PHYSICAL PARAMETER DISTRIBUTION PATTERNS IN BOTTOM SEDIMENTS OF THE BUCTOUCHE BAY COMPLEX

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INTRODUCTION

The Buctouche Bay complex offers a unique environment for the study of littoral and estuarine sedimentation. Located 40 km north of Moncton, New Brunswick (Fig. 1), it encompasses within a 33-km^2 area, a drowned river estuary, a coastwise lagoon, and a very well developed complex recurved spit.

Modern sedimentation patterns within the bay represent composite responses to a complex combination of physical, chemical and biological processes that are regulated by the bay's hydraulic regime and geologic framework. In addition, the bay's sedimentary processes are, or have also been influenced by such activities of man as agriculture, channel dredging, oyster culture programs and beach quarrying. The differentiation of natural effects from man-induced effects compounds the problem of understanding estuarine sedimentary processes. Another impeding factor is the variable nature of the estuarine hydraulic regime. It is difficult to predict net sediment responses within a circulatory system that comprises both tidal and fluvial components, each exhibiting short term and long variations in hydrologic characteristics. Still another complicating factor is that several possible contributing sources of sediment may have been operative within the estuarine system at different times. Estuarine sediments can be derived from a combination of external (fluvial, littoral), marginal (coastal erosion) and internal sources (biogenic, substrate erosion) (Guilcher 1967, Rusnak 1967, Meade 1969, Schubel 1971).

The objective of the present study was to delineate the areal variability in bottom sediments within the Buctouche Bay complex in order to determine parametric interrelationships that might provide some insight into the bay's sediment dispersal system.

PREVIOUS WORK

Ganong (1908), in his account of the physcial geography of New Brunswick's northeastern coast was perhaps the first to mention the Buctouche spit in a scientific report. This was followed in 1925 by Johnson's classic study of the New England and Acadian shoreline in which a brief description of the Buctouche "retrograding compound spit" was included.

In 1959, the Geographical Branch of the Department of Energy, Mines and Resources of Canada prepared a report on the physical character of the shoreline along the Northumberland Strait. This report dealt with the effects of tidal changes that could result from the construction of a causeway between New Brunswick and Prince Edward Island (Forward *et al* 1959). Van de Poll (1971) prepared a map showing the dispersal pattern of beach sand along the Northumberland Strait coast.

A resource inventory of Buctouche Bay (England and Daigle 1973) consisted mainly of mapping the shellfish population distribution and checking the consistency of the bottom sediments. This survey, in conjunction with the initiation of an oyster culture program in Kent County, New Brunswick led to a series of annual reports and to a study of some of the physico-biological characteristics of the Buctouche estuary (Andrews 1971, Andrews and Gallant 1972, Gallant 1973, Robichaud and Woo 1974). Billard (1974) gave a brief account of the major hydrodynamic trends of the system in relation to oyster spatfall, and McNally (1976) described some of the foraminifers found in the Buctouche estuary.

GEOLOGICAL FRAMEWORK

The study area is located within the Maritime Plain region of New Brunswick (Bostock 1970). This featureless coastal plain of typically low relief (rarely exceeding 20 m, Owens 1974) consists of gently northeasterly dipping beds of Permo-Carboniferous sedimentary rocks, which form part of the Carboniferous Central Basin (Gussow 1953). The bedrock lithology is very uniform consisting of poorly indurated beds of predominantly greyish buff, arkosic sandstone of the Pennsylvanian, Pictou Group. Siltstone interbeds locally occur within the even-bedded and cross-stratified sandstone, along with occasional thin coal seams and fossilized plant fragments.

These sedimentary rocks are undeformed but in a few exposures along the shore they exhibit closely spaced vertical joint patterns which may be related to a possible extension of the Belleisle-Millstream fault (van de Poll 1970).

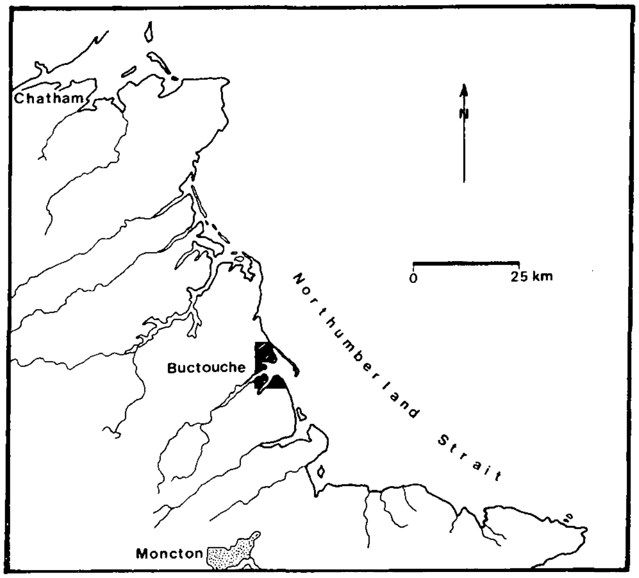

FIG. 1 Location map of the Buctouche Bay complex, New Brunswick.

MARITIME SEDIMENTS Vol. 14, No. 3, December 1978 pp. 95-102.

Prior to glaciation of the Maritime Provinces during the Pleistocene, the Carboniferous terrain was subjected to a long period of fluvial erosion. This, coupled with lithological weaknesses in the Pennsylvanian strata, led to the development of a valley which would later become the Strait of Northumberland. That valley was drained by two river systems which were separated by an isthmus that linked Prince Edward Island with Cape Tourmentine and the mainland (Kranck 1972).

During Pleistocene time, the entire Province of New Brunswick was glaciated (Prest 1970) and variable thicknesses of till and glaciofluvial sediments were deposited.

Waning of the last Wisconsinian glaciers began about 14,000 years B.P. and as the ice retreated from Northumberland Strait, the sea transgressed onto the glacially depressed coastal lowlands (Prest and Grant 1969). By 10,000 years B.P., due to the rapid rate of isostatic rebound, sea-level had fallen approximately 20 m below the present-day level (Thomas *et al* 1973). Since 8,000 years B.P. relative sea-level has risen slowly to its present position. Spits and barrier islands have developed along the gently sloping coastal plain in response to the reworking of glacial sediments by longshore currents.

BAY PHYSIOGRAPHY

The Buctouche Bay complex can be grouped into two geomorphic divisions which together form an approximte T-shaped configuration: (1) the lagoon, oriented parallel to the coastline, representing the arms of the T; and (2) the estuary, oriented perpendicular to the coast, and corresponding to the vertical segment of the T (Fig. 2).

The lagoon (10 km in length and from 0.5 to 3 km wide), was formed by the gradual development of the Buctouche spit across a coastal embayment. This sand spit which forms the seaward margin of the Buctouche Bay complex, is also the southern extremity of a nearly continuous chain of sand barriers and spits that extend for almost 200 km along the eastern coast of New Brunswick. The seaward margin of the spit is smoothly arcuate, in contrast to the highly irregular lagoonal shoreline which consists of a series of washover deltas and distal ends of recurved spits. Ridge-and-swale topography characterizes the southern subaerial portion of the spit with relief varying from sea level to a maximum height of about 7 m along the highest dune crest.

The estuarine bay, with a surface area of about 4 km^2, differs markedly from the coastwise lagoon in terms of origin, environmental characteristics, and sedimentary processes. It consists of an inundated system of river and stream valleys which was submerged during postglacial sea-level rise. Today, three rivers discharge into the estuary: the Buctouche, the Little Buctouche and the Black (Fig. 2). The Buctouche River is the more important of the three and drains a basin of 125 km^2 over which precipitation averages 75 to 130 cm/year (Simpson 1973). Mixing of both fluvial and marine environments characterizes the estuarine bay. The degree of dominance of either environmental system is a function of river discharge, tidal interchange, water depth and distance from the river mouth or tidal inlet. In the case of the Buctouche bay complex, the marine system largely dominates due to low discharge of the three rivers (except perhaps during spring thaw or after heavy rainfalls).

Unrestricted communication between the bay and the open sea is provided through a 2-km tidal inlet. Historic evidence suggests that another tidal inlet may have existed at the point where the spit is now attached to the land.

PRESENT STUDY

During the summer of 1975, a total of 166 bottom samples was obtained from Buctouche Bay. The samples were collected using a 60 lb (27.2 kg) "Clamshell Snapper" with volume capacity of one pint (0.47 l). Physical properties of the sediment (texture, color and odor) and presence or absence of fauna and flora were noted for each sample at time of sampling. The positions of sampling stations were located by sextant (Fig. 2).

Before collecting a bottom sediment sample, the following parameters were noted: (1) time of day, (2) depth of water using a point sonar and (or) a lead line, (3) conductivity, salinity, and temperature of the water using a Beckman induction salinometer, (4) turbidity of the water using a Beckman induction salinometer, (4) turbidity of the water using a Hydroproduct transmissionmeter, (5) direction and relative strength of wind, (6) bay wave direction, amplitude and period.

Laboratory analyses were made of grain size distribution and of the organic carbon content of the samples. Statistical parameters of the grain size distribution were obtained by the moment method utilizing a computer program originally prepared by James (1971). Organic carbon determinations were done following the titration method described by Gaudette *et al* (1974).

HYDROGRAPHY

Salinity

During the period of study, the waters of the lagoon and of the estuarine bay were well mixed and showed no significant salinity gradients. The average recorded value of 28 ^{o}/oo was comparable to observed salinity values in the nearby Northumberland Strait. The salinity value at any position in the bay is primarily a function of the volume of river discharge, and thus pronounced salinity gradients develop only during spring runoff and after heavy rainfalls.

The actual position of the haloclines varies in response to changes in tidal conditions and to variations in the volume of freshwater runoff. Salinity values of up to 20^{o}/oo have been recorded as far as 3 km upstream in the Buctouche River (Gallant 1973), and the author has recorded the presence of salt water 6.5 km upstream.

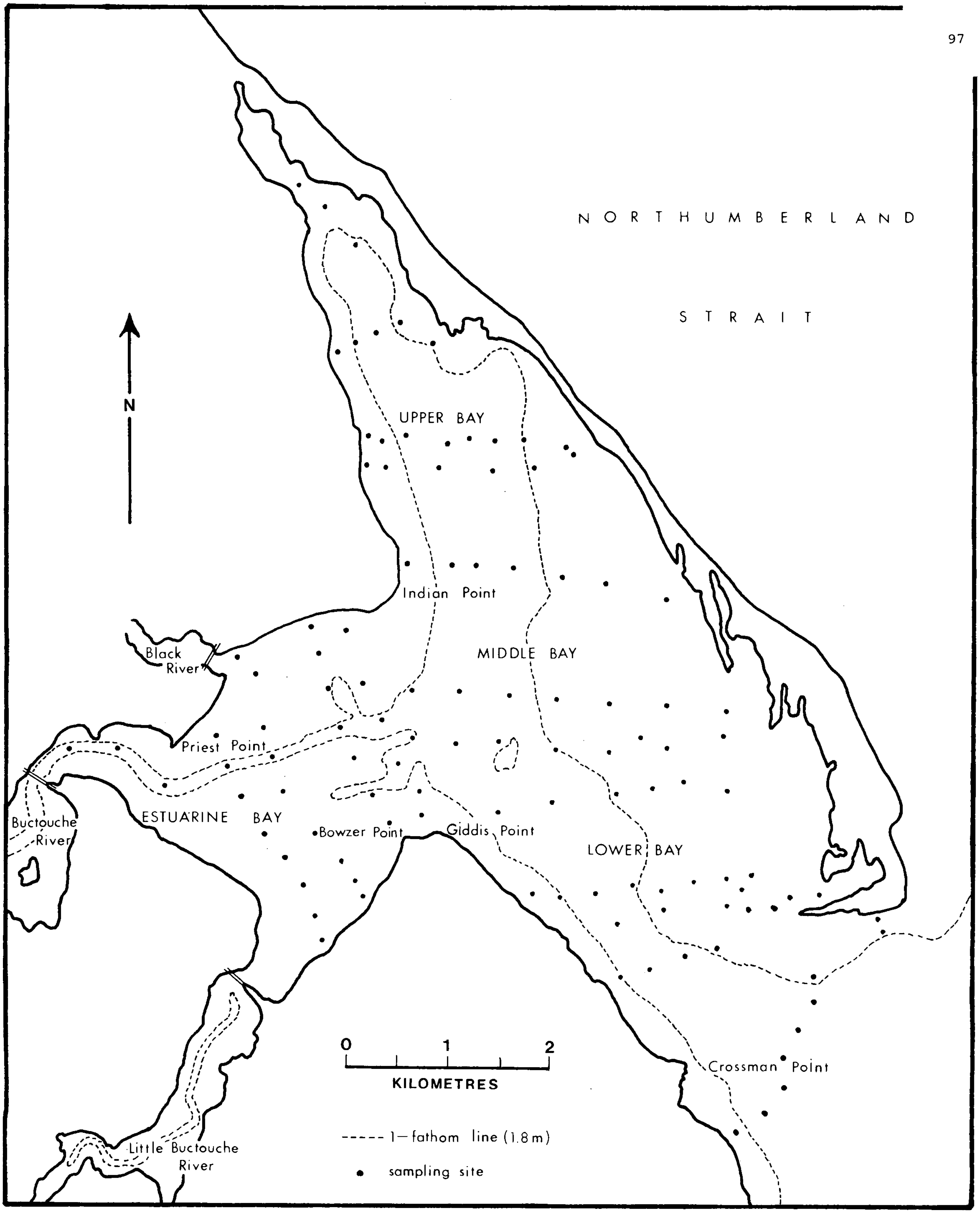

FIG. 2 Physiographic map of the Buctouche Bay complex illustrating sample location sites and bathymetry. Only the 1–fathom isobath is shown (compiled from Canadian Hydrographic Survey Chart 4441 and from field data; data reduced to Lowest normal tide).

Temperature

The bay's water temperature has an annual range of 0°C to about 25°C. during the period of study, observed water temperatures averaged 21°C. Significant thermal stratification was restricted to the deeper parts of the lagoon and to the central part of the estuarine bay. In these areas, differences of 1°C were generally recorded between the upper and the lower layers, and a maximum difference of 3.3°C was recorded in the channel south of Indian Point (Fig. 2). Relatively large and sudden changes in water temperature can occur during the summer months in response to cool northern storm weather or hot dry spells.

Tides

Water depths vary in response to astronomic tides and storm surges. Astronomic tides in the Buctouche Bay area are mixed with the semi-diurnal cycle predominating. The tidal range is from 0.2 to 1.3 m with extreme values occuring when the cycle becomes dirunal (Canadian Hydrographic Service 1975).

Occasionally, high astronomic tides are augmented by strong onshore winds from the northeast. By raising the water level significantly above the normal tidal range, such a condition can have dramatic effects on coastal features. The Buctouche spit has suffered severe breachinq in the past as a result of such abnormal high tides.

Waves

Wave fronts in the Buctouche Bav area originate mainly from the northeast or the southwest. During the summer months southwest winds predominate and, blowing over a fetch of about 6 km, produce relatively small bay waves. These waves have short wavelengths with amplitudes that can occasionally reach 0.5 to 1.0 m. Although such waves have minimal turbulent effect on the deeper portions of the bay, they can effectively erode, transport and resuspend sediment along the shore.

Northeast winds blow over a much longer fetch (over 900 km). The resultant wave fronts that originate in the Gulf of Saint-Lawrence are very effective in moving the sand along the seaward side of the spit and are principally responsible for its southerly growth.

Turbidity

During the period of study, the waters of the bay were relatively clear with light transmission values averaging 73%, the clearest waters being found over sandy substrates. Wind-induced wave turbulence will increase the degree of turbidity through resuspension of bottom mud from the intermediate depth zones in the lagoon and in the estuarine bay. Although the degree of turbidity results primarily from inorganic suspended solids, organic suspension may locally and temporarily become important. Actual data on the amount of suspended material are not available but reports of silt covering oyster culture equipment imply some accumulation of fine material (Gallant 1975, personal communication).

Most of the suspended inorganic material is thought to be derived largely from river discharge. Other potential sources include windblown silts and material derived from shoreline erosion.

TEXTURAL PATTERNS IN BOTTOM SEDIMENTS

Distribution of sediment type nt type

Following the example of several recent workers (Stauble and Warnke 1974, Reineck and Singh 1975, Shideler 1975, Reinson 1976) a reconnaissance map was prepared showing the distribution of sediment type within the bay complex. Four facies were differentiated according to their relative weight percentage of mud (material less than 0.063 mm in diameter): sand (less than 20%), muddy sand (20 to 50%), sandy mud (50 to 80%) and mud (greater than 80%).

The mud and sandy mud facies are largely confined to the estuarine bay and to the northern part of the lagoon (the upper bay), whereas the spit platform and the middle and lower bay form a sandy province with relatively little mud (Figs. 2 and 3).

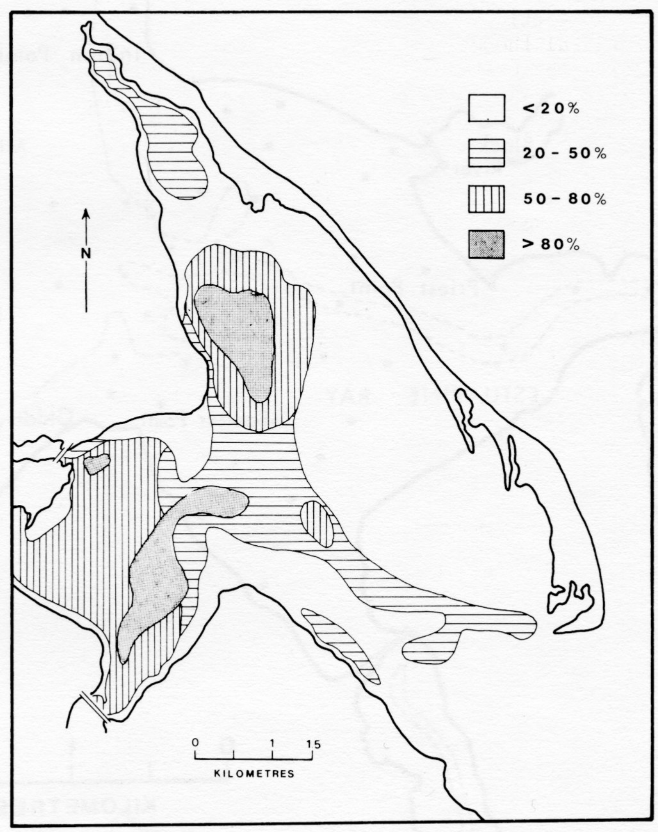

FIG. 3 Isopleth map of total mud content in bottom sediments (weight percentage of the fraction finer than 0.063 mm).

The distribution of mud facies indicates the primary depositional areas for fine-grained material derived from the three rivers, principally the Buctouche River. There is a close relationship between the bathymetry and the mud content of the sediments; this is illustrated by the progressive increase in mud content from the shallower marginal areas towards the estuarine bay and towards the deeper portions of the lagoon (Figs. 2 and 3). The muds and sandy muds are confined to depths greater than 2 m, presumably as the result of lower wave-energy levels relative to the more shallow marginal areas.

Little mud-sized material is found in the sediments of the lower bay area. This is possibly the result of two factors: (1) there is a paucity of muddy effluent contributed by the estuary to this region of the bay complex; (2) high velocity tidal currents in the baymouth region would tend to maintain fine particles in suspension, thus preventing their accumulation as bedload sediments. During the study period, currents within the bay were observed to be of low magnitude and generally restricted to the surface as wind induced currents. However, in the channel at the tidal entrance and in the Buctouche River, current velocities often were extremely high. During ebb tides, Billard (1974) observed a maximum velocity of 1.1 knots in "one particular spot of a narrow channel." In general though, current velocities in the bay, outside the channel, never exceeded 0.2 knot (Billard 1974). The inward curvature of the spit suggests that tidal currents are actively transporting sediments into the bay.

The lack of fine-grained sediments in the southern portion of the lagoon, and their concentration in the estuarine bay, indicate that offshore sources of mud are not significant. The overall mud distribution pattern indicates that the estuarine bay and the upper bay are effective mud traps with the quantity of mud influx apparently exceeding the quantity of mud outflow via the baymouth entrance. In contrast, the middle and lower bays are effective mud-bypass areas, accumulating only winnowed residual and (or) transported sand material.

Sand Texture

Although textural parameters such as mean, standard deviation and skewness have been shown to be environmentally sensitive indicators of geomorphic processes and environments (Friedman 1961, 1967, Folk 1966, Pezzetta 1973, and others), considerable controversy still exists as to the actual geological implications of these statistical parameters and as to the methods used in calculating them.

A major problem connected with the sedimentation methods of analysis of fine-grained materials is the question of whether or not the material should be disaggregated. Whitehouse *et al* (1959) have shown that clay minerals settling out of saline waters do so as aggregates. In the laboratory, where the sample is partly or completely disaggregated, the natural conditions of deposition are not duplicated. This leads to a possible misrepresentation of the original size characteristics of the particles that settled out of suspension. These analytical problems can be countered by restricting the size frequency determinations to the portion of the sample that represents the saltation population, i.e. the fraction coarser than 4 ∅. Glaister and Nelson (1974) prefer to analyze all sizes down to 5 ∅ but 4 ∅ is generally accepted (Friedman 1961, Pezzetta 1973) as an empirical boundary between the suspension and the saltation populations (Visher 1968). In the case of Buctouche Bay, the textural characteristics of the ;bottom sediments strongly suggest such a bimodal population. It was thus decided to characterize the sand fraction (greather than 0.063 mm or 4 ∅) of all bottom sediment samples in terms of their size frequency distribution, using moment statistics and in accordance with Folk's (1965) size terminology (Fig. 4). Obviously, the textural parameters calculated from the coarse data do not reflect a picture of the entire distribution and this factor enters in consideration when interpreting the data. However, Shideler (1975) and Pezzetta (1973) demonstrated that such an approach is sound inasmuch as it can help understand and explain regional variability in textural characteristics of the bottom sediments.

Throughout the Buctouche Bay complex, sand fractions range in texture from very fine-grained to medium-grained; coarse-grained sands are virtually absent (Fig. 4).

Sand textural gradients are parallel or subparallel to the isobaths. The sand fraction generally exhibits a decrease in mean grain size

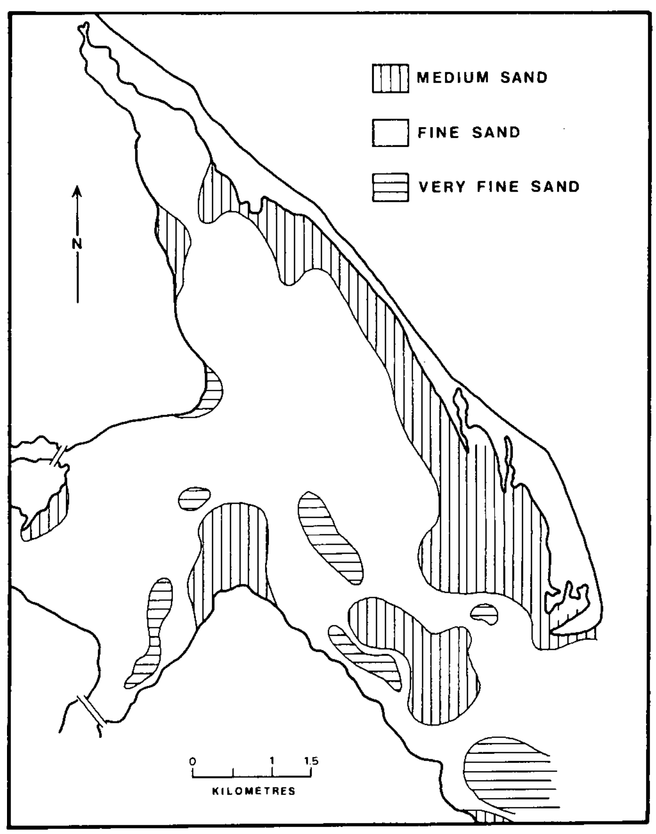

FIG. 4 Isopleth map of mean grain size for sand fractions in bottom sediments.

laterally from the marginal areas toward the central part of the bay. The areas of fine sand coinicde with the major mud areas which further support the contention that the estuary and the upper and central parts of the bay function as fine-sediment traps. Coarser sand is localized along the shallower, higher-energy marginal areas as lag sediment from shoreline erosion, or as a consequence of spit buildup. The extensive patch of medium-grained sand found in the vicinity of Bowzer and Giddis Points is the result of active erosion of a bedrock headland. This headland focuses wave energy and thus undergoes much more rapid erosion. The higher energy is also a factor in winnowing the finer material away from the headland towards the estuary. The headland erosion at Giddis Point is very evident from the bathymetry. Priest Point is also an area of headland erosion and a southward current is accumulating the sand in front of the Buctouche River in the form of a river mouth bar. The patch of medium sand found in the central part of the lower bay is probably related to the stronger currents operating in the tidal channel, and to the proximity of the encroaching spit platform (Fig. 4).

Most of the bay portions with depths greater than 1 m are covered with fine sand. The fine sand is brought in from the offshore by overwash fans and from the subaerial part of the spit by winds. The estuarine fine sand may originate from the river and from the erosion of the bedrock along the shoreline.

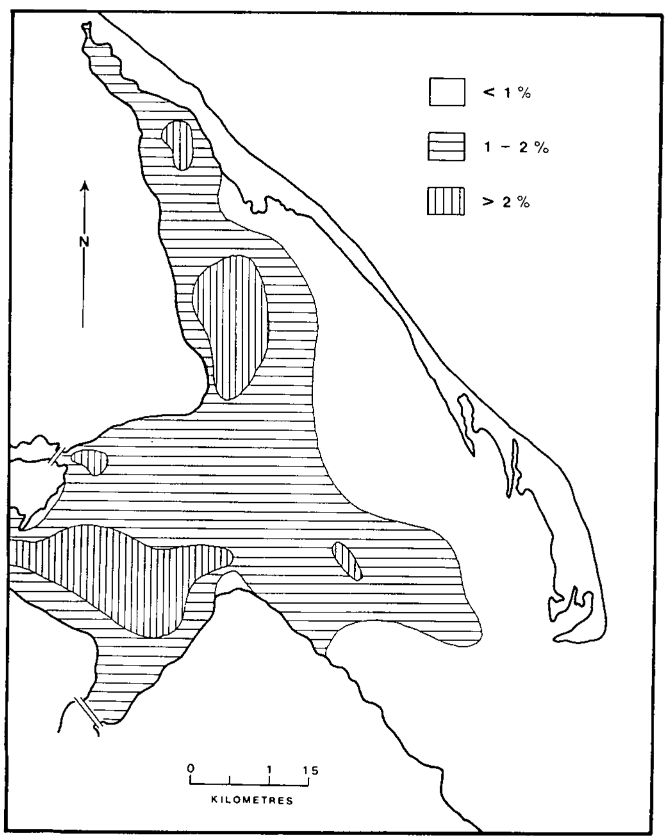

FIG. 5 Isopleth map of organic content (carbonaceous matter) in the bottom sediments (weight percentage).

Organic Carbon Content

Values of organic carbon in the sediments of the Buctouche Bay complex range from 0% to 4.8% by weight, with the majority of the sediment samples containing less than 2%. The most conspicuous feature of the regional distribution is the excellent correlation between the areas of high organic carbon content and the areas of high mud concentration (Fig. 5).

Maximum concentrations of organic carbon occur within the muddy and the very muddy portions of the bay, particularly in the central part of the estuarine bay. Areas of low to no organic carbon correlate with the higher energy zones along the shoreline, over the spit platform and in the tidal entrance.

SUMMARY

Buctouche Bay complex is a composite system consisting of an inner drowned river estuary and an outer elongated lagoon formed as the result of coastwise progradation of Buctouche spit across the baymouth. The physical parameters of the bottom sediments reflect this composite origin. Fine-grained sediments predominate in the deepest parts of the bay complex adjacent to the drowned river mouths, and sandy sediments are dominant near the tidal entrance and adjacent to the spit complex. Such a distribution indicates that the estuary proper and the upper bay are depositional sinks for fine-grained material carried into the system by fluvial discharge. Conversely, the bay complex is being in-filled from the seaward side by sand-sized material derived from the littoral zone. The zone of mixing of marine and fluvial depositional processes is characterized by sediments containing a mixture of both mud and very fine to fine-grained sand.

The enclosed nature of the bay contributes to such a sediment distribution by effecting a relatively low-energy depositional regime throughout the inner and basinal portions of the system. Relatively coarser sediments are confined to the deeper channel areas near the tidal entrance where strong tidal current prevail.

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