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MEASUREMENTS OF THE GENERATION AND DISTRIBUTION OF CARBONATE SEDIMENTS OF BUCK ISLAND CHANNEL, ST. CROIX, U. S. VIRGIN ISLANDS, WITH OBSERVATIONS ABOUT SEDIMENTS IN FRINGING LAGOONS

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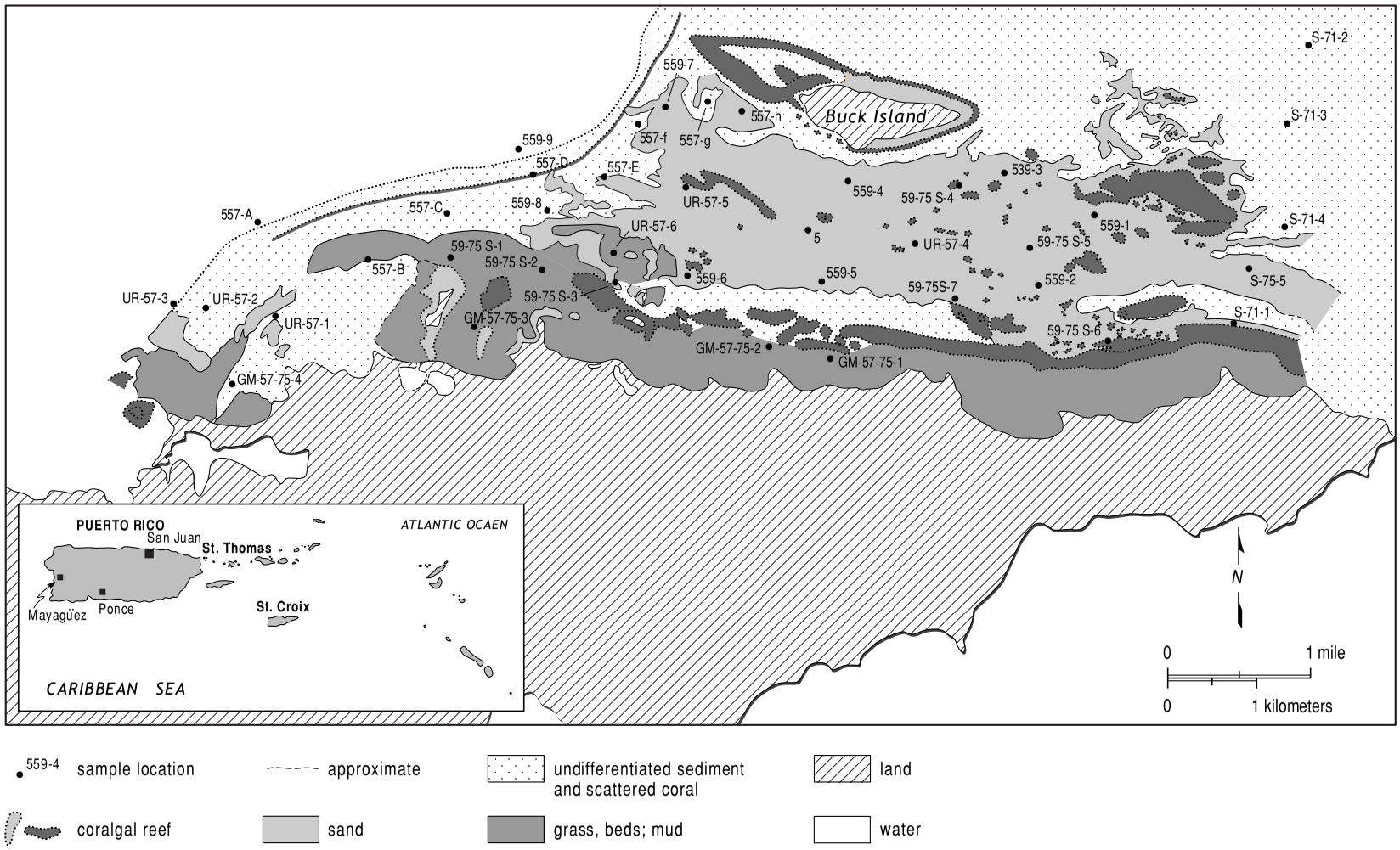

Figure 1. Location map and bottom communities of the Buck Island Channel and nearby areas.

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ABSTRACT

Sediments of the Buck Island platform northeast of St. Croix, U. S. Virgin Islands, are mostly fine-grained carbonate sands composed of *Halimeda*, molluscs, foraminifera, and coral, ratios of which are apparently related to current and depth dynamics. Sorting is controlled by organism ecology and water depth, modified by grass-bed entrapment. This paper adds to the knowledge of sedimentation on the St. Croix northeastern coast and complements earlier lagoon sediment descriptions.

Chance occurrence of severe rainstorms during a period when student research teams were present at the West Indies Laboratory of Fairleigh Dickinson University made it possible to track fresh runoff water into and out of a large lagoon facing Buck Island Channel. Fresh waters did not mix immediately with salt water. The effects of the rainfall could be tracked for 56 hours after cessation.

INTRODUCTION

Modern carbonate complexes in high-mechanical-energy settings are less commonly documented than those of evaporitic low-mechanical-energy settings. St. Croix, U.S. Virgin Islands (USVI), has an extensive shelf and platform as its northeastern quadrant terminating in the northeast in a reef (Lang Bank), which in turn marks a drop off to very deep waters (Fig. 1, Fig. 2). On the northern margin of the platform is Buck Island National Monument, eroded from Cretaceous age metaturbidites, with a fringing reef on the windward margin and a carbonate beach to the leeward. To the west, near Christiansted, the platform terminates in small reefs and grass beds west of which the water depth abruptly increases from 10 meters to 4000 meters. The northeastern margin of St. Croix, facing Buck Island and the Buck Island Channel, is a complex of banks and reefs with narrow lagoons. Predominant easterly trade winds drive currents and wave trains from the northeast and east with consequent strong east-to-west longshore drift (Hubbard et al, 1981). The maximum tide range is about 0.33 meters.

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This paper characterizes the setting and characteristics of the carbonate sediments of part of the northeastern quadrant of the St. Croix shelf, U. S. Virgin Islands, the Buck Island Channel and an associated lagoon of northeastern St. Croix.

During the period of 1971 through 1986, Fairleigh Dickinson University, Madison, NJ, USA, operated the West Indies Laboratory (WIL) on St. Croix. This laboratory was a teaching and research facility dedicated to study of the shallow marine and tropical terrestrial environments. The data from which this paper is drawn were accumulated by the writers and by some of the many students from many academic institutions who participated in research projects and course work at the West Indies Laboratory. The facility was destroyed by Hurricane Hugo in 1986 and never rebuilt. Much data, many records, and extensive collections were lost in that disaster. This paper is compiled from data taken while the senior author was resident at the WIL from 1972-1975 and on two subsequent research expeditions terminating in 1979. Ninety-eight sample locations and 15 transects provide the primary new data for this study. Major changes occurred in the reefs post-1979. Black-band and white-band coral disease and an unknown pathogen decimated reefs and the grazing sea urchin, *Diadema antillarum*, by 1984. In 1986, Hurricane Hugo created storm waves and currents that changed the character of reefs and of some bottom communities (Hubbard et al, 1991).

BUCK ISLAND CHANNEL SEDIMENTS

The open shelf between Buck Island National Park (Fig. 1**)** and the mainland of St. Croix is called the Buck Island Channel (B.I.C). Water depth in the channel ranges from 15 feet (5 meters) at the western margin to about 50 feet (17 meters) where the shelf deepens onto the main St. Croix platform in the east (Fig. 3). Water depth on the eastern main platform averages about 80 feet (26 meters). Wave trains approach from the east and northeast, varying seasonally, as do the trade winds (as summarized by Fuller, 1978). During November, December and January, winds tend to be ENE (the "Christmas Winds"), whereas during the rest of the year, winds are easterly.

The result of this wind- and wave-train geometry is that a steady current moves water from east-to-west through the channel, transporting fine-grained sediment that apparently becomes trapped by grass beds on the western terminus of the channel resulting in shallower water depths. Longshore drift behind the bay-barrier reefs on the southern margin of the channel is also east-to-west with current velocities up to about 0.33 meters per second (Fuller, 1978). Channel velocities are similar to the longshore velocities, although they have not been recorded.

Bottom communities of the channel are open sand, grass beds, coralgal reef, and scattered coral and sand (Fig. 1). Open sand areas contain standing crops of alcyonarians and are covered with thin filamentous algal mats that stabilize the sediment in gentle current regimes, but can be disrupted during storm events. Hummocky topography occurs where these sand bodies are burrowed; where shallow, the sand bodies may be rippled. Much of the open sand is coarse-grained (Fig. 4) and poorly sorted (Fig. 5).

Although statistical measures of sorting and size are not normally applied to carbonate sediments, we have found both size analysis and sorting to be useful in describing noneefal carbonate sediment bodies that are subject to mechanical transportation through extensive bioturbation, waves, and currents. These measures should not be used to compare carbonate sediment bodies to detrital sediment bodies, since transportation of carbonates is usually much less important to the resultant rock body than for detrital sediments. However, statistical comparison of carbonate to carbonate bodies is useful, since qualitative information about the role of transportation in carbonate settings can be extracted from the data. For instance, it appears that the bathymetry of the Buck Island Channel has resulted from the transportation of fine carbonate grains from east-to-west. These grains are trapped in grass beds and along a fringing coralgal reef community. Excess sediments eventually slide into deeper water off the western edge of the shelf**.** An easterly current regime can be detected by the shoaling of water from east-to-west and by the constituent particles of the sediment body (Fig. 2). Sorting of the sediment indicates a greater degree of winnowing in the shoaler portions of the Buck Island Channel (Fig. 5), although sorting of carbonate sediments is rarely good except in very strong currents or where the particles are derived from one organism source, such as the cropping of *Halimeda*. Sorting is very poor in grass beds no matter the current regime, reflecting the trapping of a wide variety of fine-grained particles which are added to the *in situ*-produced sediment.

Halimeda, mollusks, and coral are the three most abundant constituent particles in the Buck Island Channel (Fig. 2). Coral is a major constituent only where the sediment samples are adjacent to coralgal reefs along the margins of the channel and at the western termination of the B.I.C, where *Porites* coral gardens line the drop-off into the Christiansted submarine canyon. In general, coral/mollusc sands are indicative of the presence of nearby coral reefs, whereas *Halimeda*/mollusc sands are indicative of open sand and grassbed sediments. An occasional near-reef sample will contain significant amounts of coralline algae and the occasional sample from a grassbed contains significant amounts of foraminifers.

East of the main study area, the St. Croix northeastern shelf is sediment-deficient. Hardgrounds, thin sands, and scattered coral constitute the major bottom types. Water depth averages 80 feet (27 meters) in contrast to the average 50 feet and shoaler of the BIC. A framework reef (Burke and Gerhard, 1987; Gerhard, 1989; Gerhard and Burke, 1990), Lang Bank, marks the eastern extremity of the island shelf. It does not break the surface.

Although no coring was done to establish the cause of the shoaling to the west, it is likely that current-dominated sediment accumulation is a primary cause of the shoaling (Hubbard et al, 1981). Cretaceous metaturbidites of the Caledonia Formation (Whetten, 1966) crop out both on the mainland opposite the BIC and on Buck Island. Burke et al (1989) suggest that the floor of the BIC is well-indurated Pleistocene limestone although it has not been sampled except directly in front of Tague Bay Reef.

Burke et al (1989) demonstrate that the associated bank barrier reef on the northern margin of St. Croix has grown on a limestone substrate of presumable Pleistocene Age and that substrate dips to the east. It is possible that the abrupt shoaling

in the Buck Island Channel from east-to-west is related to the relict topography on the Pleistocene limestone rather than to the accumulation of modern sediments, or a combination of both.

CORALGAL REEFS AND BANKS

The term "reef" as used in this paper includes reefs of varying types ranging from true framework reefs that bound the St. Croix platform through the abundant biodetrital reefs that fringe nearshore lagoons and in the quieter bays and estuaries hydromechanical banks (Burke and Gerhard, 1987; Gerhard and Burke, 1990; Gerhard, 1991).

The reefs of the St. Croix north shore are most mature to the west and least mature to the east, reflecting bottom topography that is either relict or the result of a general tilting down to the east of the island (Adey, 1975; Burke et al, 1989). These reefs are well-developed biodetrital reefs with higher energy mechanical forms in the east into the prevailing wind and wave trains. The main reef system is about four miles long from the east tip of the island to the termination at Sand Cay (Candlelight Reef). The best-documented of these reefs is the Tague Bay Reef (Burke et al, 1989; Ogden, 1974). Reef development is also pronounced around the east end and southern side of Buck Island, part of Buck Island National Monument, but these are small compared to the Tague Bay complex.

LAGOONS

Shoreward of the barrier reefs on the north shore of St. Croix are lagoons separated from each other by points of land jutting northward from the island. The lagoons are hydraulically connected, the separations being spatial constrictions of rock points that reduce the distance between the reef and the island, thus increasing velocity of longshore flow (see Fuller, 1978). The most easterly-studied lagoon is Boiler Bay, named for its relict coralline algal "boilers" (Gerhard and Stolzman, 1974), and the largest one, Tague Bay, is located just west of Boiler Bay (Fig. 6 A, B.) separated by Cottongarden Point (see Fuller, 1978). Several studies of other lagoons and estuaries that describe nearshore sedimentary facies of St. Croix have been previously published (Gerhard and Petta, 1974; Gerhard, 1978; and Gerhard, 1981).

Tague Bay's central portion averages over six meters deep (Fig.7). Tague Bay lagoon contains medium-to-fine-grained sand, except at the entrance and exits of longshore currents where coarser grained sands predominate (Cottongarden and Tague Points, respectively) (Fig. 8). At the eastern end, near Cottongarden Point, there is a gap in the reef and here the bottom sediments are strongly rippled in response to longshore drift, wave impingement, and tidal change.

Constituents of the sands are predominantly coral near the barrier reef and near shoreline, as in Boiler Bay, but the major portion of the lagoon is a mixture of *Halimeda* with various amounts of mollusks, coralline algae and foraminifers (Fig. 9,

Fig. 10). Insoluble residues are present in a pattern that appears to reflect transport from the strandline through the bay to the west, are most abundant in a triangular arc in the southwest of the bay, and are mostly near-absent in the northeastern portion of the bay (Fig. 11). Grass beds (mostly *Thalassia testudinum*) cover much of the lagoon bottom with *Calianassa* mounds dotting the open sand areas.

The current regime is reflected in the sorting of the sediments. Near the pass between the lagoon and the Buck Island Channel, where the tidal currents and movement of water into the lagoon is highest, sorting is best, deteriorating into the leeward western end of the lagoon (Fig. 11). Near shore wave-dominated settings are better sorted than the main portion of the lagoon. Insoluble residues in the sediments reflect both proximity to shoreline sources and trapping in grass beds as contrasted to the dynamic winnowing of open sand areas (Fig. 12).

A two-meter-long sediment core taken in roughly the center of the lagoon in a sand bottom contained mostly *Halimeda* with abundant mollusks; the lack of foraminifera suggests that grass beds were never present at the core location while the sediment was accumulating. The cored sediments were coarse sand at the bottom with the median size decreasing to fine sand at the top of the core. If preserved as a rock sequence, this would be a fining upward skeletal packstone.

Storm Event Observations in Tague Bay Lagoon

Two intense thunderstorms occurred when observations of the relationship of tidal stage to runoff into the marine environment could be made. The first occurred on a falling tide and the second on a rising tide. In the first, 2.95 inches of rain fell in a short thunderstorm on a falling tide. Sediment-laden runoff through Great Pond, a major watershed on the south shore of St. Croix, streamed into the Great Pond lagoon and out through the reef pass without mixing as a density current lighter than the sea water. It left no trace in the sedimentary record of the lagoon.

The second rain storm, following 16 inches of precipitation over the preceding 45 days that saturated the thin soils and leaked ground water directly into Tague Bay lagoon, was 4.74 inches over 5 hours on a rising tide. Study of the impacts of the rainstorm was possible owing to the presence of students in a sedimentology class at the research site (Table 1).

Runoff from that rainstorm was highly turbid, carrying coarse sediment into the shallowest waters, but more important, suspended sediment was transported into the lagoon where it ponded on the rising tide. No mixing took place; clear water "shadows" around pilings and boats demonstrated that mixing was minimal. After the rainstorm event, transects were measured across the exit of Tague Bay lagoon. Water was sampled at the surface and at the sediment-water interface at intervals of 14 hours after rainfall, 34 hours, 39 hours, and 56 hours. In the initial measurements, pH was reduced to 7.8, and fully recovered to 8.1 only after 39 hours and only at the bottom; at 56 hours the surface had recovered except at the shore where dilution by seepage of freshwater still reduced pH.

Salinity was mismeasured in the first set of measurements. By 34 hours it was 32 ppt at the surface and recovered to 33 ppt by 39 hours and 34 ppt by 56 hours. The

nearshore recovery lagged the offshore recovery. In addition, the salinity and pH values show that the bottom waters recovered faster than surface waters in a wedge-shaped profile as the fresh water lay on the saline marine waters.

SUMMARY

Sediments on the northern St. Croix shelf are almost entirely carbonate skeletal remains. The sedimentary package is the result of in situ skeletal degradation of mollusks, foraminifera, coral, and *Halimeda*. In lagoons, coralline algae are also sediment contributors near reefs, particularly in the back reef environment. On the shelf, trade wind-driven current sweeps sediment from east to west. The sediment temporarily piles up on the edge of the shelf in grass beds, creating a shallow bar along the western edge of the Buck Island Channel. Effects of currents on the sediment body are ascertained by mapping sorting (Folk) and size, recognizing that these parameters cannot be directly compared to detrital sediments because of the organic origin of the sedimentary particles.

These observations add to the body of knowledge of modern carbonate sedimentary environments. Effects of storms on pH and salinity were noted owing to the fortuitous occurrence of severe storms when observations could be made. The stage of tide during severe rainfall events determines the rate at which sediment is trapped or transported through lagoons.

ACKNOWLEDGMENTS

This paper summarizes the work not only of the authors, but of numerous students who attended classes at the former West Laboratory of Fairleigh Dickinson University prior to its destruction by Hurricane Hugo. The reports of these students and their names have been destroyed along with the buildings, although much data was preserved in external files. Students who attended Field Sedimentology classes from 1973 through 1975 collected a significant portion of the data used in this report. Some of these data were previously published in West Indies Laboratory guidebooks or in other carbonate short-course manuals, but are no longer easily accessible after the destruction of that facility. Some of the data were recovered while unpacking libraries after several moves by both authors. The data have been compiled here at the request of other Caribbean researchers. We appreciate the assistance of the Kansas Geological Survey and Pat Acker who prepared the Buck Island Channel illustrations.

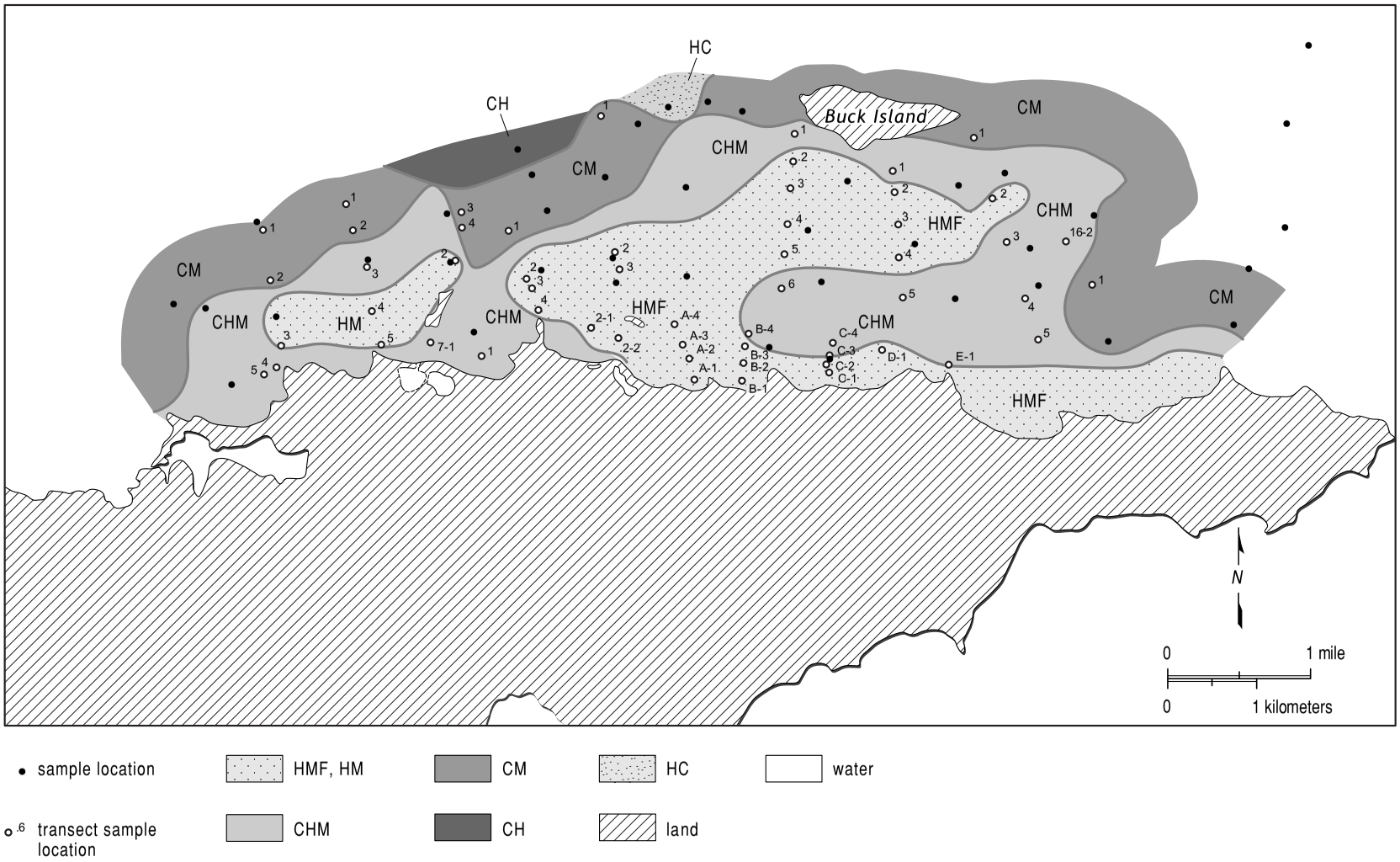

Figure 2. Constituent particles of Buck Island Channel surficial sediments.

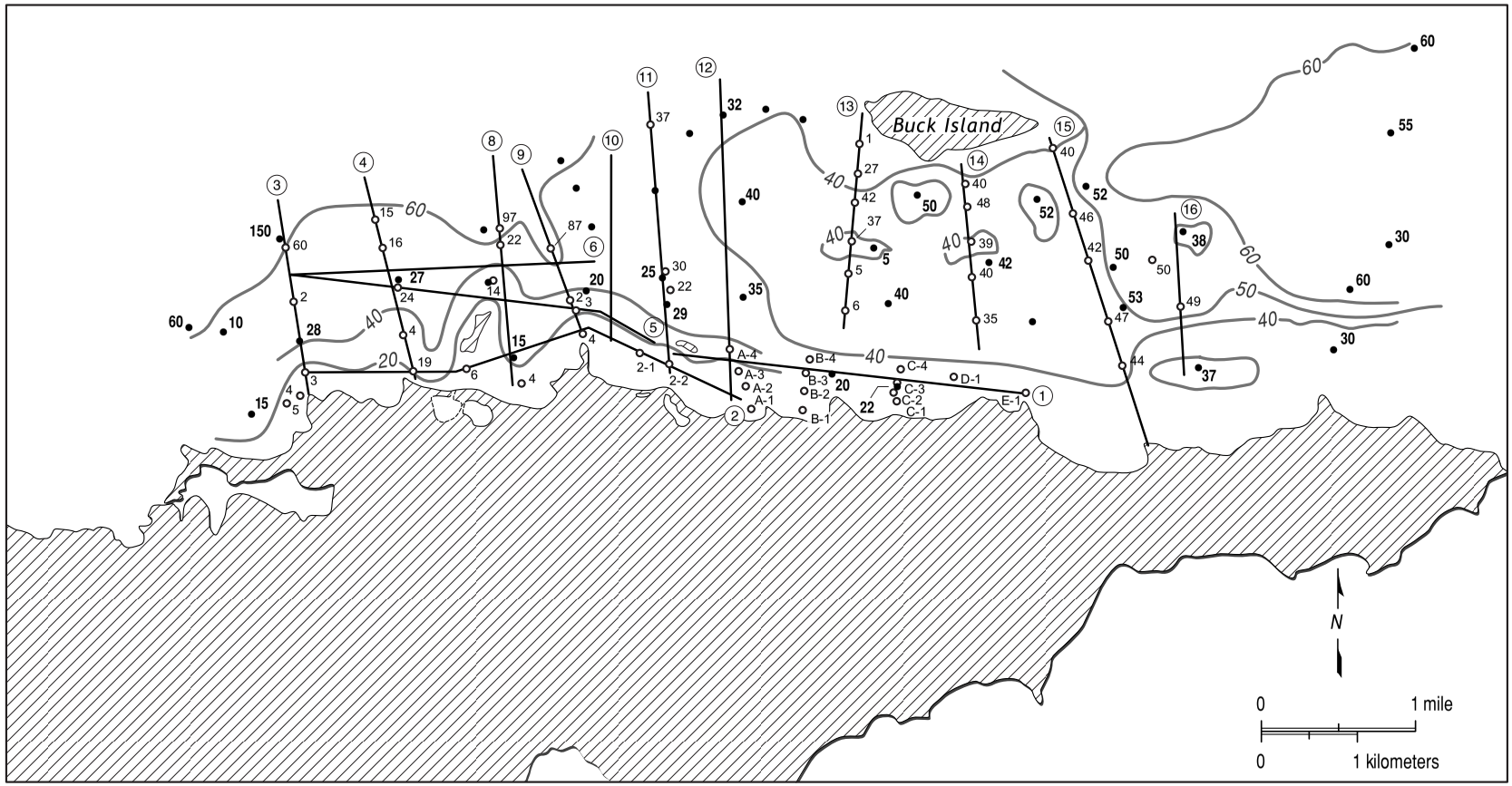

Figure 3. Bathymetry of the Buck Island Channel, showing location of sample points and transects.

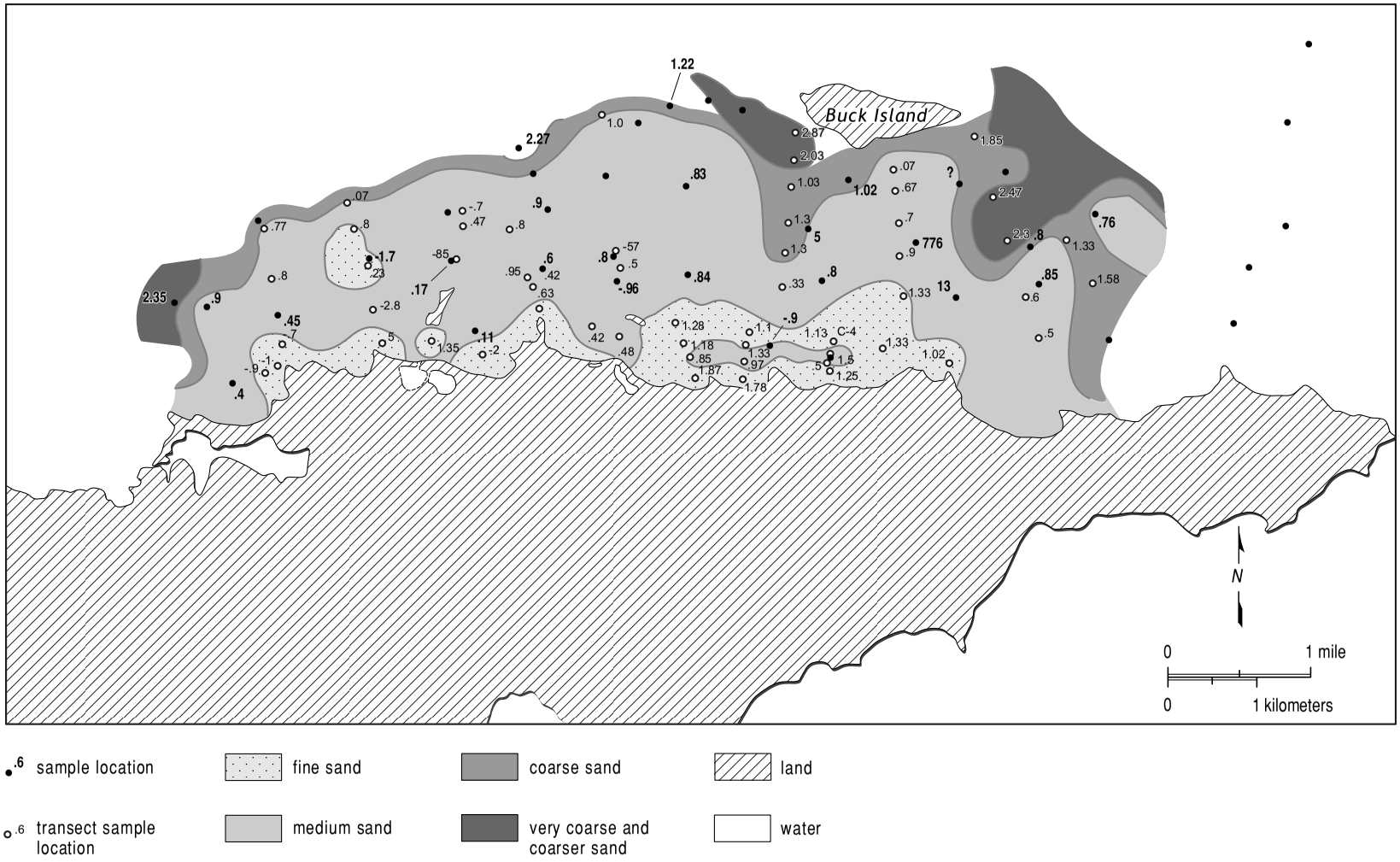

Figure 4. Sediment grain size in the Buck Island Channel, in phi units.

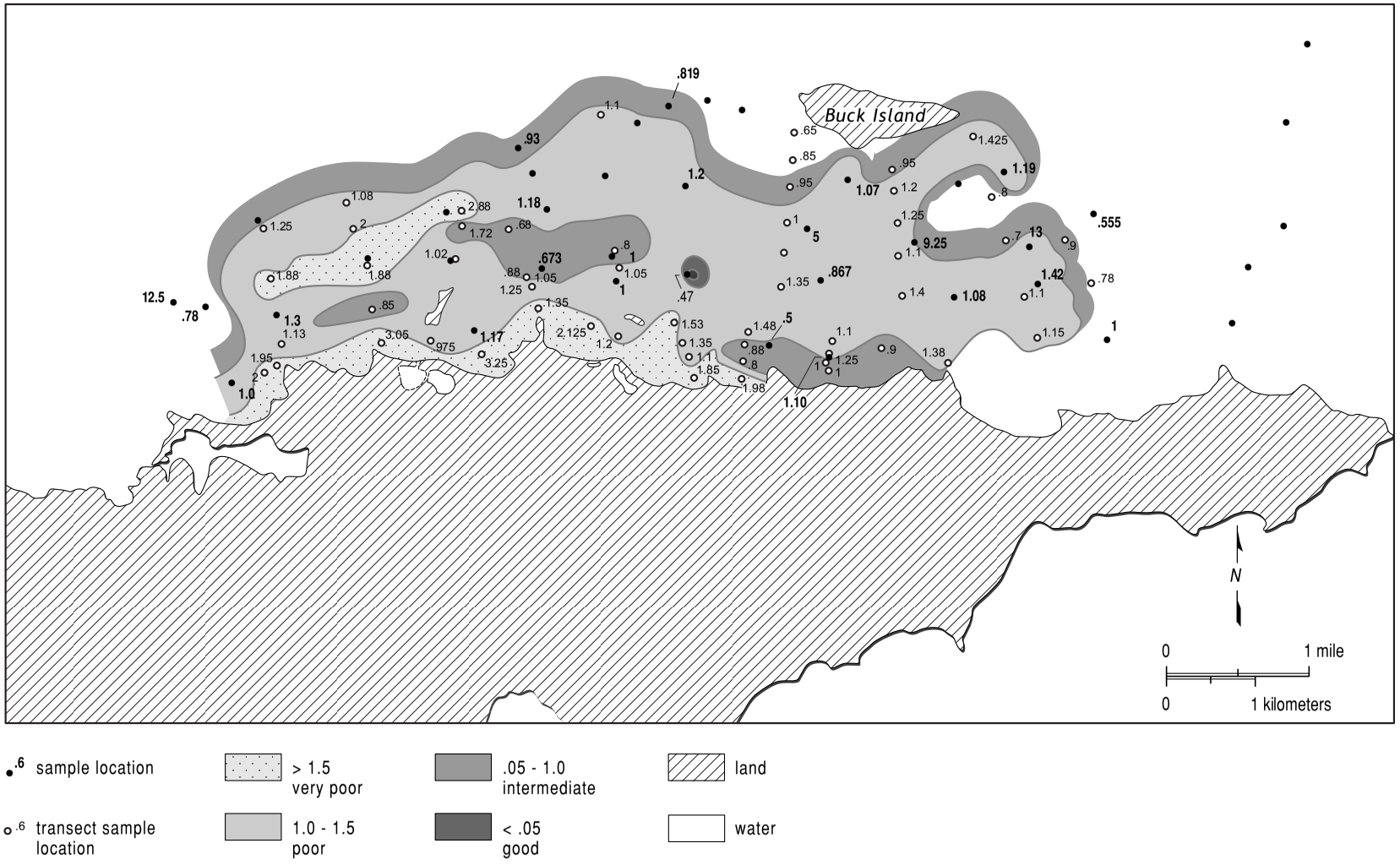

Figure 5. Sorting (Folk) of surficial sediments, Buck Island Channel.

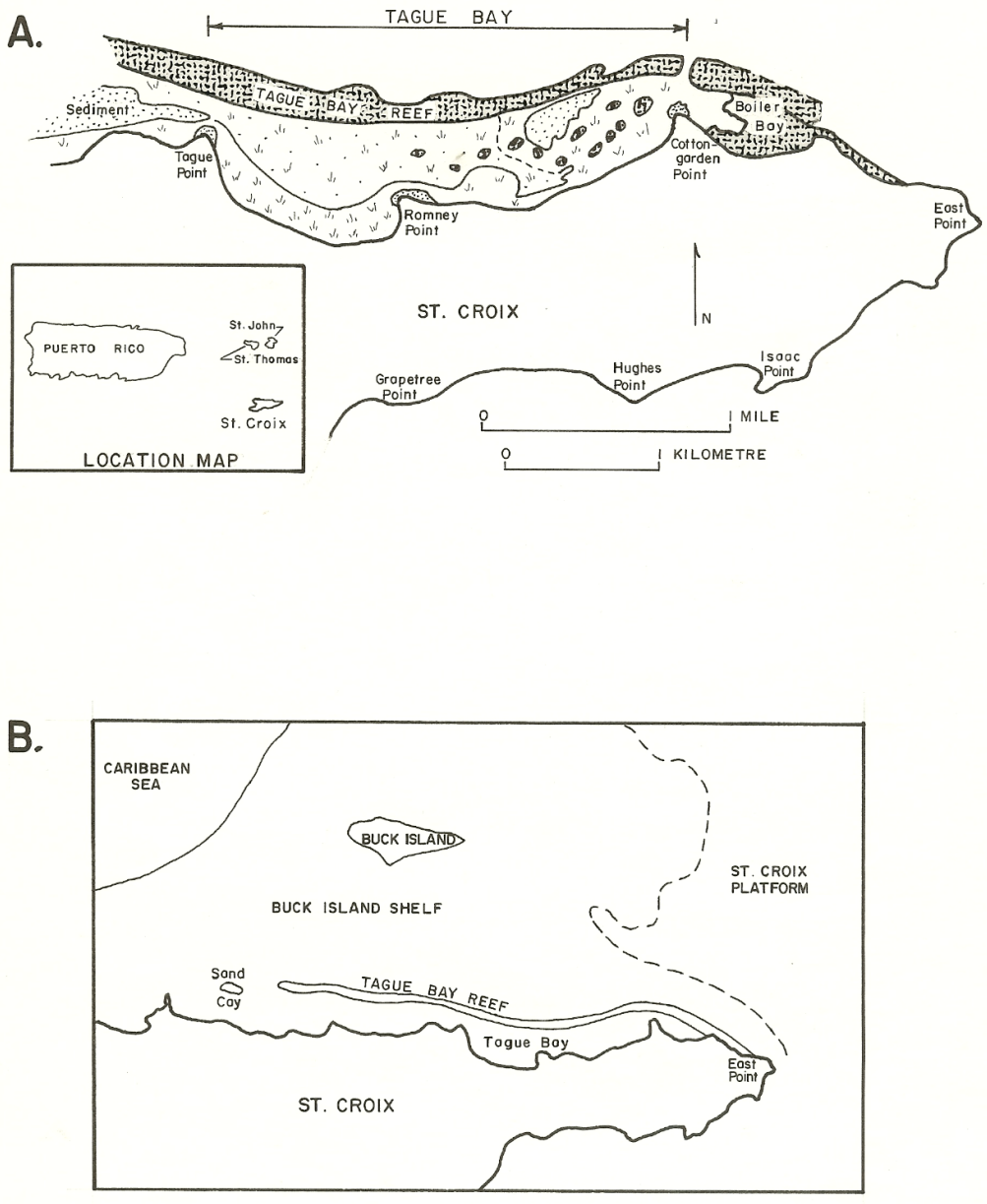

Figure 6. Location of Tague Bay (A, B) and composition of bottom communities (B). Grass symbol is *Thalassia*, grass and sand symbols are scattered grass and open sand, sand symbol is open sand, reefs are dense pattern.

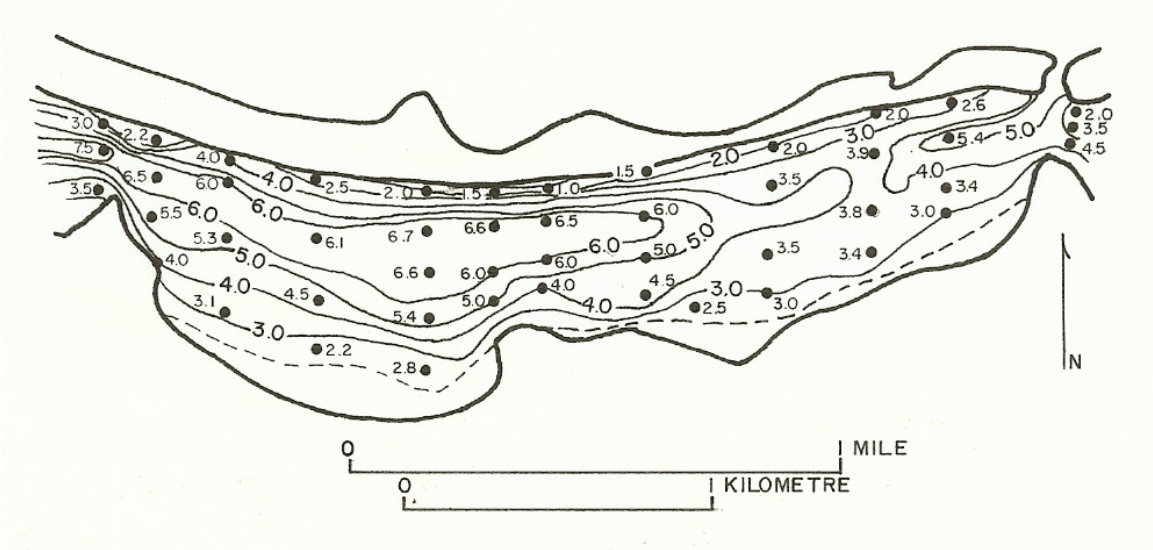

Figure 7. Tague Bay bathymetry. Contour interval is one meter. Datum July, 1974. Student data.

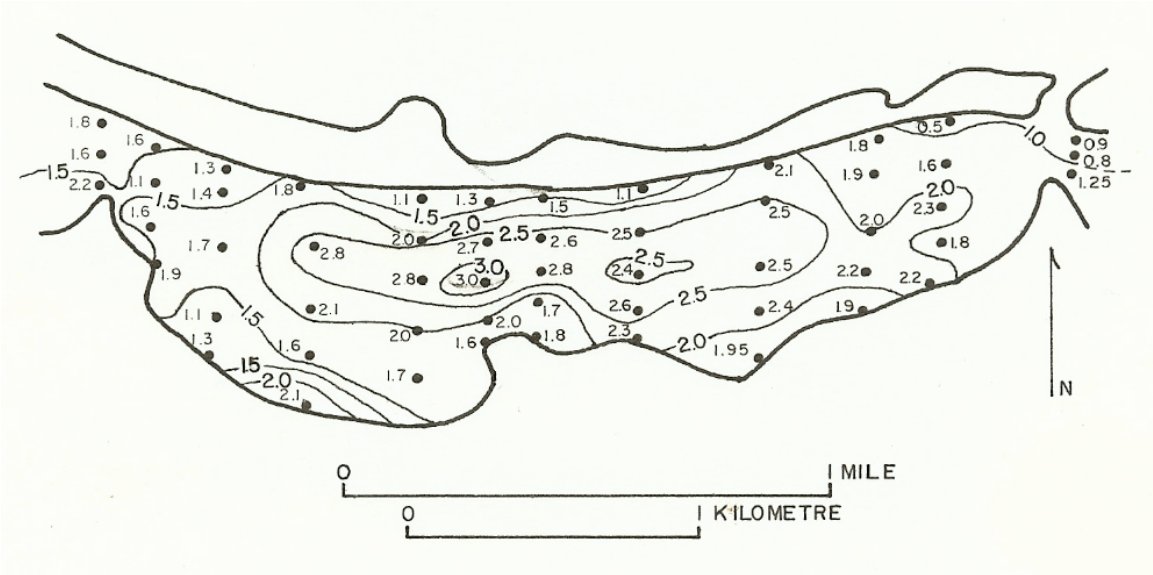

Figure 8. Surficial sediment grain size, Tague Bay lagoon Data is graphic mean mapped at 0.5 phi interval. Student data.

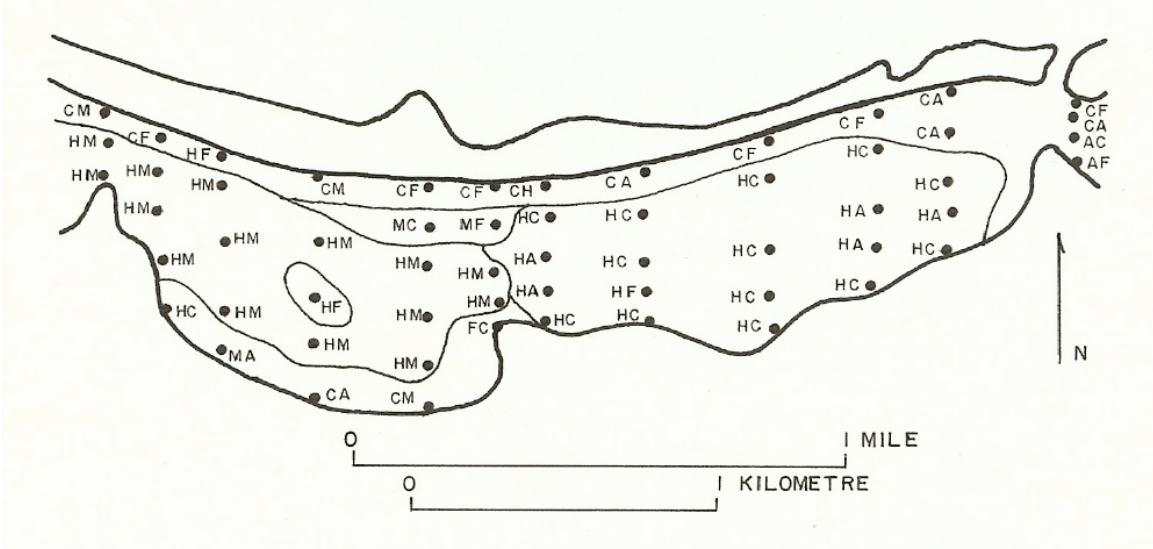

Figure 9. Constituent particles of surficial sediment in Tague Bay lagoon. The main skeletal constituents are *Halimeda* (H), coral (C), mollusc (M), foraminifera (F), and coralline algae (A).Boundaries separate major facies.

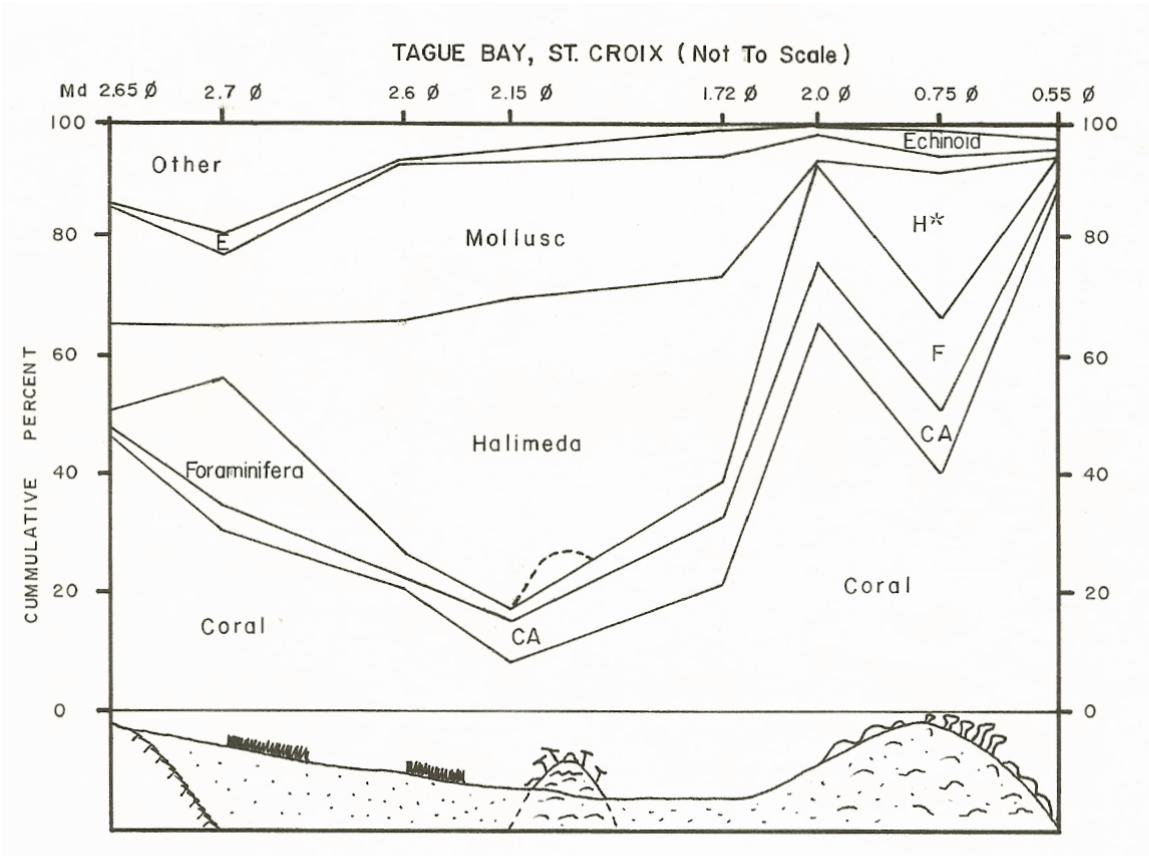

Figure 10. Shoreline to forereef transect across Tague Bay lagoon, showing constituent particles abundance. Data portrayed as percentages of total. Student data.

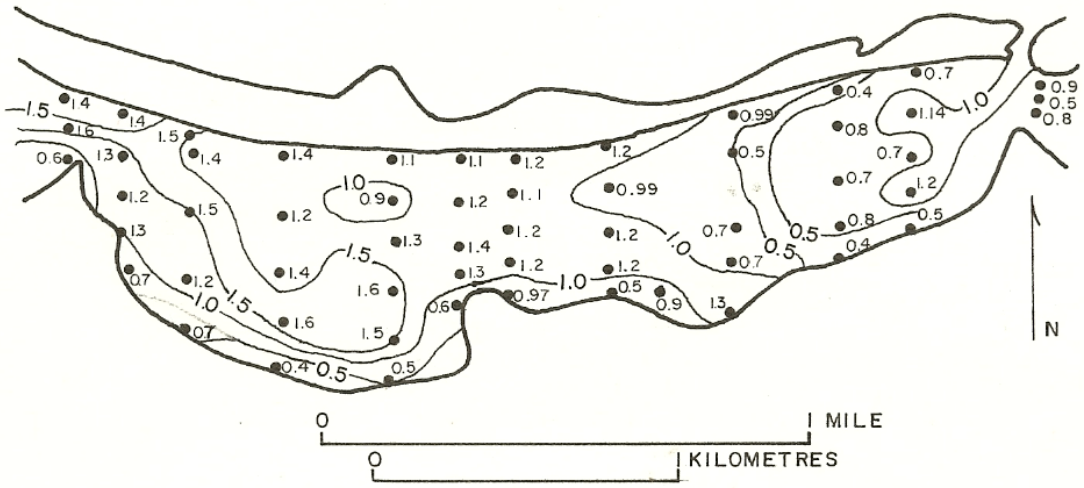

Figure 11. Sorting (Folk) of Tague Bay surficial sediments. Contour interval is 0.5. 0.5 is well sorted, 1.5 is poorly sorted. Student data.

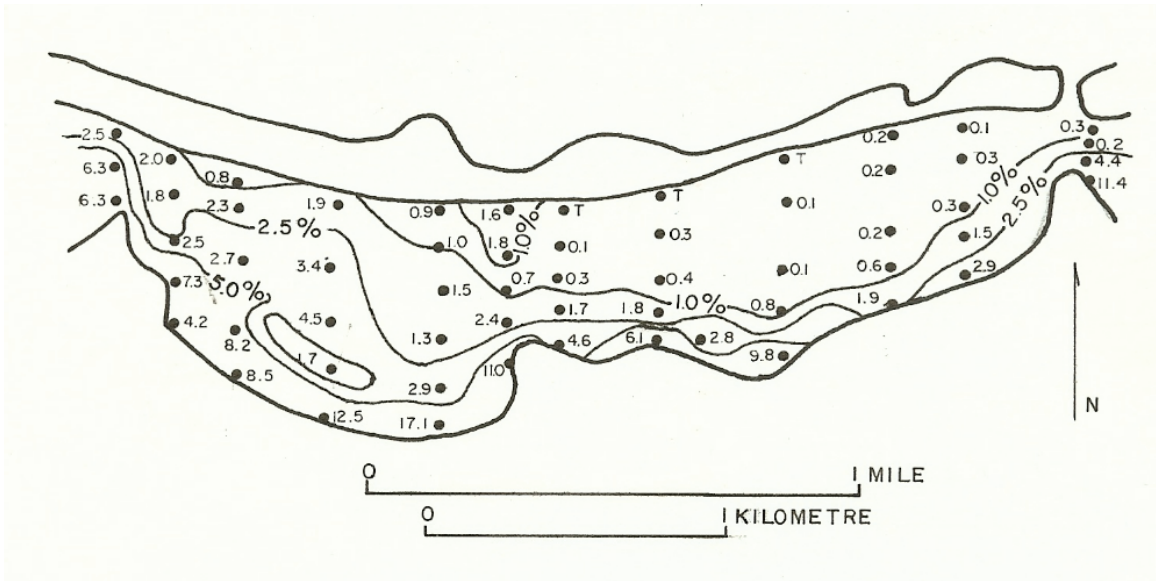

Figure 12. Insoluble residues map showing influence of terrestrial sediments in Tague Bay lagoon. Contours represent 5%, 2.5%, and 1%. Student data.

Table 1. Storm rainfall amounts at St. Croix in 1974.

Rainfall amounts from rain gauge at West Indies Laboratory, East End, St. Croix		
January	2.56	(in inches)
February	0.87	
March	3.57	
April	1.37	
May	0.26	
June	0.8	
July	1.12	
August	6.95	
September	3.85	
October	7.64	
November	13.72	
December	na	

Largest one day event: November 13, 1974, 4.74 inches.

Table 2. Salinity and pH Along Transect from Tague Point to Tague Bay Reef, November 13-15, 1974

Station	Distance from shore (meters)	Date	Hours after storm	Salinity 0/00
1 Surface	25	13-Nov	14 misrun	
1 Bottom	25	13-Nov	14 misrun	
3 Surface	85	13-Nov	14 misrun	
3 Bottom	85	13-Nov	14 misrun	
6 Surface	200	13-Nov	14 misrun	
6 Bottom	200	13-Nov	14 misrun	
1 Surface	25	14-Nov	34	32
1 Bottom	25	14-Nov	34	32
2 Surface	50	14-Nov	34	32
2 Bottom	50	14-Nov	34	32
3 Surface	90	14-Nov	34	32
3 Bottom	90	14-Nov	34	32
4 Surface	130	14-Nov	34	32
4 Bottom	130	14-Nov	34	32
5 surface	170	14-Nov	34	32
5 Bottom	170	14-Nov	34	33
6 Surface	200	14-Nov	34	33
6 Bottom	200	14-Nov	34	33
1 Surface	25	14-Nov	39	33
1 Bottom	25	14-Nov	39	33
2 Surface	50	14-Nov	39	33
2 Bottom	50	14-Nov	39	32.5
3 Surface	90	14-Nov	39	33
3 Bottom	90	14-Nov	39	33
4 Surface	130	14-Nov	39	33
4 Bottom	130	14-Nov	39	33
5 surface	170	14-Nov	39	33
5 Bottom	170	14-Nov	39	33
6 Surface	210	14-Nov	39	33
6 Bottom	210	14-Nov	39	33
NOTE BENE: EBB TIDE				
1 Surface	25	15-Nov	56	33
1 Bottom	25	15-Nov	56	33
2 Surface	50	15-Nov	56	33
2 Bottom	50	15-Nov	56	33
3 Surface	95	15-Nov	56	33
3 Bottom	95	15-Nov	56	33
4 Surface	130	15-Nov	56	33
4 Bottom	130	15-Nov	56	34
5 surface	170	15-Nov	56	33
5 Bottom	170	15-Nov	56	34
6 Surface	210	15-Nov	56	34
6 Bottom	210	15-Nov	56	34
Additional sample at 5 meters from shore, .7 meters deep (shows drainage from shoreline rocks still occuring)				32.5

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