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Cover photo: *Diploria strigosa*, the common brain coral, preserved in growth position at the Cockburn Town fossil coral reef site (Sangamon age) on San Salvador Island. Photo by Al Curran.

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SEDIMENTOLOGY OF PIGEON CREEK, SAN SALVADOR ISLAND, BAHAMAS

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ABSTRACT

The surficial sediments of Pigeon Creek can be grouped into 12 lithofacies based on the relationships between mean grain size, dominant grain morphotypes, and physical parameters such as salinity, tidal current velocities, and bathymetry. Aggregates, lithoclasts, peloids, and skeletal remains are produced within the creek and are selectively transported by tidal currents and surface tension to produce the different lithofacies. This investigation of Pigeon Creek provides a detailed modern analog for the interpretation of Pleistocene tidal creek sediments occurring throughout the Bahama Archipelago.

INTRODUCTION

Pigeon Creek is a tidal creek system located in the southwestern part of San Salvador Island (Index Map 2). A single inlet connects the creek to Snow Bay near Nancy Cay (Fig. 2a). Pigeon Creek is 9 kms in length and has a maximum width of 1.6 kms. The creek system covers an area of approximately 6 square kms and consists of two tidal creeks north and south of the inlet. These are designated the North and South Branches of Pigeon Creek (Figs. 1-3). The sediments of Pigeon Creek have been discussed briefly by Hinman (1980), Nutt and Teeter (1985), Teeter (1985), Teeter and Thalman (1984), and Thalman and Teeter (1983). No detailed studies have been made of the sedimentology and sedimentary processes of the creek. In general, little is known about the sedimentology of any of the numerous tidal creeks occurring throughout the Bahama Archipelago. The investigation of tidal creek environments in other parts of the Bahamas have been limited to Great Exuma Island (Mitchell, 1984a), Long Island and Rum Cay (Mitchell, 1984b and this volume; Mitchell and Keegan, in press). Mitchell (1985b) summarized the microbiofacies of tidal creeks in the Bahamas and Florida Keys. The use of modern tidal creeks as analogs for the interpretation of ancient tidal creek sediments has become increasingly important. Geologic mapping of Rum Cay (Mitchell, this volume), New Providence Island (Garrett and Gould, 1984), Mayaguana and Great Inagua Islands (Mitchell, 1985a, 1985c; Pierson, 1982), and San Salvador Island (Teeter, 1985; Thalman and Teeter, 1983; Titus, this volume) indicates that a significant portion of the surficial rocks of the Bahamas were formed in Pleistocene tidal creek environments when sea level was higher than at present. On some islands (Rum Cay, Mayaguana, and Great Inagua Islands) many interior Pleistocene rock units occurring at elevations up to 5 m above present sea level can be assigned to tidal creek lithofacies (Mitchell, this volume).

During the past 17,000 years sea level has risen over 100 m (McIntyre and others, 1981, p. 5). Much of this rise occurred prior to 3,000 years ago. Since then, sea level has risen much more gradually (Macintyre and others, 1977, p. 752). As a result, coastal inlets, bays, and tidal creeks have been filled with sediments transported by storms and by longshore and tidal currents. These late Holocene tidal creek-lake transitions are the major form of shoreline change over the past few thousand years (Mitchell, 1984b; Mitchell and Keegan, in press). A detailed knowledge of the sedimentology of modern Bahamian tidal creeks is necessary in order to successfully reconstruct the history of the ancient tidal creeks preserved in cores. Pigeon Creek is a typical tidal creek of the central Bahama Islands. The analysis of the sedimentology and sedimentary processes of this creek will allow much more accurate interpretations of ancient tidal creeks.

METHODS

A total of 225 surface sediment samples (upper 0-2 cm), water samples, and current measurements were collected from 200 sample stations in Pigeon Creek during five sampling periods: June 1981, December 1981, March 1982, June 1982, and June 1986. Aerial photography of Pigeon Creek was undertaken in June 1985. Water samples were collected in 10 ml vials and analyzed for salinity using a Reichert automatic temperature compensated hand refractometer, with an accuracy of 1°/oo. Current measurements were made over 15 second to 1 minute intervals using a neutral float suspended several centimeters below the water surface. Distances were determined using a tape measure, and converted to meters per minute. Directions were recorded using a compass and adjusted for the magnetic declination (4.5° west) of the field area. The sediment samples were collected using cores or small containers. In the laboratory each sample was treated with chlorox until all organic matter had been decomposed. Samples were then wet sieved through a U.S. Standard Series Sieve No. 230 (.06 mm or 4ϕ diameter mesh). The silt-clay and sand subsamples were dried and weighed. To prevent loading on the sieves, the sand was, if necessary, split into 30 to 125 g subsamples. Sand subsamples were then dry sieved through a 1/2ϕ interval set of U. S. Standard Series Sieves using a ro-tap for 15 minutes. The fraction retained on each sieve was weighed, and the percent each fraction made up of the total sand sample determined. The weight of the pan fraction was added to the weight of wet sieved silt and clay. For each sample, basic sedimentary parameters such as mean grain size, standard deviation, skewness, and kurtosis were calculated. The set of all 1/2ϕ interval cumulative percents characterizing each sample was used as input data for a Principle Components Analysis (PCA) to determine the granulometric relationships of the samples. The use and interpretation of multivariate statistics in comparing sediments has been documented by Greenwood (1969), Klovan (1966), and Sahu (1964). Long (1986) has recently completed a study of tidally influenced bay sediments. He successfully used PCA to discriminate subenvironments, variation in energy regimes, and to determine the areas of provenance. Visual and thin section identifications of the grain morphotypes occurring in the -2, -1, 0, 1, 2, and 3ϕ fractions of each sample were also undertaken. The results presented here are based on the silt-clay separation analysis of 225 samples and the 1/2ϕ interval mechanical sieve analysis of 100 samples. Analyzed samples were selected in order to include all of the possible subenvironments of Pigeon Creek.

PHYSICAL PARAMETERS

The major physical parameters related to sediment distribution in Pigeon Creek are: (1) salinity; (2) tidal currents; and (3) prevailing winds. Additional physical parameters measured include dissolved oxygen levels, dissolved organics, and the Ph of creek water samples. The approximate distribution of isohalines for the creek, based on water samples from 50 stations, is shown in Figure 4. As expected, salinities increase toward the upper reaches of the creek, with a maximum salinity of 50°/oo recorded in the northernmost part of the North Branch. During ebb tides, the positions of isohalines would shift somewhat toward the inlet. Conversely, during flood tides the positions of isohalines would shift somewhat away from the inlet. Seasonal variation in salinity may also occur, but it could not be documented since most water samples were obtained in June.

The directions and velocities of tidal currents were measured at 100 stations throughout the Pigeon Creek System at various times during the tidal cycle on different days. Maxiumum recorded velocities and average current directions (ebb and flood) are given in Figure 3. Highest velocities (25 m/minute) occur near the inlet channel; lowest velocites occur in the uppermost reaches of the creek system. Strongest current velocities are within the tidal channels. Overall, tidal currents decrease toward the upper reaches of the creek, as does the tidal range for the creek. At the inlet the average tidal range is about 0.9 m. At the northernmost part of the North Branch, the average tidal range is about 12 cm. In the latter area slack tides occur about 6 hours after the corresponding high or low slack tide at the creek inlet.

Due to prevailing easterly winds, wave activity is consistently greater on the western side of the creek system. The water along western margins of the creek has higher dissolved oxygen levels and is relatively cooler due to mixing. Water along

Fig. 1a. View of northernmost North Branch of Pigeon Creek, looking southwest.

Fig. 1b. View of North Island and northeastern North Branch of Pigeon Creek, looking west.

Fig. 1c. View of Pigeon Cay and central North Branch of Pigeon Creek, looking west.

Fig. 2a. View of inlet and lower reaches of North and South Branches of Pigeon Creek, looking southwest.

Fig. 2b. View of inlet and subtidal delta of Pigeon Creek, looking northwest.

Fig. 2c. View of south-central South Branch of Pigeon Creek, looking north.

PIGEON CREEK

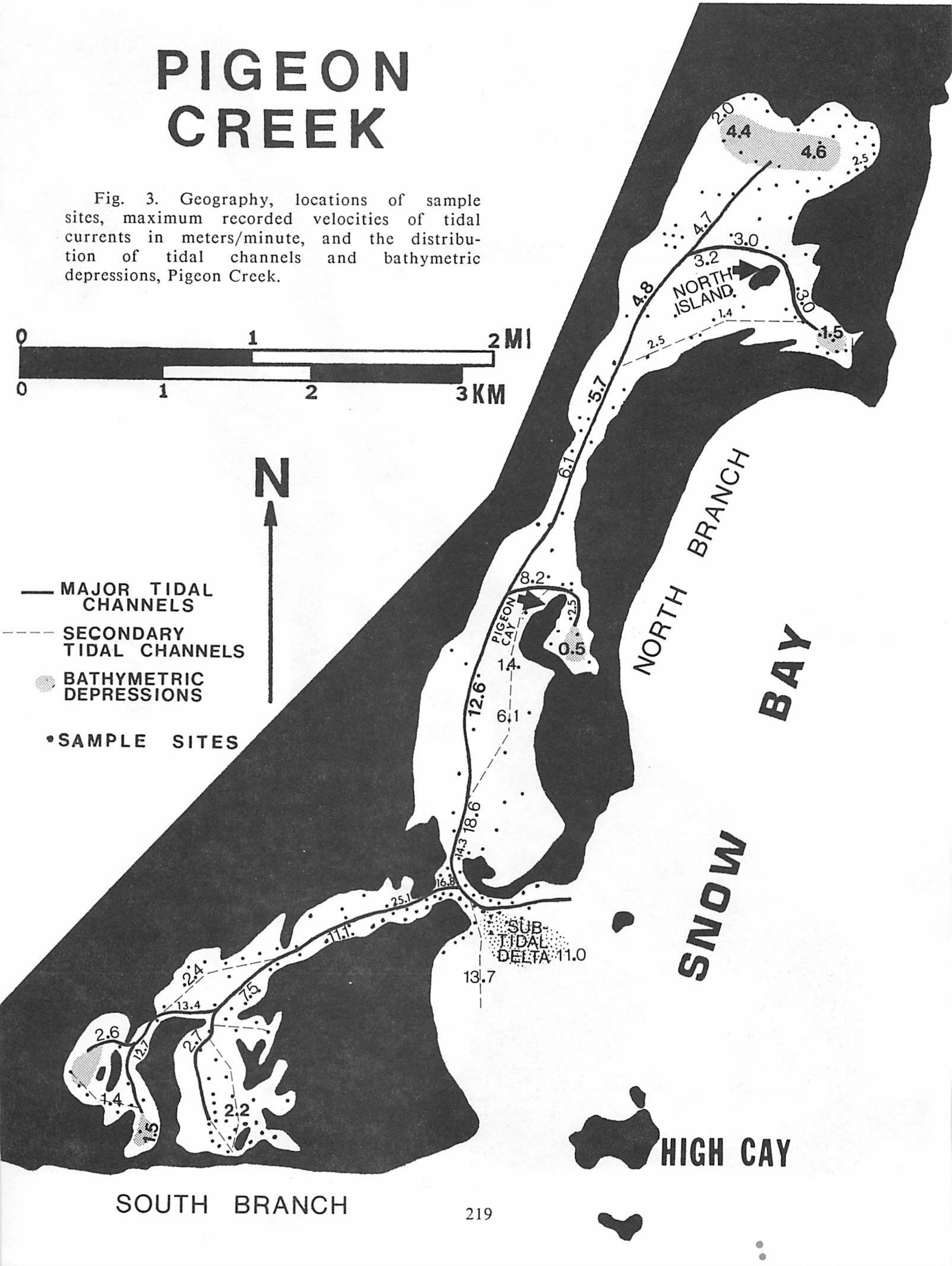

Fig. 3. Geography, locations of sample sites, maximum recorded velocities of tidal currents in meters/minute, and the distribution of tidal channels and bathymetric depressions, Pigeon Creek.

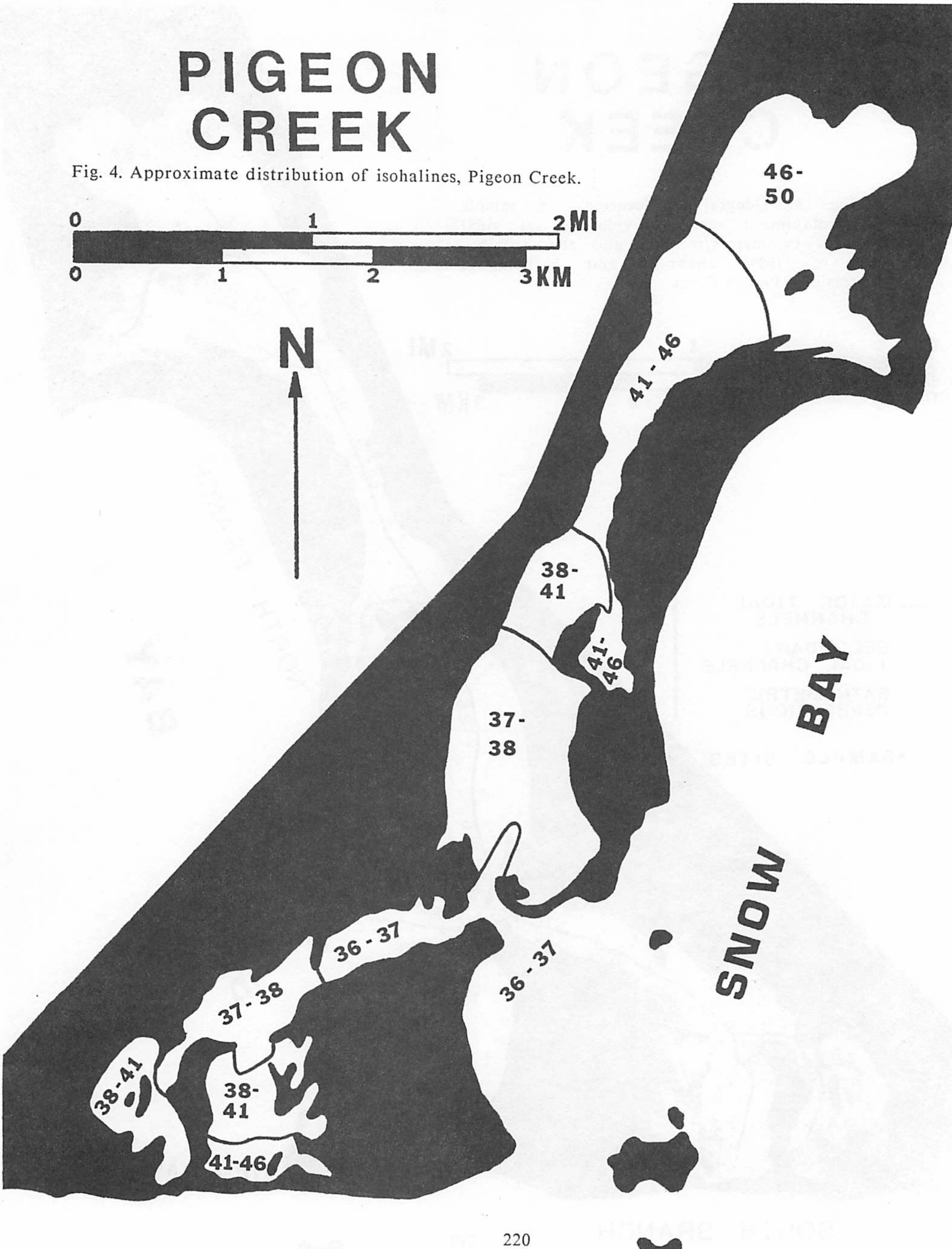

Fig. 4. Approximate distribution of isohalines, Pigeon Creek.

eastern margins has lower dissolved oxygen levels and is relatively warmer (up to 12°F warmer on a summer day with typical trade winds).

SEDIMENTOLOGY

Sediment Sources

The grain morphotypes present in Pigeon Creek are derived from a wide diversity of sources, and are transported by several mechanisms. Four basic morphotypes are recognized: (1) aggregates; (2) lithoclasts; (3) peloids; and (4) skeletal remains. Aggregates are broken pieces of cemented sediment crusts (Flugel, 1982, p. 135-136). The locations where crusts have been found to be presently forming in Pigeon Creek are shown in Figure 5. Aggregates found in surficial sediments are presumably derived from one of these sources. Lithoclasts are eroded pieces of Pleistocene limestones cropping out along the shores of Pigeon Creek. Since Pleistocene exposures occur along much of the creek margine, lithoclasts could be present anywhere. However, due to road construction immediately adjacent to the creek, lithoclasts are a significant sediment source only in the northernmost part of the North Branch. The peloids are formed by the micritization of fecal pellets (Flugel, 1982, p. 121-133). Significant peloid production occurs in two areas of the North Branch. The areas of major peloid abundance are designated the Peloid Lithofacies (Fig. 7). In these areas the peloids are usually ovoid, with a length of 0.6 to 0.8 mm. Cloud (1962, p. 28) attributes peloids of this shape and size, occurring in sediments of the Great Bahama Bank, to the micritization of the fecal pellets of the polychaete *Armandia maculata* (Webster).

A wide variety of skeletal grain types occur in Pigeon Creek. Some types (scleractinian corals, gorgonian spicules, and the branching foraminiferan *Homotrema rubra*) are derived from coastal fringing reefs. In addition to the above, shallow near-shore coastal areas have concentrations of other skeletal grain types such as coralline algae and molluscs typical of the rocky intertidal zone. The inlet to Pigeon Creek, and associated subtidal delta, produce a diversity of skeletal types from organisms living as epibiota on the dense beds of *Thalassia*. The most abundant types of epibiota are serpulid worms, encrusting melobesoid algae, and the foraminifera *Quinqueloculina*, *Cyclorbiculina*, *Sorites*, and *Archaias* (Hallock and others, 1986). Patriquin (1972) estimates that the average production of carbonate mud by *Thalassia* epibionts is 250 to 1,600 grams/square meter in one year. Within the creek, the most common skeletal types are generated by the breakdown of calcareous algae (*Halimeda*, *Penicillus*, *Acetabularia*, and *Udotea*), and by epibiota occurring on algae and three types of sea grasses (*Halodule*, *Thalassia*, *Syringodeum*). Foraminifera and ostracods are major examples. Infaunal, semi-infaunal, and epifaunal molluscs are other significant contributors to the skeletal sediments of Pigeon Creek. Skeletal grains derived from gastropods and bivalves were found at all sampling stations. Scaphopods were found in only the northern part of the North Branch. Amphineuran plates occur rarely in the area of the creek inlet.

Transport Mechanisms

The various grain types occurring in Pigeon Creek may form by local current or wave effects on surficial crusts or exposed Pleistocene rocks (producing aggregates or lithoclasts), by the micritization of fecal pellets (producing peloids), or by biological processes (producing skeletal grains). Once each of these grain types becomes a part of the sediment of the creek system, there is the opportunity for transportation by several mechanisms: (1) tidal currents and waves; (2) surface tension; and (3) bioturbation. Tidal currents are the chief mechanism of sediment transport within Pigeon Creek. Sediments are transported up creek during flood tides and settle out at slack high tide. This results in higher percentages of finer particles in the upper reaches or in creek embayments. Prevailing easterly winds concentrate wave activity on the western side of Pigeon Creek. Fine sediments are placed in suspension and moved by tidal currents. Floating sediment is a related process which moves sediments to the upper reaches of the creek system. The floating sediment is transported when there is an early morning low tide with negligible wind during the incoming tide. Dried surficial sediments of the extensive tidal flats of Pigeon Creek then "float" on the surface

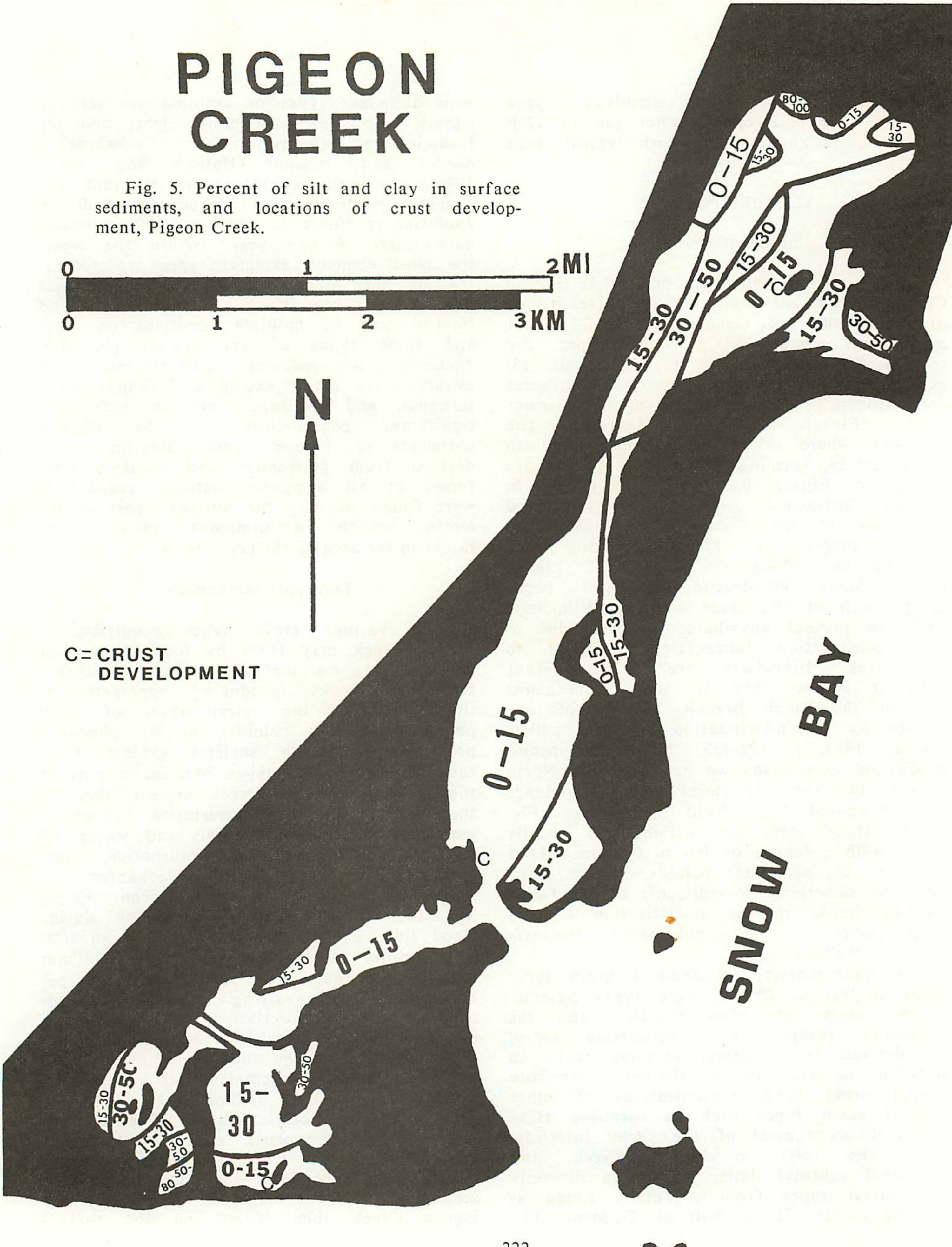

Fig. 5. Percent of silt and clay in surface sediments, and locations of crust development, Pigeon Creek.

tension of the placid flood tide. Tidal currents can transport this floating sediment considerable distances before trade winds develop in mid-morning. The sediments drop out once the surface tension is disrupted. An analysis of floating sediment from the northernmost part of the North Branch was undertaken. The sediment contained 80% silt and clay. The sand fraction was composed of the following grain morphotypes: (1) *Halimeda* (50%), (2) peloids (15%), (3) molluscs (20%), (4) miliolinid foraminifera (5%), (5) the foraminifer *Archaias anqulatus* (5%), and (6) alcyonarian spicules, ostracods, other foraminifera, and aggregates (5%). Much of the sediment of Pigeon Creek is bioturbated, especially by burrowing callianassid shrimp and a wide variety of infaunal molluscs. Bioturbation mixes the sediment in a local area, moving some fine sediment to the sediment-water interface. The finer sediment is then likely to be transported by tidal currents, waves, or flood tide surface tension. Bioturbation is, by itself, incapable of moving sediment significant distances. However, the bioturbation process assures that fine sediments are available to replenish those previously transported up creek from surface sediments.

Two additional naturally occurring, but minor, transport processes provide sediments to Pigeon Creek. Along the coast of Snow Bay east of the creek, there is a variably developed beach-dune system. Sediments from the beach are blown by prevailing winds into a vegetated dune system. The airborne dune sand can reach Pigeon Creek at times of strong trade winds. Based on archaeological excavations of the Pigeon Creek site, at the northeastern edge of the North Branch, approximately 20 cm of soil has accumulated in the past 500 years. Since the soils contain only about 50% (by volume) eolian sediment, a depositional rate of about 0.2 mm/year of wind-blown sand in the creek is possible. This is very minor compared to the depositional rates produced by tidal current activity. A final minor source of sediment transport is root-rafting. The transport of Haitian sediments to the southern Bahamas in the roots of palm trees has been documented by Keegan and Mitchell (1986). The prehistoric canopy forest of the Bahamas (Mitchell and Keegan, in press) would have provided a source for sediment transport via the root systems of dead trees. The eastern side of the Pigeon Creek system, north and south of the inlet, is presently littered with flotsam derived from coastal waters. With the presence of a native Bahamian canopy forest, these portions of the creek would be the site of poorly sorted root-rafted sediment accumulations similar to those presently found along the southwestern coast of Great Inagua Island (Keegan and Mitchell, 1986).

Silt and Clay

The percentage of silt and clay occurring in samples from 200 stations in Pigeon Creek is presented in Figure 5. Percents represent the total amount of wet and dry sieved particles less than 0.06 mm in diameter. The silt/clay size component of the sediment is greatest in creek embayments and in the uppermost reaches of the creek, and at its maximum in the northern part of the North Branch and southern part of the South Branch, where values exceed 90%. Matthews (1966), Neumann and Land (1975), and Stockman and others (1967) have demonstrated that the major sources of silt and clay size carbonate particles are the precipitation of aragonite needles and the physical and biological reduction of grains of thin-shelled molluscs, miliolinid foraminifera, and the calcified green algae *Acetabularia, Halimeda, Penicillus, Rhipoceohalus,* and *Udotea.* All of these groups are widely distributed and locally abundant in Pigeon Creek. The higher silt-clay percents do not usually correspond to significant occurrences of these organisms, but instead to the areas of lowest tidal current velocities where penecontemporaneous cementation of sediments is not taking place. The biological reduction of skeletal grains is the dominant process producing silt and clay in the creek system. The variable abundance of silt and clay provides further evidence for the importance of tidal currents, waves, bioturbation, and floating grains in redistributing the sediments of Pigeon Creek.

Granulometry

In several previously published investigations, statistical parameters have been employed in determining the relationships of samples of carbonate sediments. For example, parameters such as mean grain size, standard deviation, skewness, kurtosis, and roundness have been used in the recognition of the sedimentologic differences between reef, lagoon, and beach environments in the Bahamas, Bermuda, Florida, Mexico, and Puerto Rico (Friedman, 1961; Hollister, 1973; Hoskin, 1963; Shepard and Young, 1961; Upchurch, 1972, p. 92). In addition, the correlation between statistical parameters and grain types has been investigated in carbonate sediments from the Bahamas, Florida Keys, Virgin Islands, and Bermuda (Falls and Textoris, 1972; Ginsburg, 1956; Saunders and Schneidermann, 1973; Swinchatt, 1965). Another approach, multivariate morphometrics, which can use the same type of granulometric data base, has been utilized by Upchurch (1970) to discriminate Bermuda reef and lagoon sediments and by Gill and Tipper (1978), McCammon (1968), and Parks (1969) to map the major lithofacies of the Andros Platform of the Great Bahama Bank. Thus far, the use of this latter technique in the granulometric analysis of carbonate sediments has been extremely limited. In the present study, a type of multivariate statistics, principle component analysis (PCA), has been used to compare the granulometry of 100 samples from Pigeon Creek (Fig. 6). The first three axes of the PCA account for 45% of the variation in the data (axis 1 = 22%; axis 2 = 15%; axis 3 = 9%). The sample distribution along axis 1 is caused by mean grain size differences; sample distribution long axis 2 is the result of differences in standard deviation; sample distribution along axis 3 is caused by shape differences of the dominant grains (spherical to ovoid to tabular). Principle component axes 1 and 3 provide the best visual discrimination of the samples (Fig. 6). Ten sample clusters are recognized and can be characterized by mean grain size, as well as by the dominant grain types, shapes, and sources. Based on this PCA, physical parameters, and grain morphotypes, 12 lithofacies are recognized in Pigeon Creek.

Lithofacies

The most important factor in differentiating the sand-sized lithofacies in Pigeon Creek is mean grain size, which is directly related to the dominant grain morphotypes present. Coarser-grained sediments are characterized by grain morphotypes such as lithoclasts, aggregates, *Halimeda*, and *Peneroplis oroteus*. Finer-grained sediments are characterized by grain morphotypes such as peloids, miliolinid foraminifera, molluscs, and calcareous algae. Finer sediments are much more likely to be transported by tidal currents and surface tension. The 12 lithofacies are listed below, with a brief discussion of the physical and biological processes responsible for their occurrence. The distributions of the lithofacies are presented in Figure 7.

(1) Aggregate Lithofacies. A thin carbonate crust is developed below an organic floc at the extreme south-central edge of the South Branch. The crust provides a source of aggregates for a limited area. Much less poorly developed intertidal crusts occur on the west side of North Island and along the west side of the inlet to the North Branch (Fig. 5).

(2) Carbonate Mud Lithofacies. Sediments containing over 50% silt and clay occur at the extreme north and south-central edges of the creek system. The sand-sized component of these sediments would be assigned to the Transported *Halimeda* Sediment Lithofacies.

(3) *Halimeda* Lithofacies. This lithofacies occurs where beds of *Halimeda* are well developed. The cluster of samples assigned to this lithofacies (Fig. 6) can be subdivided into 2 groups based on the species present: (1) Group 1 has ovoid break-down products of the species *Halimedá monile*; (2) Group 2 has tabular break-down products of the species *Halimeda incrassata* and *H. opuntia.* These 2 sublithofacies are intermittently developed throughout the creek.

(4) Transported *Halimeda* Sediment Lithofacies. In areas where *Halimeda* beds are not well-developed, sediments tranported by tidal currents and surface tension become dominant. Generally this lithofacies occurs marginally to the *Halimeda* lithofacies in embayments and in the upper reaches of the creek system.

(5) Inlet Coast Lithofacies. The margins of the inlet and adjacent coast area are characterized by similar, but finer sediments than the Inlet Channel Lithofacies described below. Most of these sediments are derived from the offshore reef flat area or from *Thalassia* epibionts.

(6) Inlet Channel Lithofacies. A much coarser version of the Inlet Coast Lithofa

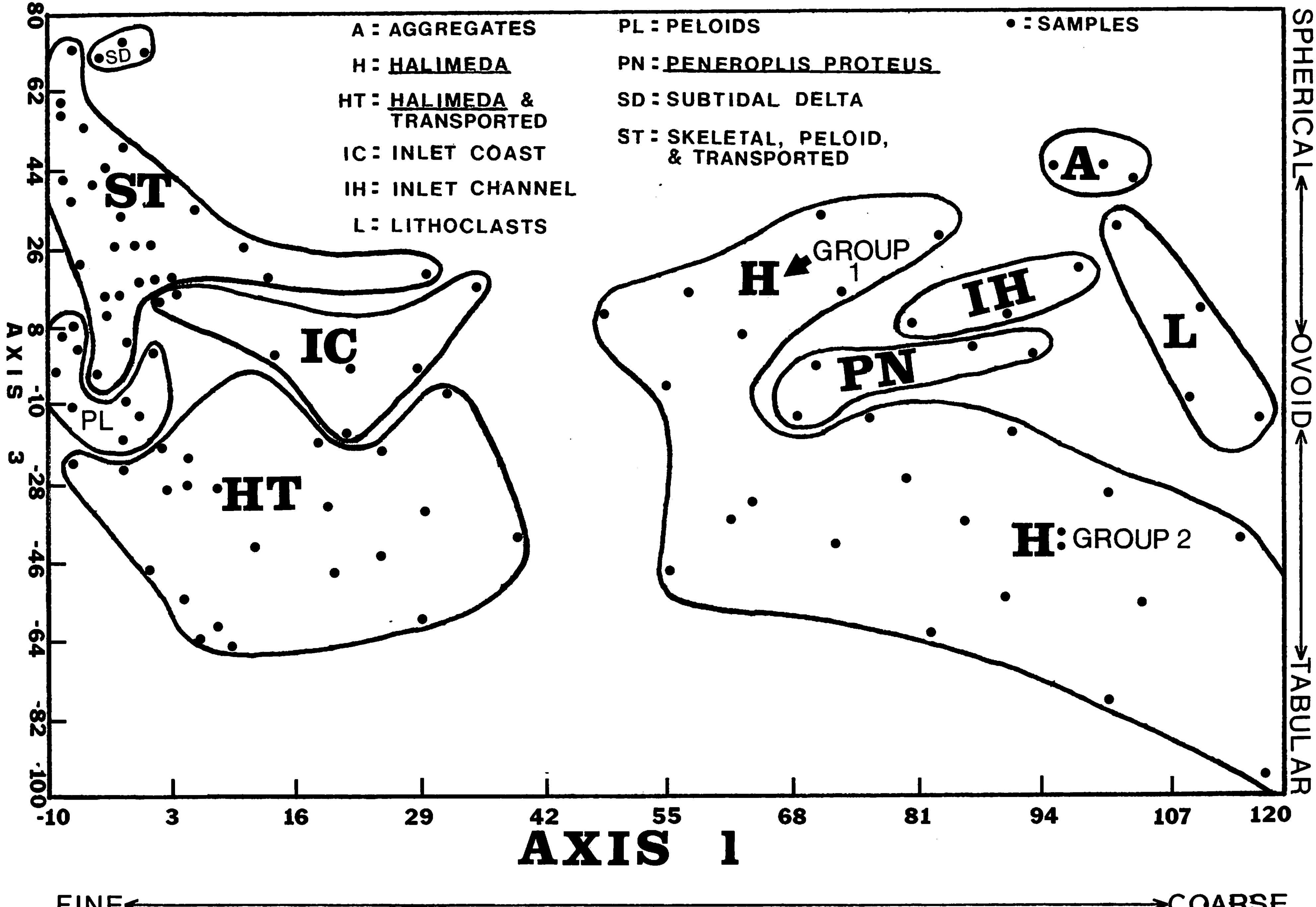

Fig. 6. Principle components analysis of granulometric data, Pigeon Creek.

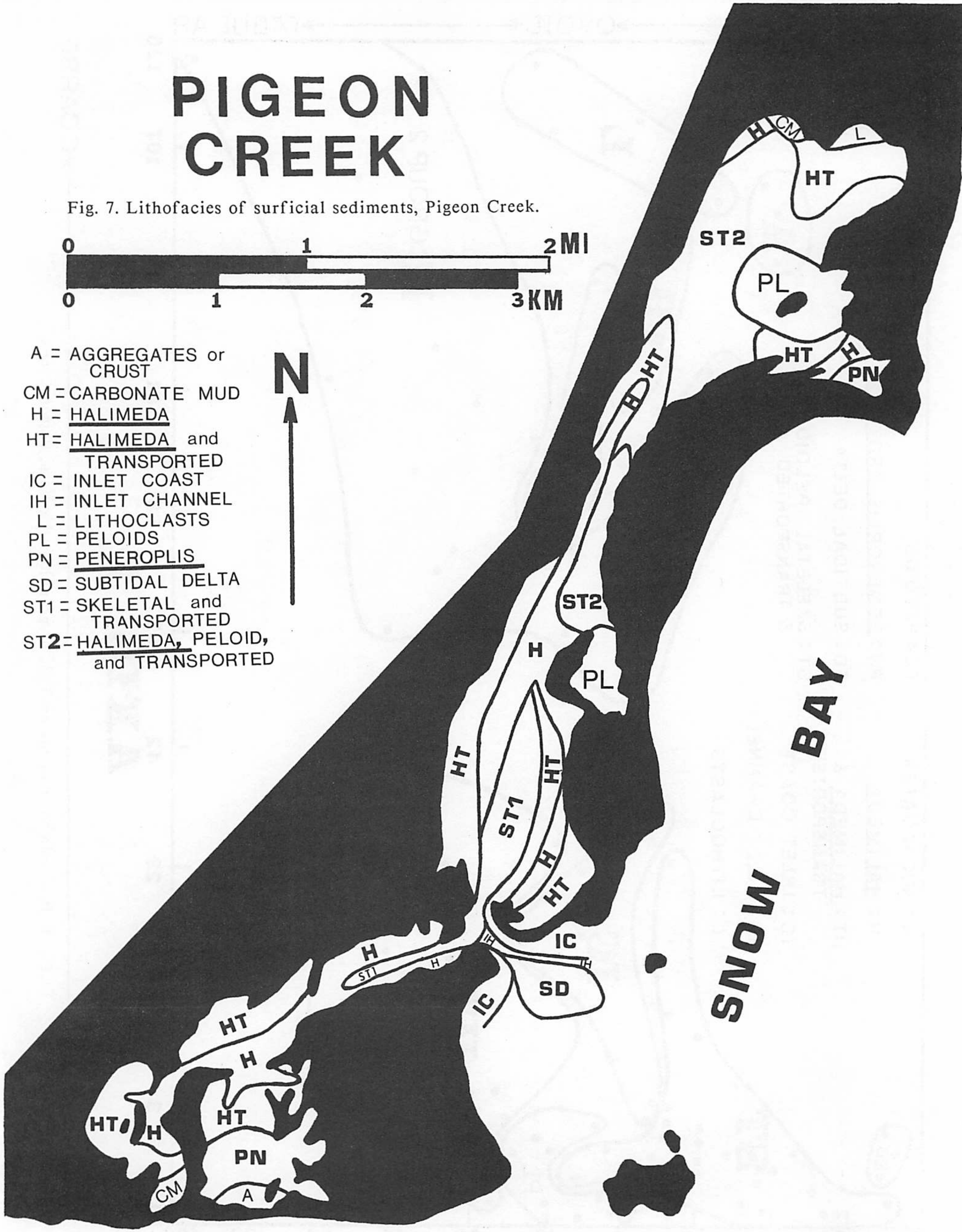

Fig. 7. Lithofacies of surficial sediments, Pigeon Creek.

cies occurs in the channel at the inlet to the creek system.

(7) Lithoclast Lithofacies. Lithoclasts of Pleistocene rock are only significant in a small area of the northernmost part of the North Branch along the road.

(8) Peloid Lithofacies. Major areas of peloid production occur around North Island and in the embayment formed by Pigeon Cay. Peloids are transported from these production areas to form the Transported *Halimeda*-Peloid Sediment Lithofacies.

(9) *Peneroplis proteus* Lithofacies. This foraminifer occurs abundantly in areas where organic flocs cover the substrate. *Peneroplis* lives on detached mangrove leaves laying on the surface of the floc. The lithofacies is developed in the embayment behind North Island, and it is associated with aggregate lithofacies at the south-central end of the South Branch.

(10) Subtidal Delta Lithofacies. The very shallow surface of the subtidal delta at the mouth of Pigeon Creek is exposed to constant wave and current activity. The grains are well-rounded with the same source as the Inlet Coast and Inlet Channel Lithofacies.

(11) Transported Skeletal Sediment Lithofacies. The sediments of this lithofacies are derived from the creek inlet area, with both reef-flat and *Thalassia* epibiota origins. The sediments are mostly fine winnowed portions of the Inlet Channel and Inlet Coast Lithofacies.

(12) Transported *Halimeda*-Peloid Sediment Lithofacies. Sediments assigned to this lithofacies are produced by a significant influx of peloids into what would have been a Transported *Halimeda* Sediment Lithofacies. This lithofacies occurs up creek from the areas of peloid production.

The boundaries of the lithofacies of Pigeon Creek are controlled by the production of grain morphotypes, tidal current velocities, and *Thalassia* development. An upcreek reduction in grain size distribution appears to occur as predicted by the transfer function X(s) (McLaren and Bowles, 1985). However, the reduction occurs in several stages in the creek, with the reef-flat, subtidal delta, *Thalassia* beds, peloid production areas, and *Halimeda* beds all acting as sediment sources. Bottom stability gradients also occur, with *Thalassia* bed development controlling bathymetry and bioturbation (Aller and Dodge, 1974). The mapped bathymetric lows (Fig. 3) are areas of lowest local current velocity, weakest *Thalassia* development, and apparently, the areas of slowest sediment accumulation rates (Hay and others, 1970, p. 19).

SUMMARY

A detailed analysis of the sediments of Pigeon Creek has been undertaken in order to develop a modern analog for the interpretation of ancient Bahamian tidal creeks. The relationships between physical parameters (salinity, tidal current velocities, bathymetry), granulometric data, and grain morphotypes were utilized in grouping samples into lithofacies. The surficial sediments of the creek are assigned to 12 lithofacies. Approximately 30% of the sediments of the creek contain peloids at a significant level.

Using the tidal creek lithofacies and inlet categories of Mitchell (this volume), Pigeon Creek would be classified as a Single-Inlet Peloid Lithofacies Tidal Creek. Pigeon Creek seems to be a fairly good modern analog for the Pleistocene Lake George Tidal Creek System of Rum Cay (Mitchell, this volume) and the Granny Lake Tidal Creek System of San Salvador Island (Teeter, 1985; Thalman and Teeter, 1983). Both of these Pleistocene tidal creeks apparently had a single inlet, but the dominant grain type, unlike Pigeon Creek, was ooids.

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