress	39-46	Strong
9	Slight structural damage occurs	47-54	Gale
10	Seldom experienced inland; trees uprooted; considerable structural damage occurs	55-63	Whole Gale
11	Very rarely experienced; accompanied by widespread damage	64-75	Whole Gale
12		Above 75	Hurricane

Mechanical Analysis of Sand

Identification No.______
Sample No. _____
Description of Sample:
Date: ______

Sampled By: ________________________________

Quantitative Results:

Size Grades	Volume Percent	Cumulative Percent
4.0mm	.	.
2.0mm	.	.
1.0mm	.	.
0.5mm	.	.
0.25mm	.	.
0.125mm	.	.
Pan	.	.
		100.00%

Histogram

100%	4mm	2mm	1mm	0.5mm	0.25mm	0.125m	Pan
90%							
80%							
70%							
60%							
50%							
40%							
30%							
20%							
10%							

Sorting index: ____________________

Biota Survey Form

Location:

Date:

Description of the Lithotope:

Faunal List

1.	6.
2.	7.
3.	8.
4.	9.
5	10.

Floral List

1.	4.
2.	5.
3.	6.

Most Abundant Forms

1.	sp.no./total no.
2.	sp. no./total no.
3.	sp. no./total no.
4.	sp. no./total no.

Apparent ubiquitous forms:

Apparent "index" forms:

Sediment Description Form

I. Location:

Date:

II. Depositional environment:

III. Degree of induration of sample:

IV. Size-grade distribution of sample:

>4mm	%
4-2mm	%
2-1mm	%
1-.5mm	%
.5-.25mm	%
<.25mm	%

V. Component types, present in sample:

A. Non-skeletal debris

Particle type	Percent of Total	Textural Range
Lumps		
Grains		
Fecal pellets		
Oolites		

B. Skeletal debris

Source	Percent of Total	Textural Range
Algal		
Molluscan		
Foraminiferal		
Coralline		
Others ( )		

VI. Remarks

Plate 9.

Specimen Tags

No:_______ Location: Lithotope: Name: ________________________________ Index form (Y/N)________ Team Mbrs:	No:_______ Location: Lithotope: Name: ________________________________ Index form (Y/N)________ Team Mbrs:
No:_______ Location: Lithotope: Name: ________________________________ Index form (Y/N)________ Team Mbrs:	No:_______ Location: Lithotope: Name: ________________________________ Index form (Y/N)________ Team Mbrs:
No:_______ Location: Lithotope: Name: ________________________________ Index form (Y/N)________ Team Mbrs:	No:_______ Location: Lithotope: Name: ________________________________ Index form (Y/N)________ Team Mbrs:
No:_______ Location: Lithotope: Name: ________________________________ Index form (Y/N)________ Team Mbrs:	No:_______ Location: Lithotope: Name: ________________________________ Index form (Y/N)________ Team Mbrs:
No:_______ Location: Lithotope: Name: ________________________________ Index form (Y/N)________ Team Mbrs:	No:_______ Location: Lithotope: Name: ________________________________ Index form (Y/N)________ Team Mbrs:

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Appendix C
Suggested Clothing and Field Gear

The following is a list of suggested clothing and field gear for those who have never visited San Salvador. On my first visit, before baggage restrictions, I carried two large suit cases with everything I could imagine that I might need on the island. I found, as you might expect, that I had much to much of some things and was lacking some very important items. I hope to minimize this problem for you.

One pair of jeans	These are useful in a variety of ways. First, and foremost they are essential for any trail hikes, like the one to Long Lake or Lighthouse Cave. The underbrush on the island is full of all manner of cutting, pricking, and stinging vegetation. They are also handy for those occasional cold days and/or nights on the island. For those who are especially sensitive to sunburn, they can also be worn in the water to prevent burns on the back of your legs while snorkeling.
One long-sleeved shirt	Also helpful for all trail walks and for sun protection. Some people rely on sun screen, but I've found that, despite their claims, it eventually washes of. Also handy on those cool evenings and when there are storms.
One sweatshirt	You won't believe how cold it seems to get on San Salvador. When the temp drops below 70, it really seems cold. I've found that one sweatshirt and one rain jacket makes a great combination that keeps you warm during the coldest of winter storms.
One rain jacket or suit	Not only useful during rainstorms, but a great wind breaker for those blustery cold days.
Tennis shoes	I suggest you bring two pairs. One for walking beaches and offshore areas. There are two dangers there, sharp rocks and occasional tar deposits, often hidden by grasses and other beach debris. This first pair is often either so badly cut up or tarry that I leave them behind. This of course, means that you need a second pair for your trip home.
Sun hat	Baseball caps are worn by some, but they don't protect your ears or the back of your neck. A wide brimmed hat is best. Be sure that it has a chin strap

Cotton gloves	The white-cotton gloves with the black nylon dots on the fingers and palm are excellent protection for hands while snorkeling and picking things up off the bottom. The are especially important for swimming around patch reefs where waves push you against the corals and other sharp objects.
Insect repellent	When conditions are just right (perhaps just wrong), the island buzzes with the sounds of no-see-um's, mosquitos, and biting flies. Products with 100% DEET are good. I have also had remarkable success using "skin so soft" from your friendly Avon lady. I don't know why it works, but it does and it smells a lot nicer than the "traditional" repellents.
Swim fins	If you don't already own a pair or have no special preference, I would recommend the type that are warn with "booties". They take longer to put on and take off, but when walking and wading are required, you have the foot protection you need on some of these rocky beaches without having to put on a pair of shoes.
Booties	They provide the foot protection you need on some of the beaches, especially rocky shorelines. They are also good for the wade in Long Lake where regular shoes are often sucked off feet. Be sure and get the kind with a semi-hard sole. The rocky shorelines cut the regular kinds to pieces.
Swim mask	Any kind you like is fine, but stay away from those that have built-in purge valves. Its true they make purging your mask easier, but after only a few minute's use, a particle of sand gets in the valve and it leaks. If your mask has a purge valve, you can close it with a piece of duct tape or bath tube caulk.
Snorkel	Again, any kind you like is fine, but try the mouth piece for a while to see if it stays comfortable after prolonged use. Some of them make for very tired jaw muscles and sore mouths.
Camera	Pictures or slides are very good for instruction before, after, and during the Field Station experience. However, getting the pictures can be difficult and expensive. I have wrecked 3 expensive single-lens reflex cameras by using them near salt water or even in salt air. If you own nice SLR, I would encourage you to leave it home. Minolta makes a "Weathermatic, dual 35" camera that uses 35mm film. It could be used in water up to about 20 feet deep and has built in flash and wide angle and telephoto lenses. It works well and seems ideal for the kind of treatment it gets on San

Salvador.

Sample bags — I have found that the best sample bags for recent sediments are zip-lock bags. The gallon size (about 11X11 inches) will hold biological and sediment samples nicely and also doubles nicely to protect forms, maps, etc.

Marking Pen — Any permanent marker is fine. I usually bring black because that seems best for marking the profiling poles and also works well in labelling all the sample sacks.

Diver's compass — Your really need a compass for laying out traverse lines, noting wind and current directions, and some cross-country navigation. Again, any compass will due, but a divers compass is waterproof and generally resistant to salt-water corrosion.

Flash light — You can count on at least one power outage on San Salvador. Besides, a flash light is helpful in getting between some buildings on campus and is essential for any after dark, off-campus hikes.

Appendix D
A Reference Guide to Molluscs of San Salvador

Gastropods

Species Name	Page no. in Abbott	Plate no. in Morris	Plate no. in Humfrey
Diodora minuta	60-4	35-10	2-26
Diodora listeri	60-1	35-8	2-4
Diodora sp.	60	35,36	2
Fissurella nodusa	62-2		2-2
Acmaea sp.	64-66	36, 37	2
Calliostoma jujubrinum	70-6	37-16	3-4
Citarium pica	72-2	37-25	5-1
Tegula lividomaculata	74-6	38-3	3-5
Tegula fasciata	74-1	38-2	3-7
Astraea phoebia	76-1	38-24	5-5
Astraea americana	76-2	38-20	
Turbo castanea	76-6	38-16	3-1
Nerita versicolor	78-2	39-21	4-2
Nerita peloronta	78-1	39-19,20	4-1
Nerita fulgarans	78-3	39-22	4-3
Purperita pupa	78-5	39-10	4-5
Echininus nodulosus	82-9	40-12	4-17
Tectarius muricatus	82-11	40-11	4-16
Littorina angulifera	82-4	40-5	4-12
Littorina lineolata	82-2		
Littorina sp.	82		4
Siliquaria squamata	84-4		
Vermicularia species	84	41	5
Planaxis nucleus	86-7	40-23	6-16
Modulus modulus	86-4	40-22	6-15
Cerithium eburneum	88-8	43-22	7-1
Cerithium literatum	88-7	43-26	7-3
Chelilea equestris	98-1	45-2	7-20
Hipponix antiquatus	98-2	45-1	7-17
Strombus gigas	104-1	46-9	12-6
Trivia nix	106-8	48-4	22-2
Cyphoma gibbosum	108-1	48-10	9-4
Cypraea cinera	110-5	48-14	9-3
Cypraea zebra	110-1	48-15	9-1
Natica canrena	114-5	47-13	10-2
Natica pusilla	114-6	47-17	
Cypracassis testiculus	116-3	6-3	11-6
Phallium granulatrum	116-1	49-4	11-1
Morum oniscus	116-5	49-1	11-7
Cymatium sp.	118	50	13
Cymatium tuberosum (muricinum)		50-3	13-11
Charonia veriegata	118-8	51-13	12-8
Tonna muculosa	120-7	50-11	11-9
Murex ponum	122-3	51-9	15-2
Nucella sp.	138		
Columbella rusticoides	130-2	54-3	
Anachis avara	130-6	54-4	
Nassariius albus	140-2	54-19	17-11
Fasciolaria tulipi	144-2	60-15	12-4

Gastropods continued

Species Name	Page no. in Abbott	Plate no. in Morris	Plate no. Humfrey
Pleuroploca sp.	144	59	
Olivella sp.	148	61	19
Mitra barbandensis	150-7	62-11	19-12
Mitra nodulusa	150-8	62-9	19-18
Conus sp.	160-162	65	21
Terebra sp.	164	67	21
Bulla occidentalis	170-2	72-20	
Purpura? patula		53-8	17-1

Pelecypods

Species Name	Page no. in Abbott	Plate no. in Morris	Plate no. Humfrey
Anadara notabilis	192-4	11-14	23-3
Arca zebra	192-1	3-4	23-10
Arca imbricata	192-2	10-15	23-9
Barbatia cancellaria	194-5	10-12	23-11
Glycimeris decussata	196-1	12-8	23-12
Glycimeris pectinata	196-2	12-9	23-13
Modiolus americanus	198-5	12-16	24-5
Brachiodontes exustus	200-3	12-14	24-2
Brachiodontes citrinus	200-1	12-13	24-1
Pinctada radiata	202-6	15-1	24-12
Isogomon radiatus	202-3	13-18	24-13
Pinna carnea	204-3	14-6	25-3
Chlamys sentis	208-1	16-3	26-4
Lyropecton sp.	210	2	26
Lima scabra	212-6	18-1	27-7
Lima lima	212-5	18-5	27-9
Spondylus americanus	212-2	18-11	25-1
Ostrea frons	214-5	19-4	28-2
Pseudocyrena sp.	218	11	
Divaricella quadrisulcata	220-8	21-5	29-3
Divaricella orbiculata	222-8		
Codakia orbicularis	222-7	22-2	29-1
Lucina pennsylvanica	222-1	21-15	29-10
Chama macerophylla	224-2	22-9	28-12
Chama sinuosa?	224	22-10	28-13
Americardium media	226-9	23-17	29-17
Laevicardiium laevigatum	226-8	23-9	29-16
Papyridea soleniformis	228-7	23-16	29-18
Cerstoderma pinnulatum	228-3	23-5	
Periglypta (Aniogona) listeri		24-13	30-3
Chione cancellata	232-4	25-2	30-6
Telina radiata	238-4	3-1	31-1
Telina listeri	240-1	3-2	31-5
Telina fausta	242-3		
Asaphis deflorata	250-3	30-5	32-1

Abbott, R. Tucker, George F. Sandstrom, 1968, Seashells of North America: A guide to Field Identification, Golden Press, New York, pp 279.

Humfrey, Michael, 1975, Sea Shells of the West Indies, Taplinger, New York, pp 351.

Morris, Percy A., 1975, Shells of the Atlantic, Houghton Mifflin Co. New York, pp 330.