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Sediments of the Bay of Fundy - A Preliminary Report*

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Introduction

The Bay of Fundy (Fig. 1) is a funnel-shaped body of water lying between Nova Scotia and the Canadian mainland. The Bay of Fundy proper is 144 kilometres long, 100 kilometres wide at the base. The northeast end bifurcates into northeast-trending Chignecto Bay, and the east-trending Minas Basin. The Bay has been incised into the red continental mudstones and sandstones, and tholeiitic basalts of a Triassic half-graben (Swift and Lyall, 1968a). Fundy was named Rio Rondo by 16th century Portuguese navigators who were impressed by its enormous tides. Fundy has tidal currents of 1. 5 to 4 knots in a water column averaging 75 metres deep.

The bulk of Fundy's sediment cover was emplaced under subaerial conditions during the repeated glacial episodes of the Pleistocene, and these relict materials are evolving into sediments adjusted to the modern hydraulic regime. Where this process has run to completion, the resulting deposits bear the distinctive impress of a high energy tidal regime, a facies which has heretofore received little attention in the literature.

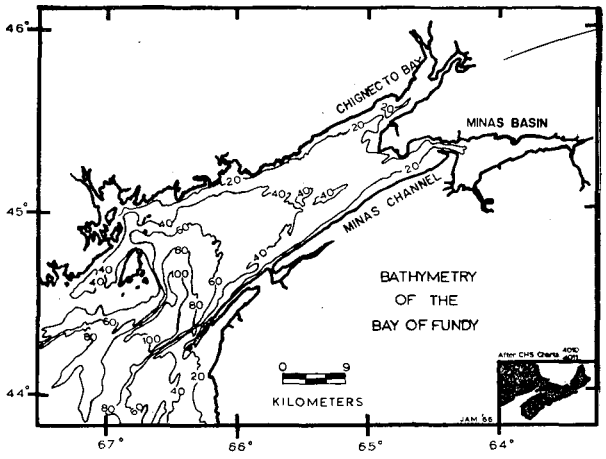

FIGURE 1 -
Bathymetry of the Bay of Fundy.

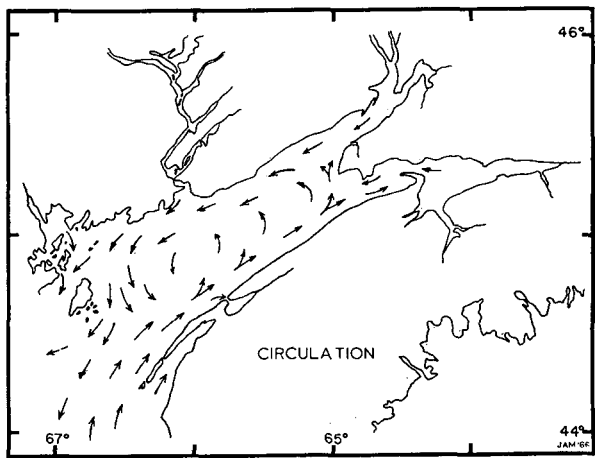

FIGURE 2 -
Counterclockwise residual current system of the Bay of Fundy.

Tides

The tides of Fundy are semidiurnal and anomalistic (markedly higher during the lunar perigee than during the lunar apogee); and Fundy is famous for their enormous range. The entering tide at the mouth has a mean range of 6. 4 metres (Grand Passage, Nova Scotia) and the range increases to 13 metres at the head of the main Bay (Halls Harbour). The world's record high tides occur at Burntcoat Head in the Minas Basin where normal (Perigean) spring tides have a range of 15. 4 metres. During spring and autumn, when the sun is in the equinox and the moon in perigee, maximum spring tides occur 0. 6 to 3. 0 metres above normal.

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The enormous tide range is a consequence of the dimensions of the Bay. The Bay averages 75 metres deep. The critical length for a standing oscillation with a node at the mouth of the Bay and maximum amplitude at the head is given by the formula.

$$L = 1/4 \; T \quad gd$$

where T is period, g is the acceleration of gravity, d is the depth, and L is the critical length (King, 1963, p. 174). Fundy's critical length is 296 km which closely agrees with the measured length of 300 km. The natural period of the Bay is 6. 29 hours which is close to one half of the semidiurnal period, or 6. 21 hours. The conditions for resonance are therefore approximated, and the entering tidal wave is amplified to the point where constructive interference is balanced by tidal friction.

The tidal wave in Fundy is therefore a standing wave rather than the progressive wave found in some other embayments. Consequently, high water is attained nearly simultaneously throughout the Bay, being only 24 minutes later at the bifurcation than at the mouth of the Bay. After analysing the tide in Fundy, as a damped co-oscillating system, Harleman (1966) notes that it is "not highly resonant" in that the amplification of the tide from the ocean entrance to the head of the Bay is only 2 1/2 times. He points out that the entrance tide at Cutler, Maine is 4. 3 metres, and "has already undergone a primary amplification due to the shoaling effect of the continental shelf at the seaward edge of the Gulf of Maine." Shoaling is a relatively minor contributor to amplification of the tidal wave within the Bay, adding . 3 to . 6 in. to the diurnal spring tides (Canadian Hydrographic Survey, Atlantic Coast Tide and Current Tables, 1966). The main reflecting areas of the tidal wave appear to be Cape Hopewell in Chignecto Bay and Scotts Bay in the Minas Channel.

Fundy's tidal wave moves 96 km^3 of water through its mouth twice a day (Bowden, 1962). The resulting tidal currents are parallel to the Bay's axis. At half flood and mid-depth they average 103 cm/sec (2 knots) on the south shore and 77 cm/sec (1. 5 knots) on the north shore. The difference in velocities is due to the geostrophic effect on the tidal currents, which tend to bank up on the south shore when flooding, and on the north shore when ebbing. As a result, the south shore experiences a 10 percent higher high tide (Harleman, 1966, p. 533) and lower low tide with correspondingly stronger currents; and there is a counter-clockwise system of residual currents (Fig. 2) with velocities of up to . 2 knots.

Towards the head of the Bay, shoaling and narrowing retard the tidal wave, and current velocities increase to 206 cm/sec (4. 0 knots) in the Minas Channel and up to 556 cm/sec (11. 0 knots) in the Minas Passage (Cameron, 1961). During spring tides, currents run 30 to 50 percent faster (Farquharson, personal communication). The currents maintain an essentially constant speed down to the viscous boundary layer, and at most places the tide turns at the surface and below at practically the same time (Dawson, 1908).

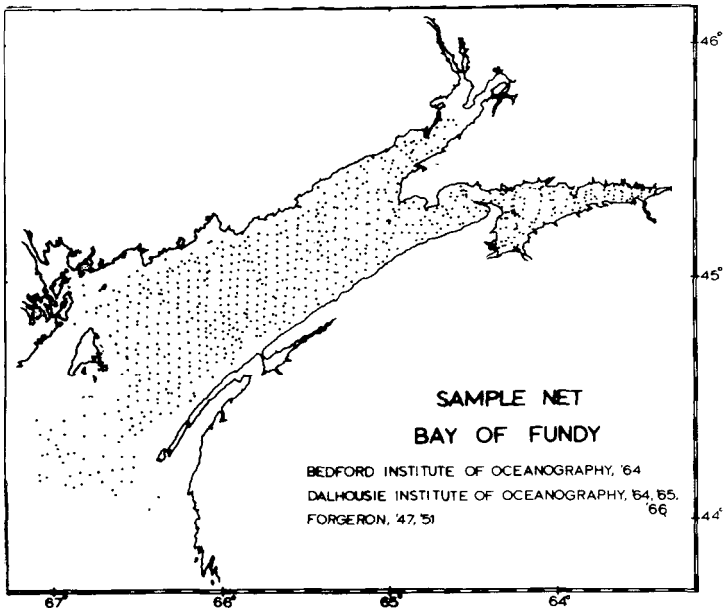

FIGURE 3 -
Sample net in the Bay of Fundy.

Bottom Sediment

General:

Bottom sampling of the Bay of Fundy was carried out by the Atlantic Oceanographic Laboratory, Bedford Institute and the Dalhousie Institute of Oceanography during the period 1961 - 1966. Samples were collected on a 2-km sample grid within the Bay of Fundy proper, using a .2 m^3 Van Veen grab (Fig. 3). Textural facies of bottom sediments in the Bay of Fundy is shown in Fig. 4, 5. The "wave length" of textural variation is in some areas considerably shorter than can be resolved by the sample grid. Each facies is named after the sediment type most abundant within its margins. Fig. 5 presents the probability of finding the namesake sediment type within each textural province. The probability is lowest for the coarser sediments, and highest for the fine sediments.

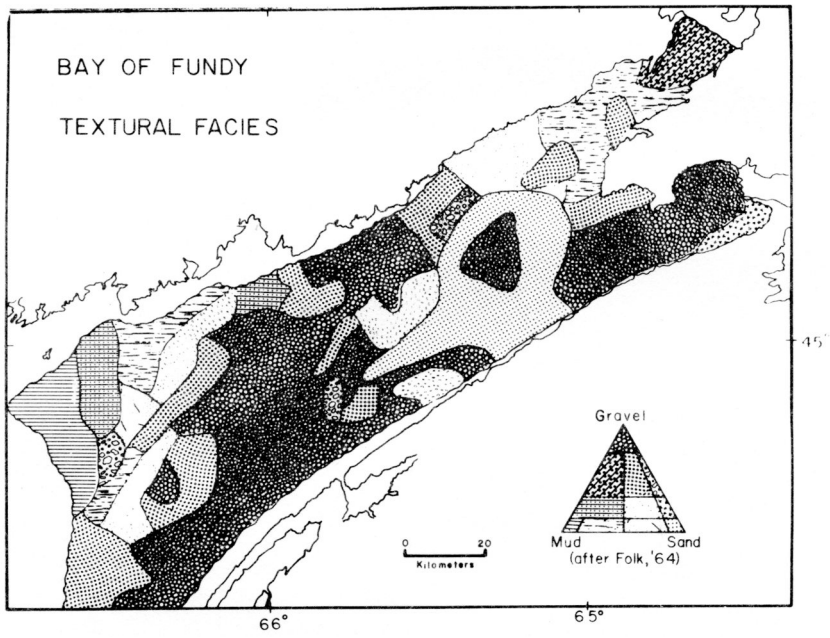

FIGURE 4 - Textural facies in the Bay of Fundy.

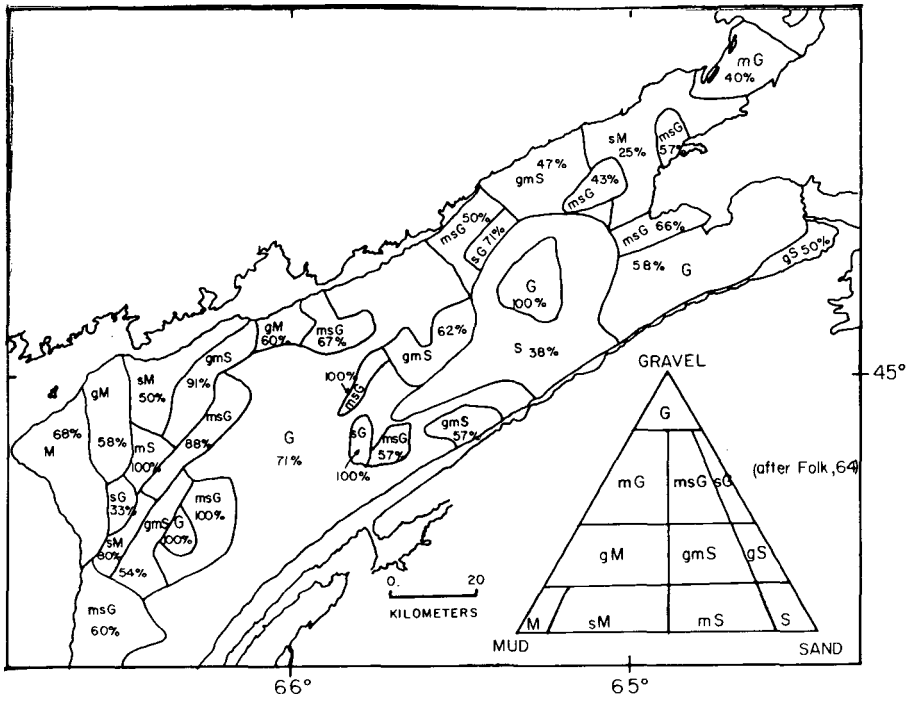

FIGURE 5 - Probability of sediment types in the Bay of Fundy.

Textural provinces in the Bay of Fundy fall into three main groups. Gravels floor most of the Bay. Sand provinces occur on the southwest and northeast side, while mud provinces are present on the northeast.

Gravel:

Medium to coarse pebble sandy gravels, and muddy sandy gravels cover 58% of Fundy's floor. They occur mainly below the 40-metre contour, where they are immune to wave action. The one to two-knot tidal currents are capable of moving very fine to fine pebbles, but the bulk of the Bay floor gravels have median diameters coarser than this, and are therefore presumably relict from Pleistocene, having been deposited as outwash and till during low stands of the sea.

Sand:

Sands, gravelly sands, and muddy sands occupy 21% of the Bay floor. Grain size is medium to very coarse, except in the vicinity of mud deposits, where it is fine to very fine. Two major sand deposits are present, one in a transverse north-south band toward the head of the Bay, and a second transverse band across the eastern corner of the Bay. It is possible to suggest a variety of reasons for the presence of the bayhead sand body. The reasons are probably complementary rather than mutually exclusive. The sand body probably serves as a depot for sand winnowed out of the underlying glacial sediments by the more intense currents of the southeast shore. To the north it comprises a hydraulically-maintained transition zone between the mud deposit at the mouth of Chignecto Bay and the gravels of central Fundy. However, the main mass of sand may be an outwash delta generated by a late Pleistocene periglacial river whose channel has been detected by sub-bottom profiles (Swift and Lyall, 1968b), or generated by melt water from a late Pleistocene local ice cap centered on southern Nova Scotia (Hickox, 1964), or by both. Sub-bottom profiles from the southeast side reveal irregular solitary sand waves with amplitudes up to 2 metres localized by bedrock or till highs. These have a flood asymmetry.

Mud:

Muds and muddy sediments occupy 21% of the floor of the Bay of Fundy. They occur along the northeast side of Fundy from Chignecto Bay to Grand Manan Island. On sub-bottom profiles, they are well stratified and acoustically transparent. Cores and grab samples indicate abundant ice-rafted cobbles and pebbles in upper Fundy muds. The mud province is presumed to be localized by the weaker tidal currents of the northeast side, and by the counter-clockwise pattern of residual tidal currents.

Suspended Sediment

General:

During the spring and summer of 1965, a detailed study of the suspended sediment system of the Bay of Fundy was undertaken by J. A. Miller (1966). Water samples were taken throughout the water column at both mid-flood and mid-ebb tides. A total of 263 water samples were taken. Bottom samples were taken at each sampling site. Sediment concentration was determined by filtering a one-litre sample of water, and weighing the residue on the filter.

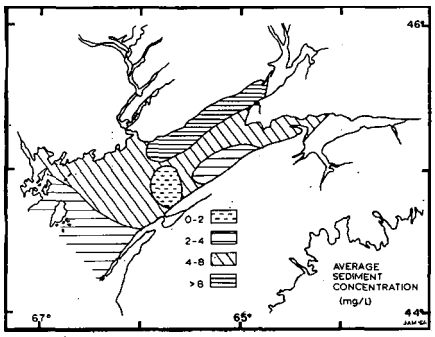

FIGURE 6 -
Suspended sediment concentration in the Bay of Fundy, averaged through the water column and through the tidal cycle.

Suspended Sediment Concentration:

Sediment concentration in milligrams per litre, averaged through the water column and through the tidal cycle, are shown in Fig. 6. Concentrations of greater than 8 mg/l occur along the northeast side. Concentrations under 4 mg/l occur locally on the south side; elsewhere intermediate concentrations exist. A comparison of mid-flood and mid-ebb concentration maps indicates that during the ebb, high-turbidity water (greater than 8 mg/l) from the head of the Bay moves south and west toward the Gulf of Maine, with the greatest advance occurring along the New Brunswick shore. High-turbidity water also appears to enter the Bay from the southwest side of St. John's Harbour.

During the flood tide, the distribution of turbidity is complex, with moderately turbid water (less than 4. 0 mg/l) forcing water of higher turbidity in north and eastward directions. High-turbidity water (greater than 8 mg/l) occurs as a band ten miles wide along the northwest shore, from Passamaquoddy Bay to the head of Chignecto Bay.

Suspended Sediment Composition:

The suspended sediment load is composed of sand, silt, clay, plankton, and organic debris; silt and organic debris are the major components. Organic carbon comprises 0. 3 to 2. 65 percent by weight of suspended materials. X-ray diffraction recordings indicate the presence of illite, halloysite, kaolinite, quartz, chlorite, feldspar, and calcite in suspended sediments, in that order of abundance.

The Suspended Sediment System:

The suspended sediment system in the Bay of Fundy is an open system. It consists of 4 components; 1) an oscillating body of turbid water, 2) a substrate that exchanges sediment with the overlying water mass, 3) minor fresh, turbid water input, and 4) minor turbid salt water output into the Gulf of Maine. The mud facies of the northwest shore is in a state of short-term near equilibrium with the overlying water mass. Grab sampling at slack tides at some stations within this facies revealed the presence of a layer of highly fluid mud a few centimetres thick that appeared to have settled out at that time. This material is resuspended as the tide begins to flow. On the south side of Fundy there is a long-term transfer of fine material, winnowed from the Quaternary bottom sediment, and incorporated in the suspended load. Much of this material is slowly restored to the Bay floor, on the aggrading mud facies of the northwest side. Calculations of residual current discharge, based on approximations, suggests that a lesser amount escapes into the Gulf of Maine.

Acknowledgements

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