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by Gordon B. Fader, Lewis H. King and Brian MacLean
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## MAP
(in pocket)


4011-G. Surficial geology: eastern Gulf of Maine and Bay of Fundy (1:300 000)

# SURFICIAL GEOLOGY OF THE EASTERN GULF OF MAINE AND BAY OF FUNDY

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## ABSTRACT

This study is based on the interpretation of echogram profiles, high resolution seismic reflection records, bottom dredge and grab samples, piston cores, bottom photographs, and adjacent land geology. The report is accompanied by Map 4011-G prepared at a scale of 1:300 000. Five sedimentary surficial units occur within the map-area and are continuous from the adjacent Scotian Shelf. The surficial sediments in the Gulf of Maine are mostly relict while those in the Bay of Fundy are presently undergoing change. The distribution and stratigraphic relationships of the surficial units were controlled to a large extent by late and post- glacio-isostatic and glacio-eustatic fluctuations.

## RÉSUMÉ

La présente étude est fondée sur l'interprétation de profils d'échogrammes, d'enregistrements de sismique-réflexion à haute résolution, d'échantillons de dragage et de prélèvements de fond, de carottes de marteau-perforateur, de photographies du fond et de la géologie des terrains adjacents. Le rapport est accompagné de la carte 4011-G établie à l'échelle de 1:300 000. La région cartographiée comprend cinq formations sédimentaires de surface se prolongeant depuis le plateau Scotian avoisinant. Les sédiments de surface dans le golfe du Maine sont généralement d'origine ancienne tandis que ceux de la baie de Fundy sont présentement en évolution. La répartition et les rapports stratigraphiques des formations de surface ont été influencés dans une large mesure par les fluctuations qui ont marqué et suivi les derniers mouvements glacio-eustatiques et glacio-isostatiques.

## INTRODUCTION

This report complements Map 4011-G (Surficial Geology: Eastern Gulf of Maine and Bay of Fundy), the westernmost and fourth in a series of maps describing the surficial geology of the Scotian Shelf and adjacent areas. The report includes brief sections on physiography, bedrock geology, and physical oceanography as well as a discussion of the possible applications of the map. Canadian Hydrographic Service Charts 4011, Approaches to Bay of Fundy, and 4010, Bay of Fundy, were used as bathymetric base maps in the interpretation of the surficial geology.

The Bay of Fundy and eastern Gulf of Maine area is unique for several reasons. The extreme tidal range in the Bay of Fundy, 16 m (52 ft) during spring tide, is one of the largest in the world. Strong tidal currents within the Bay of Fundy have modified the surficial sediments on the floor of the bay and scoured many restricted narrow passages within the area. Raised marine strandlines along the Fundy and Gulf of Maine shores attest to the postglacial emergence of the area, whereas along the southern coast of Nova Scotia the marine limit is represented by the present shoreline.

Burbank (1929) studied the petrology of the sediments in the map-area and concluded that there was a net movement of material out of the Bay of Fundy into the Gulf of Maine. The first map showing the distribution of the sediments (Hachey and Bailey 1952) was a compilation of data from the early Admiralty charts of the Bay of Fundy. From a study of the distribution of the sedimentary parameters in the Bay of Fundy, Forgeron (1962) concluded that changing oceanographic conditions were responsible for the present distribution of the sediments. Miller (1966) studied the

suspended sediment system and its relationship to the bottom sediments. The presence of till-like material overlain by possible outwash was recognized in the Bay of Fundy area by Swift and Lyall (1968a), who used continuous seismic reflection techniques. Ross (1970) studied the heavy mineral assemblages from Nova Scotia to New Jersey. The gravel occurrences in the Gulf of Maine were identified and studied by Schlee and Pratt (1970). Welsted (1971) discussed the morphology and evolution of the Bay of Fundy area. Pelletier and McMullen (1972) and Swift et al. (1973) recognized the distinct textural provinces on the floor of the Bay of Fundy from a study of bottom samples. Studies by Trumbull (1972) were concerned with the sand-sized fraction of bottom sediments from New Jersey to Nova Scotia. Schlee (1973) reported on the overall texture of the surficial material on the shelf and slope within the same area.

## METHODS

Echogram profiles were used extensively to identify the various sedimentary units; to trace their lateral extent and, where possible, their thickness; to define their stratigraphic relationships; and to study the morphology of the sea floor. Echograms collected by the Canadian Hydrographic Service for charting purposes, as well as those obtained on geological and geophysical cruises by the Atlantic Geoscience Centre, were interpreted using the methods described by King (1967a, b, 1970) for mapping the sediments of the Halifax–Sable Island area. As bathymetry of the base map is contoured in fathoms, both fathoms and meters will be used in discussions related to measurements on the sea floor.

In the Bay of Fundy the Hydrographic Service also collected bottom samples on a 4-km (2.5-mile) grid concurrent with their collection of acoustic data. A preliminary map delineating the surficial sediments of the eastern Gulf of Maine was made on the basis of echograms, and a sampling program was then laid out and executed in accordance with the sediment patterns established through the interpretation of the acoustic data. Analysis of these samples provides the textural evidence to correlate with the patterns established by the echograms. Additional echogram control was obtained between sample localities and tie lines were run between previous acoustic survey tracks. The bottom sample and acoustic control across the map-area are shown in Fig. 1.

Because the echograms provide continuous data, the surficial geology can be delineated with a degree of accuracy unattainable through the use of sample data alone. Samples can be taken where changes occur within sedimentary units, thereby reducing the total number of samples needed. Previous workers had been unable to delineate stratigraphic relationships between units, especially in the Bay of Fundy where variations in texture within single sedimentary units occur. Facies relations of the silt and clay units are well illustrated by the acoustic methods.

Echograms collected by the Hydrographic Service were run mainly at right angles to the adjacent shorelines. In the Bay of Fundy and southern approaches, the survey lines trend north–south while in the eastern Gulf of Maine the directions vary from east–west to northeast–southwest. Line spacings between echogram tracks are approximately 0.8 km (0.5 miles) or less. West of 67°20′ and south of 43°00′, Hydrographic echograms were not available. Echograms were collected in this area during geological and geophysical sampling cruises of the Atlantic Geoscience Centre on an 8-km (5-mile) grid.

Sediment samples were collected with a Van Veen grab sampler at stations located on the basis of acoustic data previously collected, and in areas where the morphology of the sea floor indicated a possible change in sediment type. Sample data were obtained from a report by Hathaway (1971) to verify our echogram interpretation south of 42°50′ and west of 66°40′.

All echograms collected within the survey area were obtained with a Kelvin Hughes 26B echo sounder. With a frequency of 14.25 kHz and a pulse length of 1 ms, this unit is particularly well suited to bottom sediment differentiation.

Continuous seismic reflection techniques provided data on the thickness of the unconsolidated sediments and on the nature of the unconformity between those sediments and the bedrock surface. A Bolt Associates Marine Profiler, Model 600, fitted with 1- and 10-cubic-inch chambers, was used to provide the acoustic energy.

In the Bay of Fundy, additional seismic data (Swift and Lyall unpublished data 1966), collected with a Huntec Mark 2A Hydrosonde sparker profiling system, was interpreted. In all, 35 500 km (22 000 miles) of echograms, 4840 km (3000 miles) of seismic reflection profiles, 800 bottom samples, 21 dredge samples, 5 piston cores, and 110 photographs were interpreted to describe the geology within the map-area (Map 4011-G).

## PHYSIOGRAPHY

Johnson (1925) suggested fluvial erosion followed by submergence along a southwesterly trending fault (Fundian Fault) as the process responsible for the origin of the Bay of Fundy. Supporting this view Koons (1941, 1942) believed that glacial erosion only slightly modified the preexisting drainage system. In contrast, Shepard (1930, 1942) and later Chadwick (1948, 1949) interpreted the morphology of the bay and gulf as mainly due to glacial erosion. Klein (1961) concluded that the bay was glaciated transversely and after a study of unpublished work by Take he suggested a Cretaceous or possibly Jurassic age for the fluvial origin of the bay. Malloy and Harbison (1966) conducted a hydrographic survey of the Gulf of Maine and collected seismic reflection and magnetic data concurrently. Studies by Uchupi (1966) and Tagg and Uchupi (1966) led to the delineation of the Triassic basin in the Gulf of Maine. Swift and Lyall (1968a) suggested a fluvial origin of the Bay of Fundy with later modification through glacial erosion and deposition.

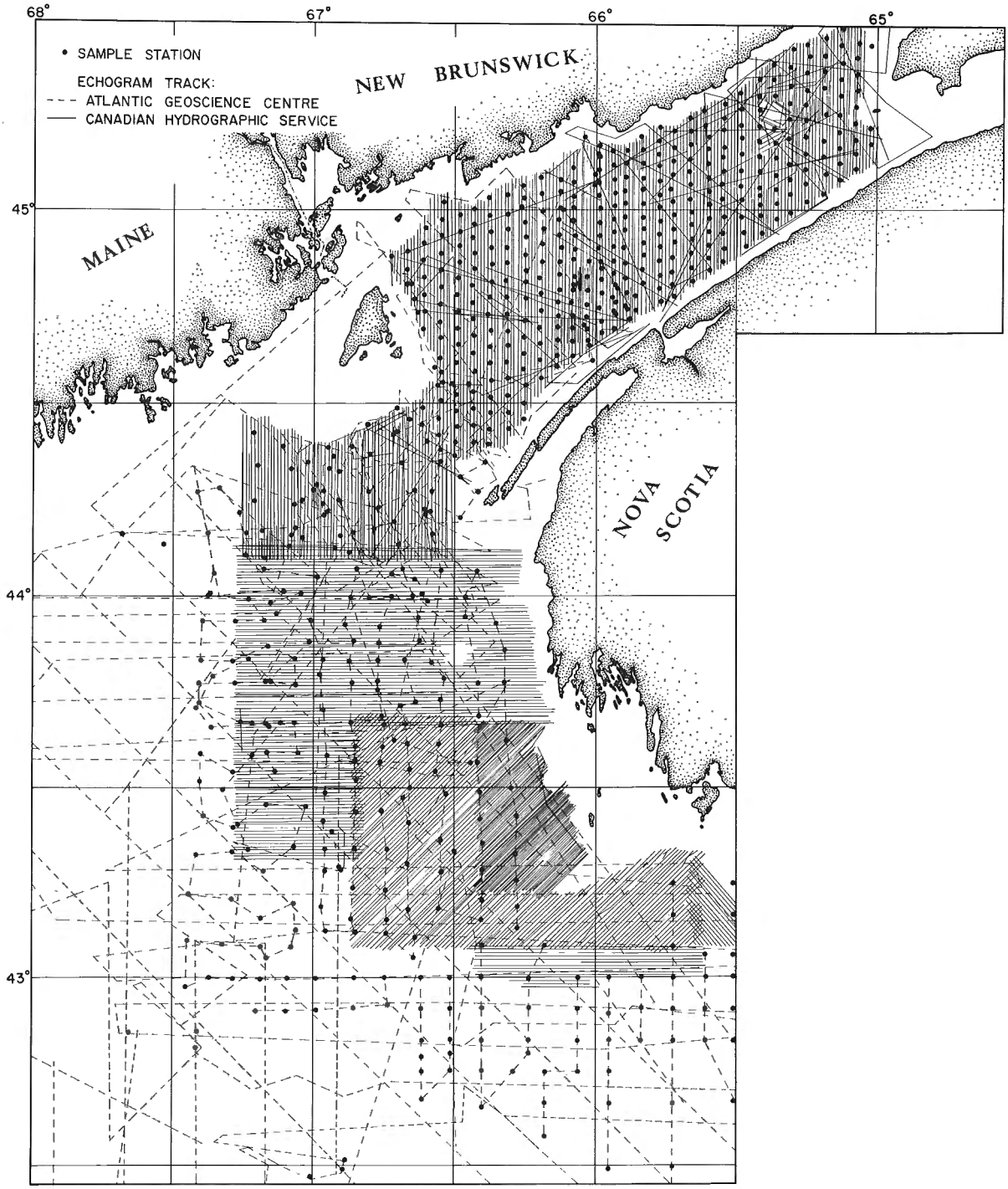


FIG. 1. Acoustic and bottom-sampling control across the eastern Gulf of Maine and Bay of Fundy map-area.

Within the map-area, three physiographic zones can be recognized, which are local elements of much larger geomorphic provinces in the maritime region (King 1972; Williams et al. 1972). These consist of a submerged upland bordering the coast of southwest Nova Scotia, a lowland comprising the Bay of Fundy and deeper parts of the Gulf of Maine, and an outer shelf consisting of broad flat banks and depressions developed on the coastal plain sediments.

The submerged upland zone is the offshore extension of the Atlantic Uplands geomorphic province (Williams et al. 1972), a low angle, southeastwardly sloping surface developed across resistant lithologies of granite, slate, quartzite, volcanics, schist, and gneiss. It encompasses an area bounded by the present shoreline and a line extending from the south shore of St. Mary's Bay, southwestward to Lurcher Shoal, southward to the westernmost tip of Browns Bank, and east-

ward along the northern boundary of the coastal plain sediments. This zone is 37 km (20 miles) wide west of Yarmouth and 93 km (50 miles) wide to the west of Cape Sable. North of Browns Bank the area is characterized by extremely rough topography, the surficial material is thin, and the bedrock surface exerts the dominant control on the topography. Where glacial material is present, it possesses a modified surface of sand and gravel. German Bank, with a minimum depth of 49 m (27 fath), is predominantly sand covered. Sand sometimes occurs as infilling between bedrock highs. Lurcher Shoal, lying 29 km (16 miles) west of Yarmouth, is an extensive shallow area with two shoal heads. The larger of these has a minimum depth of 2.1 m (1.1 fath) and consists of exposed bedrock mantled in part with large boulders.

The second major physiographic unit, a lowland, underlies the Bay of Fundy and deeper parts of the Gulf of Maine. It is part of a much larger geomorphic province, the Carboniferous–Triassic Lowlands (Williams et al. 1972). The Bay of Fundy is a linear feature 155 km (84 miles) long that tapers to 48 km (26 miles) wide at its northeastern end, where it bifurcates into Chignecto Bay and Minas Channel. The floor of the bay, although hummocky in detail, presents a gently dipping profile along its axis from northeast to southwest. Grand Manan Island and its adjacent southeastern offshore shoals ocupy nearly half the entrance to the bay, and divide it into two channels. Between Brier Island and Grand Manan Island lie several isolated depressions that together form Grand Manan Basin. The maximum water depth within these depressions is 233 m (127 fath) and the depth to the sill between the basins and the adjoining deeper parts of the Gulf of Maine is 160 m (88 fath).

The Gulf of Maine contains many broad isolated depressions typical of glaciated shelves. Uchupi (1965) studied these features and found they occupied 30% of the floor of the Gulf of Maine. Most of the depressions are isolated from each other by sills and have an irregular seaward gradient. Within the map-area, the largest depression is Jordan Basin with an area of more than 8000 km$^2$ (3100 square miles) and a maximum depth of 311 m (170 fath). Jordan Basin possesses a definite northeast–southwest trend. Seismic reflection profiles in the northern section of Jordan Basin indicate the presence of a series of bedrock channels that appear to be fluvial in origin. These preglacial channels are partially filled with glacial debris and fine muds, and their presence is evident in the bathymetry. This relationship illustrates the control exerted on the present morphology by preglacial erosion.

The Grand Manan Banks occur southwest of Grand Manan Island and are gravel-covered linear features 11 km (6 miles) long and approximately 3.7 km (2 miles) wide. Northeast and Southwest banks have a minimum depth of 35 m (19 fath) and 53 m (29 fath) respectively.

The remaining elements within this physiographic unit, Truxton Swell, Sewell Ridge, Crowell Basin, and northern Georges Basin, are oriented east–west. Crowell Basin, with an area of 1300 km$^2$ (501 square miles) and a maximum depth of 304 m (166 fath), is approximately 83 km (45 miles) long and 28 km (15 miles) wide. Sewell Ridge and the northern part of Georges Basin are underlain by the Fundian Moraine (King et al. 1972), an extension of an end-moraine complex on the Scotian Shelf. Truxton Swell is parallel to Sewell Ridge and tapers from 28 km (15 miles) in the west to 9 km (5 miles) at the eastern end. Its northern half is mantled with glacial debris, which thickens to the south. Although detailed seismic control over this feature is not available, the data suggest that Truxton Swell may in part represent a morainic ridge parallel to and north of the Fundian Moraine.

The third physiographic zone is represented by Browns Bank and Georges Basin, which are elements of the submerged Atlantic Coastal Plain geomorphic province (Williams et al. 1972). These landforms were developed during periods of subaerial erosion with later modification by glacial erosion and deposition (Uchupi 1965). Only the northern portion of Georges Basin is in the map-area. To the east it connects with Northeast Channel, 83 km (45 miles) long and 46 km (25 miles) wide, which breaches the outer banks on the continental shelf. Browns Bank is a shallow flat-topped area of low relief covered with relict lag deposits of gravel and clean, well-sorted sands. Local shallows of 29 m (16 fath) occur along the northern edge of the bank. Sand waves are abundant in the shallow areas where the hydrodynamic vigor is intense (Drapeau 1970).

The pre-Cretaceous evolution of the region is described by King (1972). The presence of Lower Cretaceous channel fillings (Stevenson 1959) along a drainage system within the Fundian lowland suggests an early beginning for the development of the lowland, in late Jurassic time or earlier. On the basis of the distribution of Tertiary outliers in the Gulf of Maine, large areas may have been covered with sediment and subsequently exhumed and modified through fluvial erosion during the Cretaceous and Tertiary periods (King 1972). Glacial modification transformed much of the landscape through local overdeepening and deposition of glacial debris. Details of the surficial geology will be discussed in later sections of this report.

## BEDROCK GEOLOGY

In this section the bedrock units found on the cross sections are described briefly and the nature of the intimate relationship between physiography and rock type is outlined (Table of Formations). King and MacLean (1976) mapped the bedrock geology within the map-area and this discussion is based on their study.

Notable among earlier studies in the Gulf of Maine and Bay of Fundy are the refraction work of Drake et al. (1954, 1959), the magnetic and seismic surveys by Malloy and Harbison (1966), studies of the bedrock geology of the Fundy embayment by Swift and Lyall (1968b), the work of Tagg and Uchupi (1966) in the northeastern Gulf of Maine,

the interpretations of gravity and magnetics by Kane et al. (1972), and more recently a synthesis by Ballard and Uchupi (1972). The bedrock geology is based on the interpretation of seismic reflection and refraction profiles, gravity and magnetic data, dredge and grab samples, published data on exploratory wells, and adjacent land geology.

The oldest rocks within the map-area are pre-Pennsylvanian in age (map-unit 1) and include deformed Cambro-

Table of Formations

| Era | Period or epoch | Map-unit | Lithology | Thickness (metres) |
|---|---|---|---|---|
| Cenozoic | Quaternary | Sable Island sand and gravel (11) *Time equivalent of map-unit 10.* | Clean, reddish-to-grayish brown, medium- to coarse-grained, well-sorted sand, grading laterally to coarse, angular-to-subrounded glacial lag gravels. | 0–20 (generally thin) |
| | | LaHave clay (10) *May in part be time equivalent of upper portions of map-units 8 and 9; mostly younger.* | Dark grayish brown to dark olive silty clay, grading locally to clayey silt and silty clayey sand. In Bay of Fundy can be older than uppermost Sambro sand, the latter time transgressive. In parts of bay LaHave clay mapped as subsurface unit underlying Sambro sand. | 0–70 |
| | | Sambro sand (9) *Time equivalent of map-unit 8.* | Dark grayish brown, fine- to coarse-grained, sublittoral silty and clayey sand, grading to sandy gravel or modified till. In Bay of Fundy consists of well-sorted sands grading to angular gravel. Because bay was not transgressed by Holocene sea due to isostatic depression of the area, and because of strong modern current regime, unit is time transgressive and upper part may overlie LaHave clay (see text). | 0–20 |
| | | Emerald silt (8) *Basal section in part a time equivalent of drift (7); otherwise younger.* | Dark grayish brown, fine-grained clayey and sandy silt, grading locally to silty and clayey sand with minor angular gravel; proglacial. | 0–55 |
| | | Scotian Shelf drift (7) | Dark grayish-to-reddish brown, poorly sorted, cohesive till; includes angular fragments of pebble- to boulder-sized material, sand-, silt-, and clay-sized sediments; occurs in morainal deposits, and may include some stratified drift. | 0–92 |
| | | | Unconformity | |
| | Tertiary and latest Cretaceous | (6) | Tertiary material identified from grab samples consists of light brown to pinkish gray mudstone with minor sandstone. | — |
| | | | Unconformity | |
| Mesozoic | Cretaceous | (5) | Nearby well samples consist of mudstone, siltstone, shale, sandstone, and limestone (Shell Canada Ltd. 1970). | — |
| | | | Unconformity | |
| | Jurassic | (4) | Nearby well samples consist of sandstone, shale and limestone, salt and dolomite (Shell Canada 1970). | — |
| | | | Unconformity | |
| | Triassic | (3) | Dredged samples consist of olive gray to red sandstones and tholeiitic basalt. | — |
| | | | Unconformity | |
| Paleozoic and Mesozoic | Pennsylvanian–Jurassic | (2) | Undifferentiated sedimentary rocks. | — |
| | | | Unconformity | |
| Paleozoic and older | Pre-Pennsylvanian | (1) | Acoustic basement (undifferentiated); includes Precambrian–Mississippian sedimentary, metasedimentary, volcanic, and intrusive rocks. Includes Meguma Group and Devonian granite as well as White Rock Formation. Locally may include some younger sedimentary and volcanic rocks. | |

Ordovician–Silurian sedimentary and volcanic rocks found on the adjacent land (Taylor 1969). This unit has been delineated on the basis of its hard undulating surface (acoustic basement), and appears on cross sections CD, EF, GH, and IJ of Map 4011-G (in pocket).

Most of the Gulf of Maine is underlain by undifferentiated pre-Pennsylvanian bedrock (acoustic basement). This forms the bedrock along the western edge of the map and underlies the southern half of Jordan Basin, Truxton Swell, Crowell Basin, and Sewell Ridge. To the south, it is onlapped by coastal plain sediments of Jurassic, Cretaceous, and Tertiary age, whereas in the northern Gulf of Maine it underlies the Acadian Triassic Basin.

A narrow graben (interpreted from seismic reflection and refraction data) containing undifferentiated Pennsylvanian–Jurassic sediment (map-unit 2) extends northeasterly from the western end of Sewell Ridge across the central area of Crowell Basin (cross section EF).

Triassic clastic rocks (map-unit 3) floor the Bay of Fundy in a synclinal structure. The axis of the structure trends along the central bathymetric axis of the bay (cross section AB and CD). These rocks extend into the Gulf of Maine in a series of linear troughs defined by pre-Pennsylvanian acoustic basement ridges (cross section CD).

The Mesozoic and Cenozoic section (cross section GH and IJ) within the map-area is a continuation of the coastal plain sediment that borders the coast from the Gulf of Mexico to New England. Southwest of Nova Scotia these strata lie on the folded Cambro-Ordovician and Devonian–Silurian rocks that extend seaward from the mainland. The section thickens rapidly seaward. Most of Georges Basin is underlain by inferred Jurassic strata (map-unit 4), which rest unconformably on the pre-Pennsylvanian acoustic basement. Browns Bank is underlain by Tertiary strata (map-unit 6), which lie unconformably upon Jurassic (map-unit 4), Cretaceous (map-unit 5), and pre-Pennsylvanian rocks within the map-area. No Cretaceous beds are exposed at the bedrock surface within the map-area. West of Yarmouth an outlier of probable Tertiary sediments unconformably overlies the Triassic rocks.

## PHYSICAL OCEANOGRAPHY

To fully understand the distribution of sediments within the Bay of Fundy it is necessary to consider the characteristics of the water mass within the bay and its approaches.

Twice daily, volumes of water in excess of 96 km$^3$ (Bowden 1962) move in and out of the Fundy embayment. The Atlantic Ocean tides that propagate through the Gulf of Maine into the Bay of Fundy increase in range. At the head of the Bay of Fundy the maximum range in elevation between high and low water is ±16 m (52 ft). The abnormally high tides are thought to be the result of near resonance between the semidiurnal tides and the natural oscillation of the water in the Bay of Fundy–Gulf of Maine system. Further amplification of tide heights occurs in the upper Bay of Fundy where rapid narrowing and shoaling take place. A difference of .46 m (1.5 ft) in tidal range occurs between the south and north shores of the Bay of Fundy with the higher range on the north side due to the counterclockwise circulation resulting from the effects of the Coriolis force. This force influences the residual circulation pattern in the Bay of Fundy.

The average tidal stream velocities in the Bay of Fundy range from 0.5 to 6 knots (Langford 1966). Figure 2 shows the tidal stream velocities at mid-depth and half-flood. Maximum velocities of the tidal streams occur at half-flood and half-ebb tide (Forrester 1958) and are homogeneous throughout the water column. These velocities are greatest on the south shore of the bay. In restricted narrow passages such as Minas Channel and Petite Passage velocities exceeding 9 knots have been reported. The residual currents, which are the net velocities after the short-term fluctuations have been removed, indicate a movement of water into the bay along the Nova Scotia side, a net movement out of the bay around Grand Manan Island, and a general cyclonic circulation within the bay. Godin (1968) analyzed data from a 1965 current survey in the Bay of Fundy and proposed a circulation pattern (Fig. 3) to fit spot observations. The system agrees with the circulation pattern interpreted by Bumpus and Lauzier (1965) from drift bottles released in the bay.

As will be further discussed in the succeeding sections of this paper, the distribution of the sediments on the floor of the inner Bay of Fundy and the adjacent raised marine deposits indicate that the physical hydrologic conditions have varied with time and are presently responsible for adjusting the distribution of the surficial materials toward a state of dynamic equilibrium.

## SURFICIAL GEOLOGY

The eastern Gulf of Maine and Bay of Fundy map-area overlaps the Yarmouth–Browns Bank map-area (Drapeau and King 1972). The latter adjoins the Halifax–Sable Island map-area to the east. King (1970) discussed the Quaternary history of the Scotian Shelf from his studies of

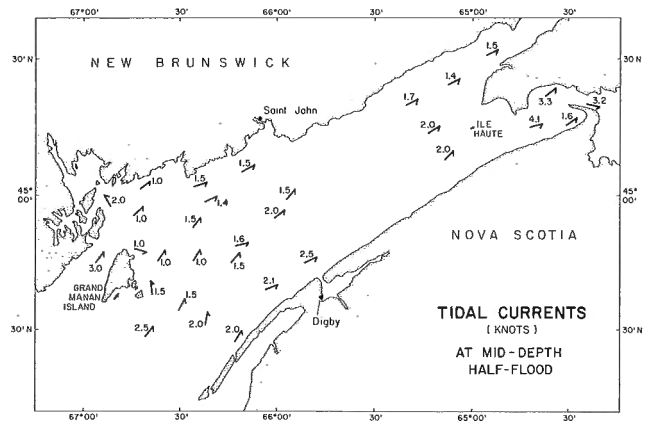


FIG. 2. Tidal stream velocities (knots) at mid-depth and half-flood tide (from Swift et al. 1973), Bay of Fundy.

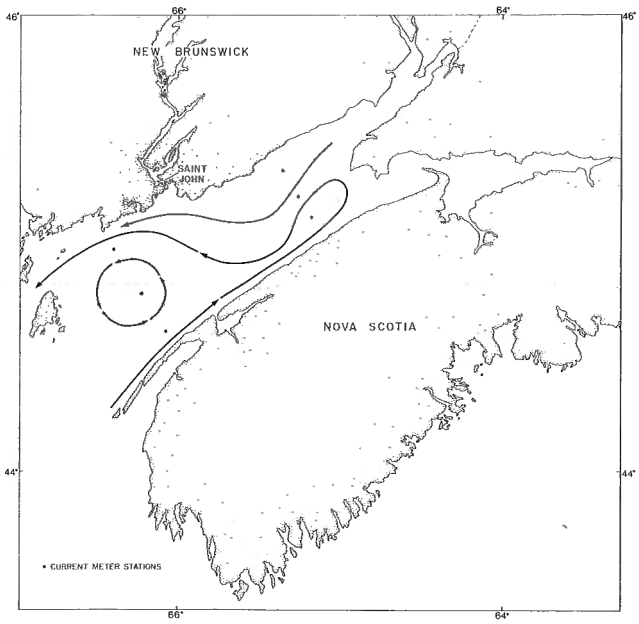


FIG. 3. Circulation pattern, Bay of Fundy, interpreted by Godin (1968) to fit spot observations. Note large gyre east of Grand Manan Island.

the sediments within the Halifax–Sable Island map-area. Essentially the same sedimentary units with minor textural variations are continuous from the Scotian Shelf. The differences that exist result from a complicated sequence of post-glacio-eustatic sea level and glacio-isostatic adjustments evidenced from raised strandlines on land, which combined to change the physical oceanographic characteristics within the map-area. The sediments on the Scotian Shelf and in the Gulf of Maine are mostly relict, whereas those in the Bay of Fundy are undergoing change. Knowing the late and post-glacio-eustatic sea level and glacio-isostatic changes from the onshore geology and adjacent submarine map-areas helped to establish the initial framework to define the geological units in the map-area. This framework will be discussed before the lithostratigraphy of the actual units.

### SEA LEVEL CHANGES

The lowest position of sea level prior to the Holocene transgression is critical to the distribution of the surficial sediments and their stratigraphic relationships. On the Scotian Shelf in the adjacent map-area, this position occurs at a constant depth of 115–120 m (63–65 fath) and is determined on the basis of (1) the terrace developed at 115–120 m (63–65 fath) below present sea level as indicated from a study of echogram profiles, (2) textural dissimilarities between the surficial sediments above and below this terrace, and (3) the presence of thick accumulations of glacial debris below, and its absence or modification above, the terrace.

In contrast to the Scotian Shelf, the terrace within the map-area is interpreted to decrease in depth to <37 m (20 fath). This interpretation is based on three observations:

1. The occurrence of thick accumulations of glacial till within the map-area at depths above the level of the terrace on the Scotian Shelf. From a study of seismic reflection profiles, glacial till occurs in decreasing depths from the Gulf of Maine to the Bay of Fundy. Thirty-seven metres (20 fath) is the shallowest depth at which the seismic profiles were run; hence, the till may occur in shallower depths.
2. Differences in the texture of the sediments above 115–120 m (63–65 fath) in the map-area from the texture of the sediments above the terrace on the Scotian Shelf. On the Scotian Shelf the glacial debris was reworked during the Holocene transgression above the terrace, removing the fine fractions and leaving well-sorted sands and lag deposits of gravel. In the map-area north of Browns Bank and continuing northward in the Bay of Fundy the percentage of silt and clay in the samples increases in depths shallower than 115–120 m (63–65 fath) indicating the presence of the terrace at shallower depths. The gravels on the floor of the Bay of Fundy well above 115–120 m (63–65 fath) are angular to subangular indicating that the material has not been transgressed, in contrast to the gravels above the terrace on the Scotian Shelf, which are well rounded.
3. The occurrence of soft angular fragments of Tertiary mudstone (G. Williams personal communication) in the eastern Gulf of Maine, which could not have survived reworking by a transgressing sea, are found at the sea floor in depths as shallow as 92 m (50 fath) overlying Tertiary beds in the subsurface. This indicates that the terrace occurs at a shallower depth in this area.

Several eustatic sea level curves have been postulated for the period of 20 000 years BP to the present; the major difference among them is in the time of maximum lowering of sea level, 19 000 years BP (Curray 1960), and 15 000 years BP (Milliman and Emery 1968) (Fig. 4). The amount of lowering of sea level appears to have been about 120–125 m. Eustatic sea level rose steadily until approximately 6000 years BP, when the rate slowed. The present position of the submarine terrace in the study area is controlled by the amount and rate of eustatic sea level change and glacio-isostatic rebound that occurred since its formation.

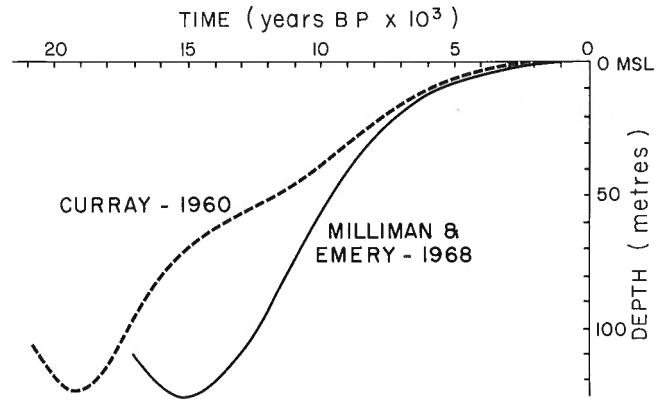


FIG. 4. Late Quaternary eustatic sea level curves.

Along the southwestern and southeastern shores of Nova Scotia no evidence exists for a postglacial marine limit higher than the present shoreline. The vertical distance between the Pleistocene terrace and the marine limit in this area is 115–120 m (63–65 fath) and closely approximates the maximum eustatic change. This suggests that either little glacio-isostatic rebound of the Scotian Shelf occurred during this period and that it was not depressed significantly under a weight of ice during the Wisconsin or that rebound was more or less complete before sea level began to rise. If the latter is true, the terrace was formed quickly after deglaciation and before the transgression which reworked much of the glacial debris between the present shoreline and the low terrace.

Studies by Goldthwait (1924), Goldthwait (1949), Hickox (1962), Bloom (1963), Swift and Borns (1967), Grant (1971), Gadd (1973), Schnitker (1974), and Stuvier and Borns (1975) indicate the occurrence of raised marine strandlines and marine deposits north of Yarmouth and along the south and north coasts of the Bay of Fundy and the Gulf of Maine. These features attest to the late glacial rebound of the land. In Nova Scotia the marine limit increases in elevation northward from the hinge line, which passes slightly north of Yarmouth and trends northeastward on land, parallel to the geographic axis of the Bay of Fundy. Along the Nova Scotian side of the Bay of Fundy the highest marine limit is 45 m (148 ft) above present sea level (Grant 1971). The only radiometric age determination on the marine limit of Nova Scotia is 14 100 ± 200 yr (G.S.C. — 1259), determined on intertidal seaweed from Gilbert Cove, north of Yarmouth, where the marine limit is 1 m above sea level (Grant 1971). The height of the marine limit in New Brunswick is 73 m (240 ft) above present sea level (Gadd 1973). A minimum age for this limit is 13 325 ± 500 yr BP (G.S.C. — 7). Figure 5 illustrates the relationship between sea level during the formation of the marine limit when the land was isostatically depressed, and the present sea level along a line of section from Saint John, N.B., to Digby, N.S. In central Maine the height of the marine limit is 135 m (443 ft) (Stuvier and Borns 1975) and is dated at 13 000 yr BP. In southern New Brunswick a date of 16 500 ± 370 yr BP (G.S.C. — 1063) on freshwater organic material north of the marine limit suggests an early deglaciation for the area (Gadd 1973). This discrepancy between the age of deglaciation in southern New Brunswick and in Maine

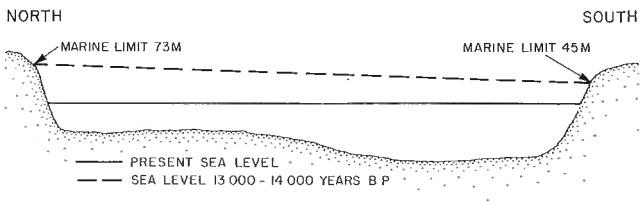


FIG. 5. Diagrammatic profile showing the relationship between present sea level and sea level during the formation of the marine limit in the Bay of Fundy between Saint John, N.B., and Digby, N.S.

presents difficulty in interpreting the postglacial history of the area; however, studies by Mott (1975) indicate the 16 500-yr date to be anomalously old when compared with pollen profiles from the area.

## POSTGLACIAL HISTORY

The determination of former sea levels is difficult because few data are available on the state of isostasy, and much of the record may have been eroded. Depending on the rate and amount of isostatic rebound that may have accompanied deglaciation, a regression or transgression would have resulted. The preservation of glacial till in depths of 37 m (20 fath) within the Bay of Fundy defines the depth limit which a regressive phase of sea level may have reached if rapid rebound accompanied the early deglaciation.

After 13 500 BP, when the marine limit was formed along the south coast of New Brunswick, rebound exceeded the rate of eustatic sea level rise, with a resulting emergence of the land. On the basis of Curray's (1960) sea level curve a minimum value can be calculated for the amount of crustal rebound in southern New Brunswick, most of which occurred during early postglacial time. It is the total of the present elevation of the marine limit, 73 m (240 ft), and the positive eustatic change in sea level from 13 500 years to the present, 55 m (180 ft), a total of 128 m (420 ft). On the basis of Milliman and Emery's (1968) eustatic sea level curve, the raised beaches were cut when eustatic sea level had risen from its lowest position by approximately 20 m (66 ft) (Fig. 4). Thus the further 95 m (312 ft) of eustatic sea level rise, and 73 m (240 ft) elevation of the present marine limit combine to indicate a minimum isostatic rebound of 168 m (551 ft) for the southern coast of New Brunswick.

If we apply the same reasoning to the south shore of the Bay of Fundy where the elevation of the marine limit is 45 m (148 ft), a minimum isostatic rebound is estimated at 100 m (328 ft) utilizing the sea level curve of Curray (1960), and 140 m (459 ft) according to that of Milliman and Emery (1968).

From a study of aggraded material in intertidal estuaries Grant (1971) estimated that sea level fell to a position 20–30 m (66–99 ft) below its present level on the south shore of the Bay of Fundy sometime after 13 000 BP because of rapid isostatic rebound of the area. Thus transgression may have modified the sediments in only the nearshore zone along the shores of the Bay of Fundy.

Refinement of the history of land and sea adjustments throughout the map-area is a complex problem. Much of the evidence that may have existed between the marine limit and the low terrace probably was removed by wave action during the transgression and regression that followed deglaciation. In some areas, as evidenced by the spotty occurrence of the marine limit on land, local ice centers may have protected the former shore zone, preventing the sea from

modifying the sediments and marking the marine limit. Changes in tidal ranges complicate measurement of the height of the marine limit and can create a false impression of transgression.

Previous workers (Miller 1966; Swift et al. 1969) have suggested subaerial deposition for the glacial till on the floor of the Bay of Fundy. Our studies indicate that the till was originally laid down as a submarine deposit beneath the ice and below sea level, in depths greater than 37 m (20 fath), and that the till probably has never been subaerially exposed. Interpretation of seismic data indicates a near-continuous sheet of unsorted glacial debris covering the floor of the bay. Seaward of the marine limit on land in southern New Brunswick, little till is present as it has been removed through undercutting by transgression and regression of the ancient beach zone. Marine deposits of silt and clay exist for the most part in protected preglacial river valleys (Gadd 1973, Map 12-1971). The presence of large amounts of till on the floor of the Bay of Fundy and the nature of the angular-to-subangular material covering the till suggest that the till has not been transgressed and exposed to the high energy of a beach zone.

The distribution of the glacial till and lag deposits of sand and gravel representing reworked glacial debris within the map-area indicates that the ice extended to the southern limits of the map-area. It is not known whether one or more ice sheets were responsible for the distribution of the glacial till.

Prior to 8000 BP Georges Bank and Browns Bank were emergent, effectively isolating the Gulf of Maine and Bay of Fundy from Atlantic tidal dynamics with a resultant small tidal range (Grant 1970). Early postglacial tidal ranges of

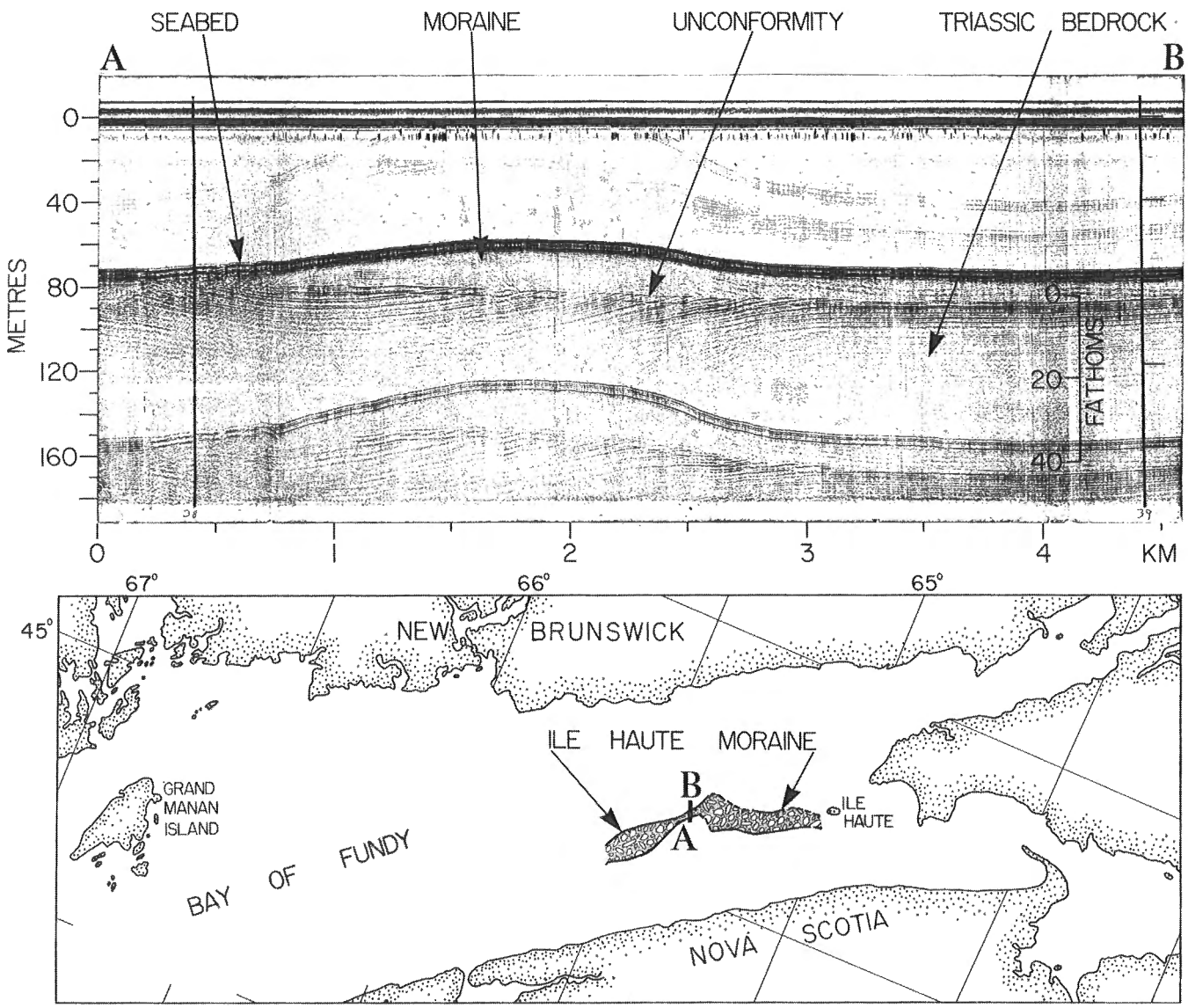


FIG. 6. Seismic profile across the Ile Haute Moraine, Bay of Fundy.

less than 2 m are interpreted from foreset beds deposited on the shores of the Bay of Fundy (Swift and Borns 1967). During this period fine sediments were being deposited on the glacial till in the Bay of Fundy as a result of reworking and erosion of the material in the emergent areas around the bay as rebound exceeded eustatic sea level rise. Tidal amplification commenced about 6000 years ago, accompanied by high tidal currents (Grant 1970). Coupled with the increased hydrodynamic vigor and the shoaling bottom of the Bay of Fundy, a change in sedimentation began. Modification of the surface of the till occurred, with the removal of the finer particles and a smoothing of the till profile due to infilling between local undulations with fine sand and gravel. Fine sands were redistributed and deposited over silt and clay pockets in some areas. Large areas of angular lag gravels developed and protected the underlying till from further erosion. Sand waves formed in localized fields as well as singly; these range in height from a few metres to more than 18 m (59 ft).

An end moraine complex is located on the Scotian Shelf more or less parallel to and 26–32 km (16–20 miles) seaward of the present coastline. Studies by King et al. (1972) indicate that the system extends along the northern edge of Browns Bank, westward across Sewell Ridge, and may link with the New England moraine system at Cape Cod. It has not been established whether the feature marks the southern limit of ice advance during the Wisconsin or is a recessional moraine. Swift and Lyall (1968a) described a crescent-shaped mound, believed to be a morainal segment, in the central Bay of Fundy. Subsequent investigations indicate it is part of a much larger feature, herein described as the Ile Haute Moraine, a linear ridge approximately 43 km (23 miles) long and parallel to the axis of the bay (Fig. 6). It is difficult to interpret the direction of ice movement from the configuration of the feature. It may represent a moraine that resulted from a northward advance of ice from a local center on Nova Scotia for which evidence exists on land (Hickox 1962).

### Surficial Lithologic Map-Units

All five sedimentary units recognized by King (1970) on the Scotian Shelf are represented within this map-area (Table of Formations) and are continuous from the Scotian Shelf. They comprise glacial debris, silt, sand, clay, and a sand and gravel unit. In the Gulf of Maine the silt and sand are in part contemporaneous proglacial deposits. The sand and gravel unit is limited to the transgressed areas above the Pleistocene low stand of sea level. Below the Pleistocene terrace, the glacial debris was modified by strong current action in the Bay of Fundy. The profile of the till surface has been smoothed by this effect. The winnowed fines have been transported by currents and deposited along the northern shores of the Bay of Fundy and east of Grand Manan Island. Some modification has also taken place at the entrance to the Bay of Fundy in isolated localities where topographic highs composed of till have been modified. Unlike the Gulf of Maine, where the sediment distributions are relict, the inner Bay of Fundy possesses very high current velocities that are continually adjusting the distribution of the sediments.

As a result of the postglacial isostatic rebound of the Bay of Fundy area, raised marine shore and basin deposits are now found on land. These materials are lateral equivalents of the surficial units that floor the Bay of Fundy and Gulf of Maine. The silts and clays that occur on land between the marine limit and present sea level are equivalents of the LaHave clay unit, and the sands and gravels are equivalents of the Sable Island sand and gravel unit.

*Scotian Shelf drift (map-unit 7)* — The Scotian Shelf drift is an informal term introduced by King (1970) to describe the material deposited by glaciers during the Pleistocene. It is a dark grayish-to-reddish brown, poorly sorted sediment, containing angular fragments of pebble–boulder sized material, and sand-, silt-, and clay-sized sediments in varying proportions. The average range for the median diameter of the till is 0.18–1.5 mm.

The sand-sized fraction within the till is composed of quartz and feldspar grains, rock fragments, and dark minerals. The fragments are angular to subangular and their surfaces are often rough with percussion marks and irregular conchoidal fractures. Many of the sand grains are iron stained, which indicates an origin from the Triassic sandstones of the Bay of Fundy area. In general, the glacial till in the map-area contains a higher percentage of sand-sized material than that on the Scotian Shelf. This may be a function of the lithology of the parent rock from which the till was derived. Plate 1 is a bottom photograph of the Scotian Shelf drift in the Gulf of Maine.

Striations and polished surfaces on many of the larger clasts within the till attest to the glacial transport of the material. The gravel fraction of the till is generally angular to subangular but some fragments are well rounded. The gravel material consists of fragments of sandstone, mudstone, metamorphic rocks, and basalt.

Glacial till is characterized by a rough and undulating surface with little or no penetration of the acoustic energy from the echo sounder as represented in Fig. 7, profile A, and from 9–14 km along profile D. In part the irregular surface of the glacial till may be the result of early postglacial iceberg furrowing but this cannot be determined without side-scan sonar profiling. The glacial till in the Gulf of Maine, as interpreted from seismic reflection profiles, does not possess any coherent internal reflectors. Frequently associated with the till are parabolic seismic displays, represented singly or in groups, resulting from point source reflectors, usually large boulders, incorporated in the till matrix.

In a trough more or less coincident with an area underlain by Triassic sediments, extending from between Brier Island and Grand Manan Island southwestward to 43° 30′, glacial till rests on a smooth bedrock surface (cross section AB, Map 4011-G, in pocket) and possesses very little relief on its surface. Areas of high relief are overlain by thin deposits of glacial debris, for example, Southwest and Northeast banks and an area south of Maine underlain by pre-Pennsylvanian rocks. Exceptions are to be found where morainic

ridges, isolated mounds, and infilled bedrock channels dominate the topography. The average thickness of the till varies according to the lithology of the underlying bedrock and its morphological configuration. In the Bay of Fundy the maximum thickness of glacial till, 73 m (240 ft), occurs in old fluvial bedrock channels. Commonly the thickness of the till ranges from 18–37 m (60–120 ft). The thickest deposits of glacial till in the Gulf of Maine are channel fillings approaching 130 m (426 ft) thick. Across low-lying Triassic clastic rocks the till averages 55 m (180 ft) thick while the till that is deposited on harder bedrock (acoustic basement) of high relief is thinner with an average range of 18–37 m (60–120 ft). Several isolated mounds of till southeast of Grand Manan Island (cross section AB, Map 4011-G, in

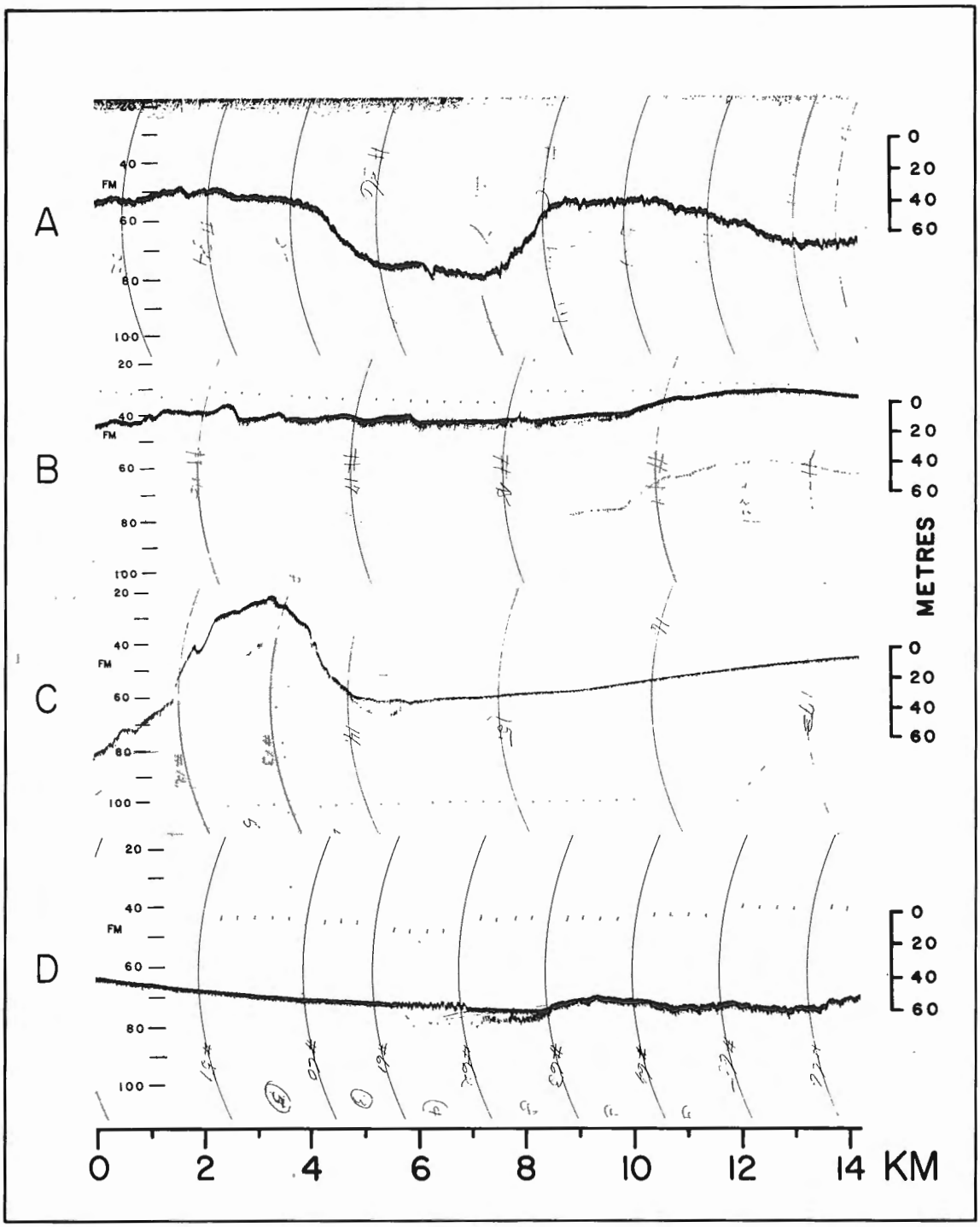


FIG. 7. Selected echogram profiles from the Gulf of Maine–Bay of Fundy map-area.

pocket) and in the central Gulf of Maine are nearly 92 m (300 ft) thick.

Glacial till grades laterally to modified till in areas close to the submarine terrace and in areas where strong currents have modified the till surface through removal of the surface fines. This boundary is difficult to establish. The sample data give an indication of the degree of modification of the till and reflect changes in the till surface that are undetected by acoustic information. However for purposes of mapping the distribution of modified vs. unmodified till, the interpretation was based mainly on the rough undulating surface of the till as interpreted from echograms and seismic data. Areas remote from the submarine terrace where modification of the till surface by modern currents occurs are confined to the inner Bay of Fundy and the area south of Grand Manan Island at the entrance to the bay.

An end moraine system on the Scotian Shelf is represented within the map-area by the Fundian Moraine (King et al. 1972), which occurs as a ridge north of Browns Bank extending westward across Sewell Ridge and the northern part of Georges Basin (cross sections EF, GH, and IJ, map 4011-G, in pocket). North of Browns Bank, because it is close to the Pleistocene terrace, its surface has been modified by removal of the surface fines; here the moraine is 7 km (4.4 miles) wide and 70 m (230 ft) high. It extends at least 110 km (68 miles) to the west, where it probably joins the New England Moraine at Cape Cod (King et al. 1972). It separates into two lobes 15 km (9.3 miles) wide west of Browns Bank and has a steep-sided northern flank as opposed to a gently sloped southern flank. Along most of its length it is exposed at the sea floor but in places it is mantled by a thin cover of Emerald silt and LaHave clay. A less pronounced ridge of till to the north of this feature may be an inner ridge of this moraine complex.

The Ile Haute Moraine, a subsurface feature in the south central Bay of Fundy, is 43 km (23 miles) long, and has a maximum thickness of 37 m (120 ft) (Fig. 6). It is a sinuous feature and its axis parallels that of the Bay of Fundy. Because it is a subsurface feature, it is not illustrated on Map 4011-G.

In the northeast section of the Bay of Fundy, Minas Channel, and in an area extending from Cape Chignecto to Ile Haute, thick deposits of stratified material overlie the unstratified glacial debris. Swift et al. (1973) traced the unit into the intertidal zone, examined it in outcrop, and interpreted the material as glaciofluvial outwash. This deposit has an average thickness of 37 m (120 ft) and may reach 64 m (210 ft) in thickness in channel deposits. The unit is characterized by the stratified nature of the material and the abundance of internal parabolic reflectors as interpreted from seismic reflection profiles.

*Emerald silt (map-unit 8)* — The Emerald silt is an informal term proposed by King (1970) for a proglacial silt unit. It is a dark grayish brown, fine-grained sediment composed of clayey and sandy silt (8a) which grades locally to a silty and clayey sand with minor angular gravel (8b). Plate 2 is a bottom photograph of Emerald silt from the Gulf of Maine.

Within the map-area the Emerald silt is confined to the outer Gulf of Maine where it is ponded between till ridges or lies in many small basins developed on the till surface (cross sections CD and EF, map 4011-G, in pocket). It is overlain by the LaHave clay in most of these depressions and can be easily distinguished from the clay unit because of the acoustic transparency of the clay as represented on the echograms in contrast to the silt. The major exposures are found in Crowell Basin and the northwestern part of Georges Basin where the maximum thickness is 55 m (180 ft). Where the Emerald silt overlies glacial till, it is easily distinguished from the till, which is characterized by a rough undulating surface not penetrated by the acoustic energy from the echo sounder. In contrast, where the silt unit occurs, the seabed possesses a smooth surface easily penetrated by the acoustic energy of the echo sounder but lacking the acoustic transparency of the clay. Stratification within the unit is sometimes evident.

Continuous seismic profiles indicate that the silt and till units are in part contemporaneous and that they interfinger laterally (King 1969). The boundary between the Emerald silt and the Sambro sand is determined on the basis of a hard smooth seabed for the sand, and an easily penetrated smooth seabed for the silt. The boundary is difficult to establish as it is gradational.

King (1970) interpreted the depositional history of the Emerald silt on the Scotian Shelf. He concluded that the silt was a proglacial unit that interfingered with the till and was deposited from floating ice and sediment-laden water in front of the ice sheet. The unit varies in texture and these variations were attributed to such factors as the dynamics of the tidal regime, topography of the sea floor, proximity of the ice front, and the nature of the littoral and sublittoral environments with respect to the Pleistocene shoreline. In several isolated areas where stratigraphic control is lacking and the unit is not overlain by LaHave clay, the interpretation of the silt unit is based on the textural and acoustic characteristics of the sediment. The sediment in these localities may represent a coarse facies of the LaHave clay and not the Emerald silt.

*Sambro sand (map-unit 9)* — The Sambro sand is an informal term proposed by King (1970) for a sand formation that in part overlies the Scotian Shelf drift and occurs below the submarine terrace. It is partly a lateral equivalent of the Emerald silt unit and is older than the Sable Island sand and gravel unit. King (1967a, b, 1970) related the occurrence of the sand unit to a submarine terrace developed at a depth of 115–120 m (63–65 fath) and concluded that the unit was deposited in the littoral zone adjacent to the old Pleistocene shoreline. In some areas the Sambro sand represents a modified glacial till surface and in these areas the gravel fraction is high. Because the Bay of Fundy and adjacent areas underwent postglacial isostatic adjustment, the present position of the Pleistocene terrace lies in shallower depths in these areas. Therefore the position of the

boundary between the Sable Island sand and gravel and the Sambro sand decreases from 115–120 m (63–65 fath) north of Browns Bank and on the Scotian Shelf, to < 37 m (20 fath) south of Brier Island, at the entrance to the Bay of Fundy.

The Sambro sand is a dark grayish brown, fine- to coarse-grained sediment containing silty and clayey sand with some gravel (Plate 3). It is designated 9a where the gravel content is less than 10% and 9b where the gravel content is greater than 10% (Plate 4). The seabed across this unit is hard, as indicated on the echograms by a wide return pulse from the sea floor, which is similar to the Sable Island sand and gravel unit but is differentiated on textural characteristics. The Sable Island sand and gravel unit generally does not contain any silt- and clay-sized sediment. Figure 7, Profile B (10–14 km), is an echogram across a Sambro sand deposit. The overall average median diameter for the Sambro sand is 0.2–2.0 mm.

The Sambro sand in the Bay of Fundy and approaches was formed as a result of increased current activity which occurred in late postglacial time and modified the surface of the glacial till. These strong currents were initiated when the sea covered the outer banks at the approaches to the Gulf of Maine as a result of eustatic sea level rise and created the necessary resonance in the Bay of Fundy that resulted in increased tidal heights. The Sambro sand in the Gulf of Maine and on the Scotian Shelf is a relict sediment. In contrast, the unit in the Bay of Fundy is presently undergoing modification. The Sambro sand in the Bay of Fundy is for the most part devoid of silt- and clay-sized material and locally consists of sand and angular lag gravels (Plate 4). A subsurface unit underlying the Sambro sand has been mapped in the Bay of Fundy. The unit represents undifferentiated pockets of LaHave clay that were deposited on the surface of the glacial debris and have subsequently been covered by Sambro sand. These subsurface deposits of sediment were protected from erosion in a high energy zone as they were very firm clays existing in depressions on the till surface. Therefore in the Bay of Fundy Sambro sand overlies LaHave clay, showing that the Sambro sand can be a time-transgressive deposit.

The sand generally is not thick enough to acoustically mask the underlying soft deposits. Delineating the lateral extent of these soft sediments is a function of the ability of the echo sounder to penetrate the overlying sand and for this reason the deposits may be more extensive than indicated on the map. The Sambro sand in the Bay of Fundy is characterized by extensive fields of sand waves, small ripple-like features, and isolated megaripples. These features possess many variations in their symmetry. They range in height from a few metres to 18 m (60 ft) with wavelengths as long as 183 m (600 ft). Sand waves are shown on the echograms in Fig. 7, Profile B (6–8 km) and D (5–7 km), as regular spikes on the seabed and their distribution is indicated on the map. Profile B (6–10 km) shows the more recent Sambro sand overlying a pocket of LaHave clay (map-unit 10). Here the Sambro sand is represented on the echogram by a wide acoustic pulse at the sea floor with small sand waves on its upper surface. The LaHave clay is represented by the acoustically transparent area below the seabed acoustic pulse and above a subsurface reflector (glacial till surface).

The Sambro sand usually occurs as a thin veneer a few metres thick overlying the glacial debris, but thickens locally to 20 m (66 ft). The width of the zone in which the Sambro sand occurs is dependent on the depth and slope of the sea floor. West of Yarmouth, where the shelf generally has a flat profile, the Sambro sand extends for 56 km (30 miles) seaward.

The Sambro sand unit encircles Browns Bank and extends northward from the northwestern tip of Browns Bank to Brier Island. Isolated patches of Sambro sand occur in the entrance to the Bay of Fundy and on localized topographic highs of glacial till. The boundary between the Sambro sand and the glacial till is difficult to establish in the areas where the Sambro sand formed as a result of modification of the till surface by modern currents. Varying degrees of modification of the glacial debris are evident on echograms. Unmodified till is represented on the echograms by a jagged, rough, undulating surface as illustrated on Profile A, Fig. 7. Till modification ranges from small-scale infilling between the local projections of the till surface to large-scale smoothing of the till profile as a result of winnowing of the surface fines and the development of protective lag gravels and sands.

*LaHave clay (map-unit 10)* — The LaHave clay is an informal name proposed by King (1970) for a formation that consists of a dark grayish brown to dark olive silty clay (10a) and clayey silt (10b), which overlies the Scotian Shelf drift and the Emerald silt and is a time equivalent of the Sable Island sand and gravel. In the present study area a coarser facies of the LaHave clay, containing more than 20% sand-sized material (Shepard 1954), is designated as map-unit 10c. The lower part of the clay section in the more central part of the basins may be contemporaneous with the Emerald silt and Sambro sand, especially on the flanks of the basins. The LaHave clay has an average median diameter of 0.003–0.06 mm. It is characterized on the echograms by its smooth featureless surface (Plate 5) and its acoustic transparency. The width of the acoustic pulse from the sea floor as portrayed on the echograms in areas where the LaHave clay forms the seabed is normally very narrow (Fig. 7, Profile C, 5–14 km).

The LaHave clay generally occurs in isolated basins or in depressions between topographic highs on the surface of the glacial debris. The unit floors northwest Georges Basin, Crowell Basin, most of Jordan Basin, and occurs as a wedge of sediment east of Grand Manan Island (cross sections AB, CD, and EF, Map 4011-G, in pocket). It overlies the Emerald silt in Georges and Crowell basins and part of Jordan Basin. Elsewhere in Jordan Basin the LaHave clay lies on the glacial debris. Ridges of till protrude in a northeast–southwest orientation through the clay within Jordan Basin. Numerous irregularly shaped, localized deposits of clay are distributed on the surface of the glacial till north of Truxton

Swell, but here a lack of sample control and the coarse facies of the clay unit make differentiation between the Emerald silt and the LaHave clay units difficult. The unit varies in thickness from a few metres to a maximum of 70 m (230 ft) in the southern part of Jordan Basin. South of Maine, over acoustic basement, isolated deposits of LaHave clay appear to lie unconformably on the bedrock surface.

Foraminiferal tests constitute a large percentage of the sand-sized fraction of the clay unit in the Gulf of Maine and form as much as 60% in Jordan Basin. Other organic debris consists of sponge spicules, diatoms, radiolaria, and fecal pellets. Numerous rod-shaped cylinders 1–2 cm long and 0.2 cm diam. were found in several of the grab samples in Jordan Basin. These appear to be either internal molds or casts of organisms, tubes, or fecal matter that have been replaced by forms of pyrite. An examination by scanning electron microscope reveals possible marcasite rosettes against a background of octahedral crystals. X-ray diffractometer analysis indicates the material to be pyrite. Trumbull (1972) found and studied similar rod-shaped particles in the Wilkinson-Murray Basin of the western Gulf of Maine.

The LaHave clay in the Gulf of Maine was derived by the winnowing of silt and clay from the glacial debris on the banks and shallow area during the transgression of the sea and by the deposition of silt- and clay-sized material from late glacial and present-day rivers and streams that terminate in the Gulf of Maine. Material is also being deposited in these low-lying areas as a result of redistribution of sediments by storm waves and currents acting on the shallower parts of the shelf.

The acoustic and textural characteristics of the LaHave clay in the Bay of Fundy differ slightly from those of the unit in the Gulf of Maine and on the Scotian Shelf. The largest deposit of LaHave clay within the Bay of Fundy lies to the east and northeast of Grand Manan Island. The width of the acoustic pulse from the sea floor, as represented on the echograms, varies across the deposit from west to east, and differs from the typical narrow sea floor pulse from other deposits in the Gulf of Maine. Figure 7, profile C (5–14 km), is an example of an echogram across the western portion of the deposit where an analysis of material in grab samples indicates a silty clay bottom. The acoustic pulse from the sea floor as represented on the echogram is much wider than the pulse received from the LaHave clay on the Scotian Shelf. These sediments in the Bay of Fundy are compacted to a greater degree than LaHave clay in the Gulf of Maine and Scotian Shelf. Figure 7, Profile D (0–8 km), is an example of an echogram across the eastern portion of the deposit. The return pulse from the sea floor as represented on the echogram is much wider, and grab samples from this area contained silty sand. These localized deposits of sand-sized material represent time-transgressive deposits of Sambro sand but were not mapped as such because of their very limited areal extent. In the inner Bay of Fundy subsurface deposits of LaHave clay underlie uppermost Sambro sand. The underlying pockets of clay have been mapped as subsurface deposits.

Northeast of Grand Manan Island, several isolated areas within the LaHave clay unit contain a strong reflecting horizon at a depth of 9 m (30 ft). This horizon possesses a smooth surface and tends to acoustically mask the underlying sediments (Fig. 8). We interpret this horizon to represent a gas-charged sediment, which may result from an accumulation of peat or a concentration of organic debris at depth.

The deposits of LaHave clay within the Bay of Fundy for the most part coincide with an area of comparatively low current velocities. Forgeron (1962) referred to the

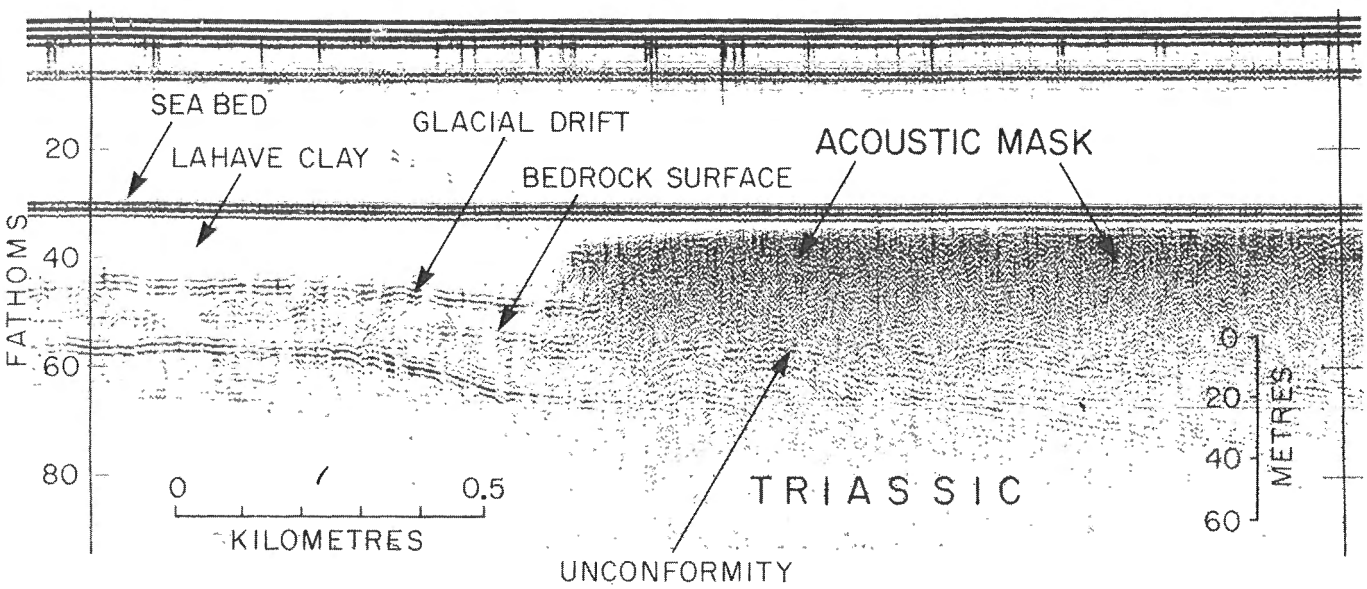


FIG. 8. Seismic profile northeast of Grand Manan Island, Bay of Fundy. Acoustic mask occurs within the LaHave clay unit and tends to obscure the underlying deposits.

deposit of LaHave clay to the east and northeast of Grand Manan Island as the Saint John Delta. We feel that this is a misnomer as it implies that the source of the material is the Saint John River alone. Although the river plays an active role in supplying sediment to the system, volumetric analysis indicates that most of the material in the deposit was more likely derived from the winnowing of glacial till on the floor of the Bay of Fundy. This sediment was transported to the area by the circulation pattern. Two piston cores taken east of Grand Manan Island penetrated 12 m (40 ft) of soft silty clay that was homogeneous throughout the section.

*Sable Island sand and gravel (map-unit 11)* — The Sable Island sand and gravel is an informal name proposed by King (1970) for a sand and gravel formation overlying the Scotian Shelf drift and contemporaneous with the LaHave clay unit. It occurs above the depth of the Pleistocene submarine terrace at 115–120 m (63–65 fath) across the inner shelf and shallow outer banks. The unit varies in thickness from a few metres to 15–20 m (50-66 ft).

The Sable Island sand and gravel unit consists of clean reddish-to-grayish brown, medium- to coarse-grained, very well-sorted sand, which grades laterally to coarse gravel with well-rounded boulders. Locally bedrock may be exposed as ridges of upturned strata or projections through the sand and gravel. The unit is divided into two members: 11a, sand with less than 50% gravel (Plate 6), and 11b, gravel with less than 50% sand. Unlike the Sambro sand unit the Sable Island sand and gravel unit contains less than 3% silt- and clay-sized sediment.

Acoustically, the unit is represented on the echograms as a wide return pulse from the sea floor. Where the unit is dominantly sand, the seabed is generally flat with little relief; however, gravel bottoms, especially on the outer banks, may also have a smooth profile. Examination of continuous seismic reflection profiles confirms that areas of high relief at the sea floor are controlled by the morphology of the underlying bedrock surface.

During the development of the Sable Island sand and gravel unit, most of the glacial debris was reworked from above the terrace by removal of the silt- and clay-sized material by the transgressing sea. Some redeposition and adjustment of the sediments is still occurring in shallow areas where currents are strong and storm waves affect the sediments. A survey on Browns Bank by Drapeau (1970) has shown the existence of sand waves and megaripples and that sand in the shallower areas of the bank is in sheet transport.

The gravel-sized material in the Sable Island sand and gravel unit is derived from the reworking of glacial debris, much of which was transported from the land areas. The gravel fraction consists of fragments of granite, volcanic, and metamorphic (mostly schist) rocks. Softer sedimentary rocks are generally absent within this unit but they do occur within the glacial till suggesting that the softer rocks were destroyed in the transgressing beach zone. On the inner shelf southwest of Nova Scotia granitic rock fragments dominate the lithology of the gravel-sized fraction.

## APPLICATIONS

The map can serve as a basis for future biological and geological studies in the eastern Gulf of Maine and Bay of Fundy.

It affords the physical oceanographer an opportunity to study the relationship between tides and currents and their effect on the distribution of the surficial sediments, especially in the Bay of Fundy. In view of possible tidal power development in the Fundy region, an understanding of the nature of the surficial materials adjacent to potential sites is essential to preliminary investigations.

A detailed description of surficial sediments is necessary to understand the relationships between the community of benthonic fauna and bottom sediment type. These relationships are directly related to commercial fisheries.

The map and report are particularly useful for engineering studies. In determining route selections for submarine cables and pipelines, the map can provide important preliminary information. Data pertinent to the anchoring of drilling platforms and mining barges can be found on the map. It may also serve as a basic guide in delineating the distribution of possible economic sand and gravel deposits that could be used as aggregate or might contain marine placer deposits.

The amount of sand and gravel within the map-area is difficult to determine because of the lack of data on the thickness of these deposits and vertical variability in their textural characteristics. A program of high resolution seismic reflection profiling and vibracore sampling would be necessary in order to accurately assess the amount of sand and gravel. The gravel deposits within the map-area are patchy and most are thought to be thin lag deposits. The Sable Island sand (map-unit 11a) occurs over an area of 2280 $km^2$ (880 square miles). Assuming an average thickness of 2.7 m (9 ft) for this unit, as much as 6.2 billion $m^3$ (8.1 billion cubic yards) or 10.4 billion tonnes (11.5 billion tons) of sand could be present. Sambro sand (map-unit 9a) contains varying amounts of silt and clay that could render it undesirable as a construction material. However in the Bay of Fundy fine material is absent from the unit. The Sambro sand deposit in the Bay of Fundy contains 0.6 billion $m^3$ (0.8 billion cubic yards) or 1.1 billion tonnes (1.2 billion tons) of sand if an average thickness of about 1.2 m (4 ft) and an areal distribution of 518 $km^2$ (200 square miles) is assumed.

The following section is included to describe the degree of roughness of the bottom as an aid to those engaged in fishing operations within the map-area.

Mud bottoms represented by map-units 8 (Emerald silt) and 10 (LaHave clay) are generally smooth and flat. In areas where units 8 and 10 are thin and overlie the till, which possesses an irregular surface, the bottom is a smooth gently undulating surface.

Sand bottoms are represented by map-unit 11a (sandy part of the Sable Island sand and gravel unit) and are generally flat and smooth. Bottoms of unit 9a (sandy part

of the Sambro sand) range from smooth to very hummocky where the unit forms a thin cover over the glacial till. Sand waves occur singly and in fields on the shallow parts of Browns Bank and in the Bay of Fundy.

Gravel bottoms within the Sable Island sand and gravel, unit 11b, may be flat with well-sorted material, as across the eastern part of Browns Bank, or they may be undulating, including very large boulders or sometimes jagged, as on the inner shelf north of Browns Bank. Bedrock is often very close to the sea floor on the inner shelf off southwestern Nova Scotia and sometimes outcrops at the sea floor. Gravel bottoms within the Sambro sand unit (map-unit 9b) are generally smooth and scattered with pebbles, cobbles, and large boulders. Closer to the unmodified glacial till, the surface becomes more hummocky.

Glacial till (map-unit 7) is a mixture of clay, silt, sand, and gravel in varying proportions. It possesses a rough undulating surface that would probably be unsuitable for most near-bottom fishing operations.

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We thank the Canadian Hydrographic Service for making available echograms and samples collected in the Bay of Fundy during its field program; the late Captain W. J. Vieau, Captain F. W. Mauger, Captain M. J. Wagner, Captain D. W. Butler, and the ships' companies of CSS *Kapuskasing*, CS *Dawson*, and CSS *Hudson* for their cooperation. We also thank D. Clattenburg for laboratory analysis of the samples; V. Coady, H. Josenhans, and M. Gorveatt for technical assistance at sea; T. Lambert for identification of marine benthos on bottom photographs; R. O. Miller and J. Lord for drafting assistance; and R. H. Fillon, Atlantic Geoscience Centre, N. R. Gadd, Geological Survey of Canada, and M. P. Latremouille, Atlantic Oceanographic Laboratory, for critical review of the manuscript.

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PLATE 1. Bottom photograph of the Scotian Shelf drift (map-unit 7). The glacial till consists of a mixture of angular fragments of pebble–boulder-sized material in a matrix of sand and mud. Numerous brachiopods (*Terebratulina septentrionalis*) can be seen in the upper half of the photograph as can several brittle starfish (Ophiuroidea). In the lower left corner a chiton (Polyplacophora) is on a large boulder and to its right is a small starfish (Asteroidea). The underwater current vane and compass indicate bottom current direction. Taken on Sewell Ridge at 42°49.5′N, 67°24′W at a depth of 194 m (106 fath).

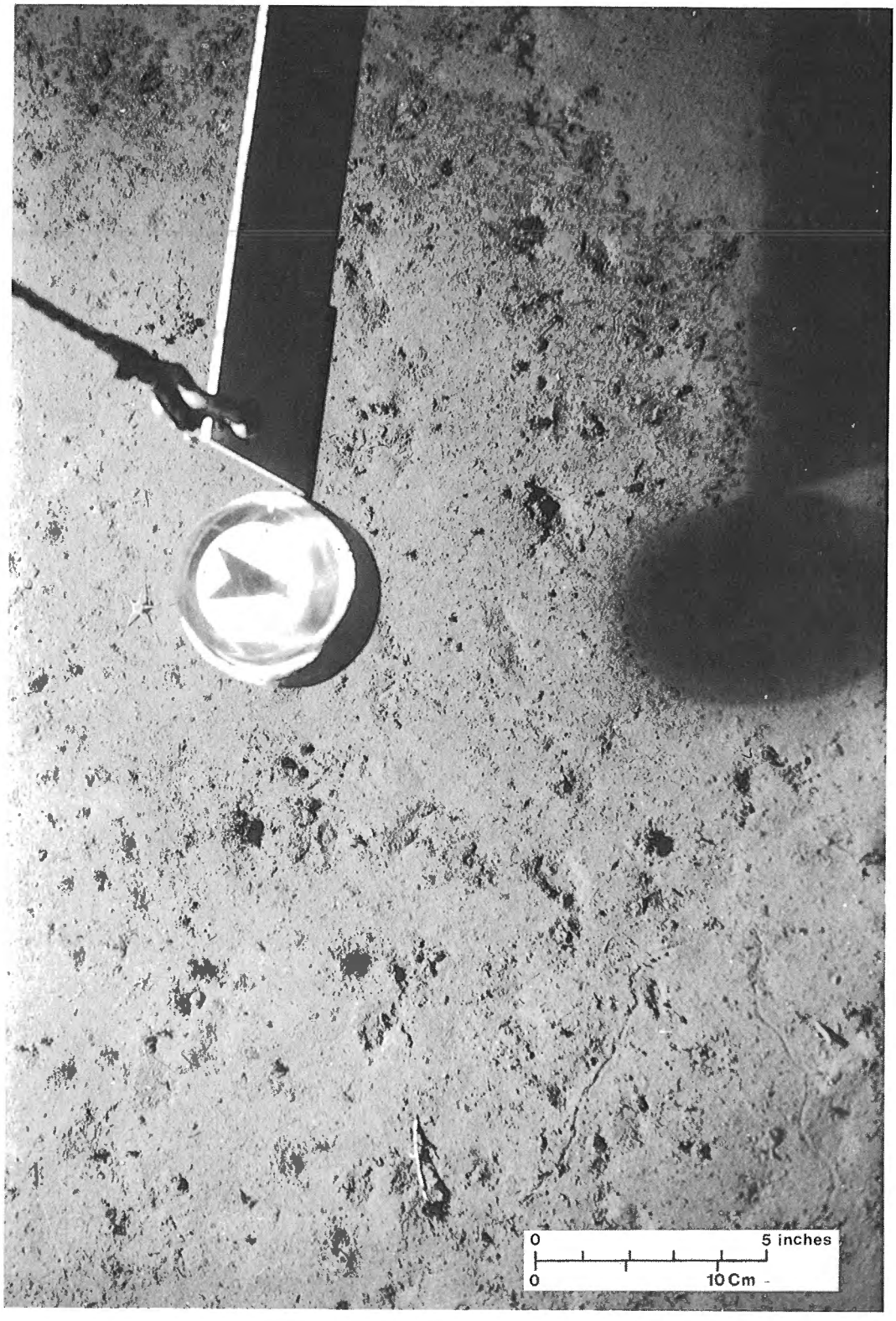


PLATE 2. Bottom photograph of the Emerald silt (map-unit 8), a soft mud bottom similar in appearance to the LaHave clay bottom (Plate 5). Several brittle starfish (Ophiuroidea), tracks and holes of burrowing organisms, and probable tubes of polychaete worms are visible. Taken in Crowell Basin, 42°51′N, 67°39.3′W, at a depth of 220 m (120 fath).

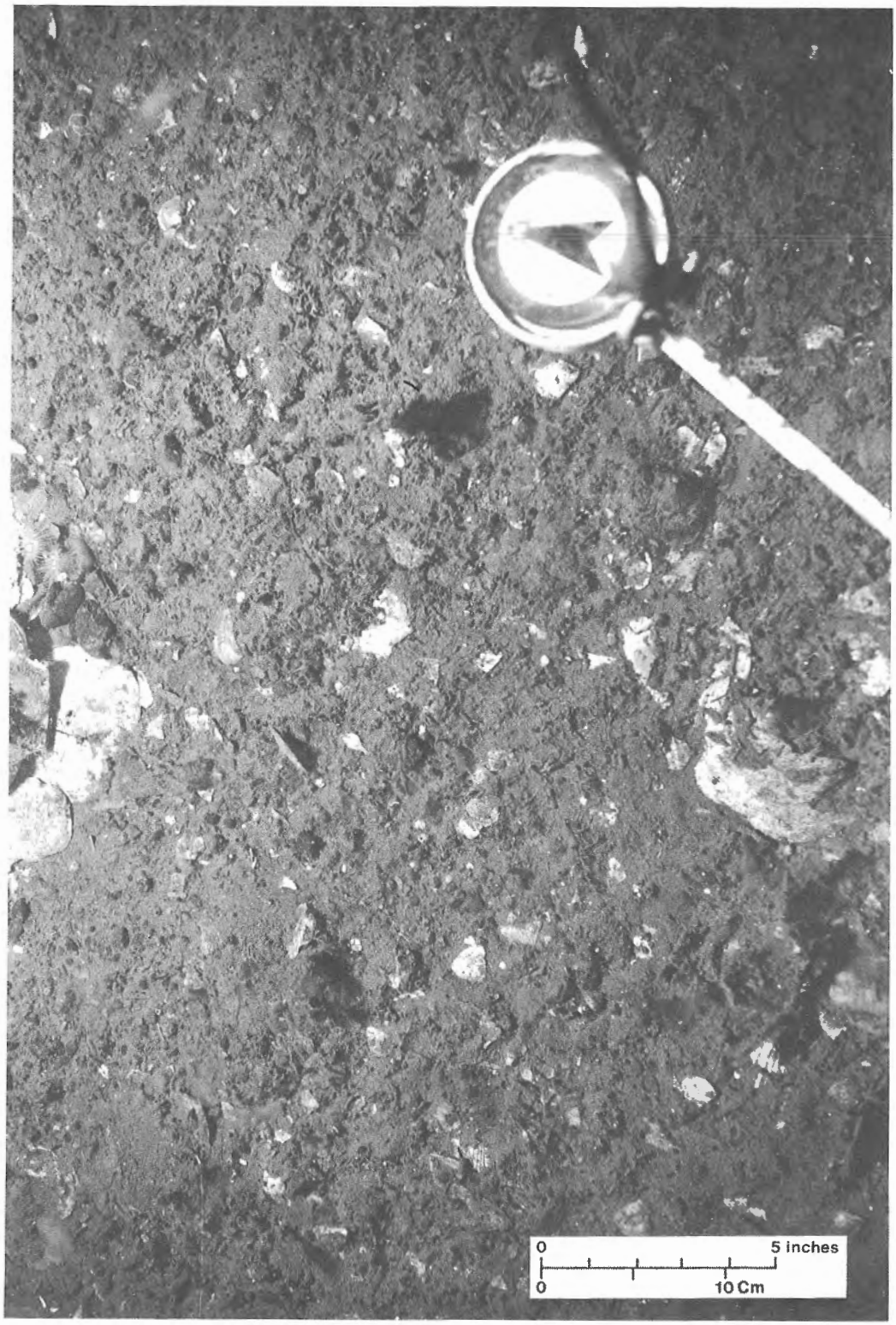


PLATE 3. Bottom photograph of the Sambro sand (map-unit 9a) in the Gulf of Maine: muddy sand, covered with much organic material and shell debris. In left center a scallop (*Placopecten*) appears to be resting on broken shells of the same. Probable burrowing anemones are found beside the scallop shell. Numerous siphon tips indicate presence of live clams and other tube-dwelling organisms below surface. Taken southwest of Brier Island, 44°0.5′N, 66°37′W, at a depth of 128 m (70 fath).

PLATE 4. Bottom photograph of the Sambro sand (map-unit 9b) (gravel facies), a modified glacial till surface composed of a lag deposit of angular to subrounded gravels with a matrix of muddy sand and pebbles. Shell debris consists of broken bivalve mollusc shells. Several horse mussels (*Modiolus*) are in the central area of the photograph. Taken west of Brier Island at the entrance to the Bay of Fundy, 44°13.5′N, 66°00.0′W, at a depth of 73 m (40 fath).

PLATE 5. Bottom photograph of the LaHave clay (map-unit 10), soft mud bottom with some organic debris similar to the Emerald silt bottom (Plate 2). Several brittle starfish (Ophiuroidea) are almost covered in the clay, and holes of burrowing organisms are scattered across the photograph. Taken in northern Jordan Basin, 44°09′N, 67°33.6′W, at a depth of 201 m (110 fath).

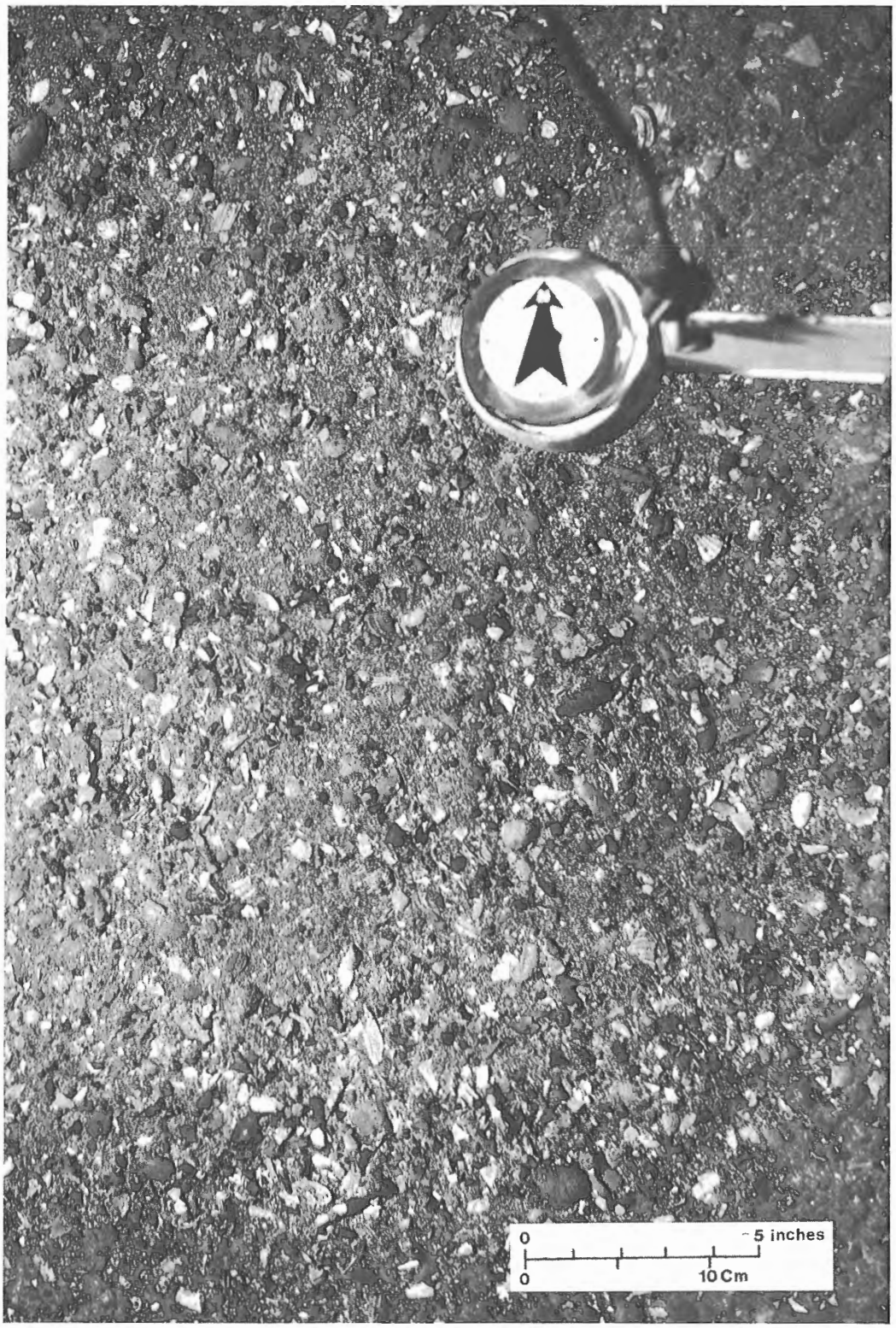


PLATE 6. Bottom photograph of the Sable Island sand and gravel (map-unit 11a), well-sorted sand- and pebble-sized material. Much debris of broken bivalve mollusc shell, small scallops (*Aequipecten*), horse mussels (*Modiolus*), clams (*Mya*), slipper shells (*Crepidula fornicata*), small cockles and gastropods, small sand dollars (*Echinarachnius*), and horizontal worm tubes is present. Taken on German Bank, 43°19′N, 66°28′W, at a depth of 48 m (26 fath).