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surficial geology of the laurentian channel and the western grand banks of newfoundland

by Gordon B. Fader, Lewis H. King, and Heiner W. Josenhans
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ABSTRACT

Five surficial formations are identified on the basis of high resolution seismic reflection profiles, side-scan sonograms, echo sounder data, seabed grab samples, piston cores, and bottom photographs: Scotian Shelf–Newfoundland Shelf Drift, Emerald Silt, Sambro Sand, LaHave Clay, and Sable Island Sand and Gravel. Scotian Shelf–Newfoundland Shelf Drift is a poorly sorted till occurring at the base of the surficial succession, and has been deposited beneath a grounded ice sheet that advanced across the continental shelf. An end moraine complex occurs south of Cape Breton Island on the Scotian Shelf and south of the Burin Peninsula, on the western Grand Banks of Newfoundland. It is the easternmost extension of a submarine end moraine system on the Scotian Shelf. Emerald Silt is a proglacial muddy sediment deposited from floating ice and is interbedded with the till at the distal side of the moraines. Sambro Sand is a sublittoral muddy sand developed below a Late Pleistocene sea-level terrace at 115 m. It is formed by reworking of the till and proglacial sediments. LaHave Clay is a homogeneous marine mud deposited in the basins and depressions on the shelf. The material was derived from reworking the sediment on the bank and inner shelf areas during the Late Pleistocene–Holocene transgression. Sable Island Sand and Gravel is a transgressive deposit formed by erosion of till and proglacial sediment in depths less than the 115-m depth of the Late Pleistocene terrace. The distribution and stratigraphic relationships of the surficial formations were controlled by an advance of the continental ice sheet across the shelf together with late and postglacial isostatic and eustatic fluctuations. The sediment distributions are mostly relict except in the shallow areas where some reworking of Sable Island Sand and Gravel occurs in response to the modern hydrodynamic regime. All surficial formations have been scoured by grounded icebergs unlike the Scotian Shelf where iceberg furrows are confined to till surfaces.

RÉSUMÉ

Cinq formations superficielles sont identifiées sur la base de profils séismiques réflexion à haute résolution, de sonographes à balayage latéral, de données d'échosondeur, d'échantillons prélevés sur les fonds marins, de carottages par piston et de photographies du fond: le Scotian Shelf–Newfoundland Shelf Drift, l'Emerald Silt, le Sambro Sand, la LaHave Clay et le Sable Island Sand and Gravel. La première est un till mal trié se trouvant à la base de la succession superficielle; elle s'est formée sous une nappe glaciaire échouée qui s'est avancée à travers le plateau continental. Un complexe de moraine terminale se trouve au sud de l'île du Cap-Breton sur le plateau continental Scotian et au sud de la péninsule Burin, sur la partie ouest du Grand banc de Terre-Neuve. Il s'agit de l'extension la plus orientale d'un système sous-marin de moraine terminale sur le plateau continental Scotian. La deuxième se compose de sédiments boueux pro-glaciaires qui se sont déposés à partir de la glace flottante et qui sont interstratifiés avec le till à la face distale des moraines. La troisième est un sable boueux sublittoral qui s'est formé sous une terrasse située à 115 m de profondeur, qui se trouvait au niveau de la mer à la fin du pléistocène. Elle est le résultat d'un remodelage du till et des sédiments pro-glaciaires. La quatrième se compose de boues marines homogènes qui se sont déposées dans les bassins et les dépressions du plateau. Les matériaux proviennent du remodelage des sédiments sur le rivage et les zones intérieures du plateau pendant la transgression qui a eu lieu à la fin du pléistocène et au début du holocène. La cinquième est un dépôt de transgression formé par érosion du till et des sédiments pro-glaciaires au-dessus de 115 m, profondeur de la terrasse de la fin du pléistocène. La distribution et les relations stratigraphiques des formations superficielles étaient régies par une avance de la nappe glaciaire continentale à travers le plateau ainsi que par des fluctuations isostatiques et eustatiques ultérieures et post-glaciaires. La répartition des sédiments correspond essentiellement à des reliefs-reliques sauf dans les zones peu profondes où la formation de Sable Island Sand and Gravel a été quelque peu remaniée sous l'effet du régime hydrodynamique de l'ère moderne. Toutes les formations superficielles ont été décapées par des icebergs échoués, au contraire du plateau continental Scotian où seules les surfaces du till comprennent des sillons creusés par les icebergs.

SURFICIAL GEOLOGY OF THE LAURENTIAN CHANNEL AND THE WESTERN GRAND BANKS OF NEWFOUNDLAND

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INTRODUCTION

Map 4015-G (Surficial Geology: Laurentian Channel and western Grand Banks of Newfoundland) accompanies this report, the easternmost and sixth in a series describing the surficial geology of the southeastern Canadian continental shelf. These regional geological studies have been conducted on a systematic basis. Canadian Hydrographic Charts 4015 (Sydney to St. Pierre), 4041 (Banquereau and Misaine Bank), 4016 (St. Pierre to St. John's), and 8009 (St. Pierre Bank to Whale Bank), were used as bathymetric base maps in the compilation of the surficial geology. The map covers 120 046 km^2 (35 000 mi^2), and is presented at a scale of 1:350 000. The surficial geology is based on an interpretation of data collected on seven cruises conducted by the Atlantic Geoscience Centre at the Bedford Institute of Oceanography. The report also includes brief discussions of the physiography, bedrock geology, and physical oceanography. Figure 1 is an index map of the Grand Banks of Newfoundland and the eastern Scotian Shelf.

The surficial formations described by King (1967a, b, 1970) on the Scotian Shelf occur in the Laurentian Channel and western Grand Banks of Newfoundland map area. The surficial geology is interpreted from acoustic information supplemented with numerous seabed samples that together provide the means for preparing a lithostratigraphic map.

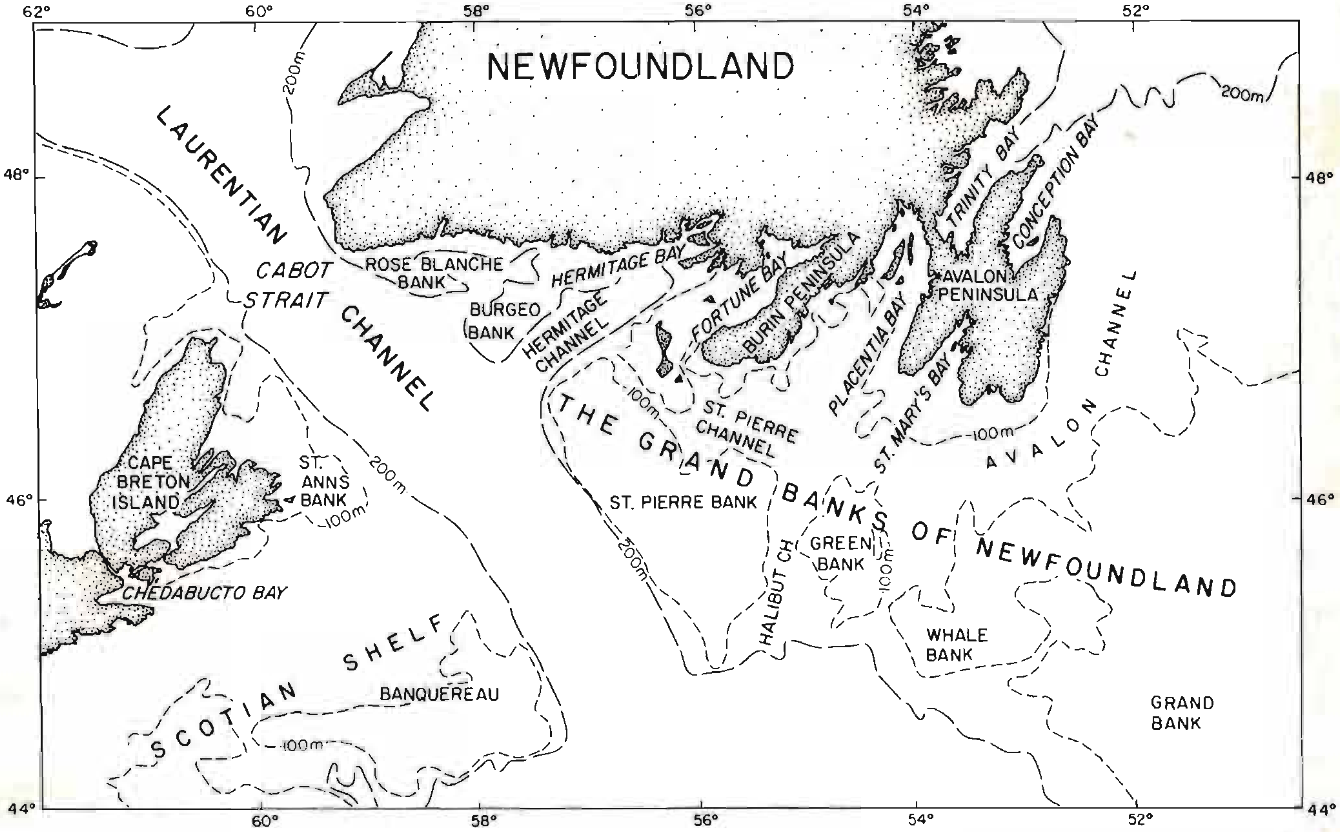

FIG. 1. Index map of the Grand Banks of Newfoundland and the eastern Scotian Shelf.

During the past century, interpretations of the Quaternary history of the offshore areas of Newfoundland have been attempted based on sparse data (often only the bathymetry). This study, through a lithostratigraphic classification of the surficial sediments, provides the evidence on which to base an interpretation of the glacial and postglacial history of the map area.

In contrast to the adjacent Scotian Shelf, the morphology of the study area indicates extensive glacial erosion; this is shown by the fiordlike character of Laurentian Channel and its tributaries.

METHODS

Echograms were used to study and map the surficial sediments and were obtained with a Kelvin–Hughes MS-26B echo sounder, which has a frequency of 14.25 kHz and a pulse length of 1 ms. This echo sounder provides acoustic information that enables differentiation of bottom sediment types. The length and amplitude of the bottom echoes vary according to the sediment type. The acoustic energy of the sounder can penetrate silt, clay, and thin layers of sand to reveal subbottom horizons. The information was displayed on a conventional Kelvin–Hughes echo sounder and, during several cruises, on a precision graphic recorder. In total, 20 400 km (11 000 mi) of Kelvin–Hughes MS-26B echo sounder profiles within the map area were collected and interpreted.

Echograms were collected by the Canadian Hydrographic Service and the Atlantic Geoscience Centre during geological and geophysical cruises. Hydrographic echograms were generally run along north–south, east–west lines at a track spacing of 3.7–5.6 km (2–3 mi) in the area west of Laurentian Channel; on the Newfoundland Shelf, north–south lines were run at 2.8-km (1.5-mi) intervals. Isolated zones (mainly shallow areas) were surveyed along tracks spaced 0.5 km (0.25 mi) apart. Hydrographic echogram coverage for this map area is less dense than on the adjacent Scotian Shelf. Echograms collected by the Atlantic Geoscience Centre were run mainly at right angles to the adjacent coastlines with a track spacing of 9.3 km (5 mi), or in directions chosen to best define the surficial sediment relationships. On St. Pierre Bank, the line spacing was expanded to 18.5 km (10 mi) because our knowledge of the surficial geology from adjacent areas to the west in similar environments indicated that this density of control was sufficient to define the relationships between the surficial formations. No bathymetric data exist in several areas adjacent to the south coast of Newfoundland. Correlation of the geology between adjacent tracks is difficult in these areas.

The echograms were interpreted using the methods described by King (1967a, b, 1970) for mapping the sediments of the Halifax–Sable Island map area. From a study of echograms, he noted that the length of the return echoes (pulse stretching) varied with sediment type. Clay-sized sediments showed a small amount of pulse stretching at the seabed, and were easily penetrated by the acoustic pulses of the echo sounder. In contrast, areas of sand and gravel showed a marked increase in the degree of pulse stretching, and no penetration occurred through these hard sediments. The morphology of the seabed, as interpreted from the acoustic profiles, was also used in a limited way as a classification parameter of sediment type.

The acoustic information on the echo sounder profiles was used to identify the various acoustic stratigraphic units, to trace their lateral extent, to measure their thickness where penetration was achieved, to define the stratigraphic relationships between units, and to study the morphology of the seabed and subbottom reflections. Preliminary maps were prepared showing the distribution of the units defined on the basis of their acoustic signature as they appeared on the echograms. A sampling program was then undertaken on the basis of acoustically established patterns. The continuous aspect of the echogram profiles and their systematic pattern of closely spaced parallel tracks greatly reduces the number of samples needed to describe the surficial formations. The bottom sample locations and survey lines within the map area are shown in Fig. 2.

Analysis of these samples provides the textural and lithologic information on which the lithostratigraphic units were established, and further defines lateral variations within each unit. Additional echograms were obtained between sample locations, and in areas where high density control was needed to delineate more complex distributions.

Airgun seismic reflection profiles were obtained to provide information on the thickness of the unconsolidated sediments in areas where the echo sounder could not penetrate the coarser materials. The airgun profiles also provide data on the unconformity between the bedrock surface and the unconsolidated sediments. These data were collected with a Bolt Associates Marine Profiler airgun, Model 600, fitted with 1-, 10-, and 40-in.^{3} chambers. In total, 5600 km (3000 mi) of airgun seismic reflection profiles were collected in the map area.

A new high resolution deep towed seismic reflection system (DTS) (Hutchins 1974; McKeown 1975; Hutchins et al. 1976) developed by Huntec ('70) Limited, was deployed during the latter part of the study in the eastern part of the map area. The system is capable of resolving acoustic events to a precision of about 0.3 m and can penetrate up to 200 m of surficial material. It provides detailed information on the stratigraphic relationships of the surficial formations and, through digital data processing, lithologic information can be extracted. In total, 300 km (160 mi) of Huntec (DTS) data were collected within the study area.

A Bedford Institute side-scan sonar system (Jollymore 1975) was used to obtain information on the distribution and texture of the surface sediments and to define the morphology of the seabed. The instrument consists of two 70 kHz transducers mounted on a fish,

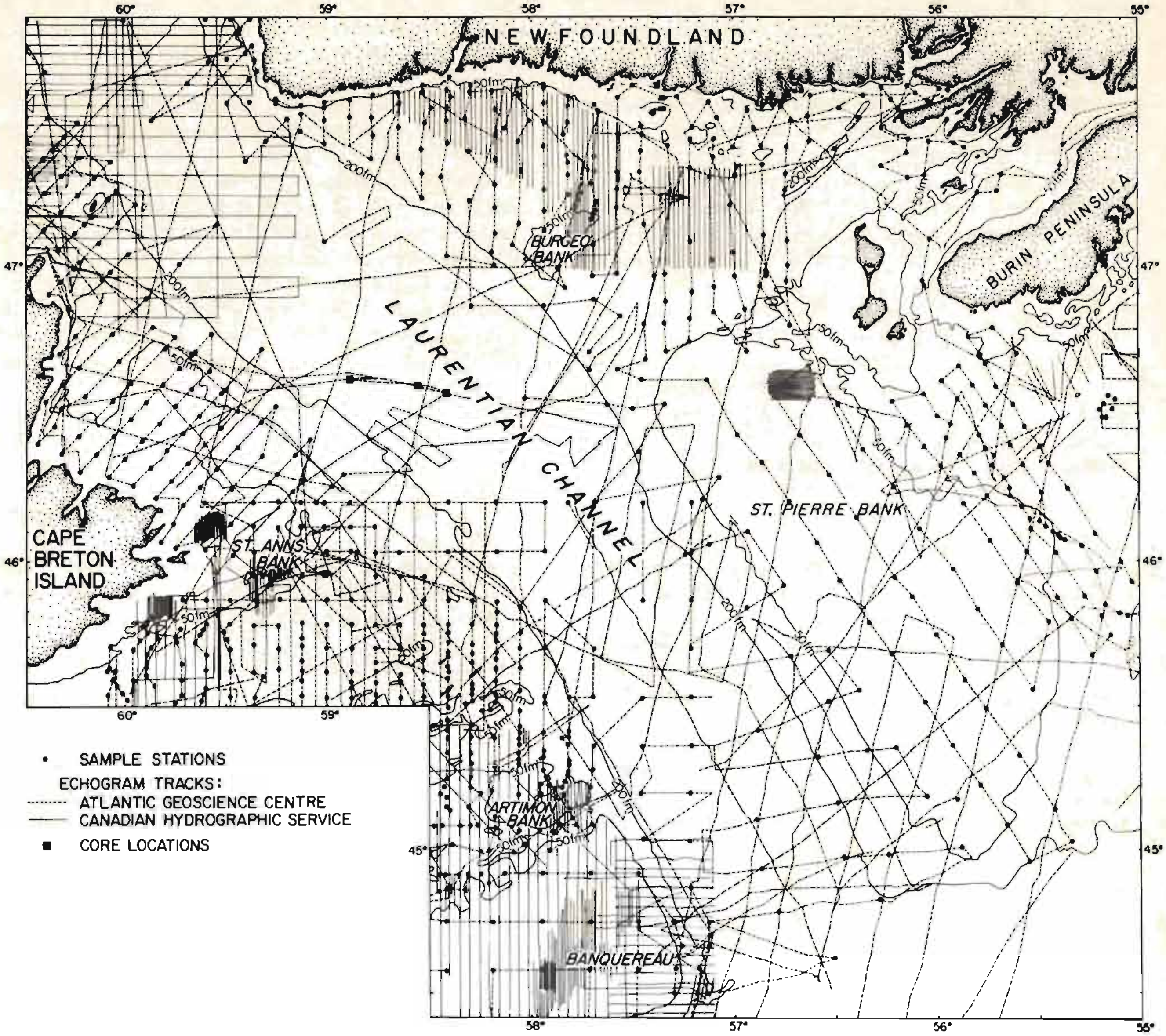

FIG. 2. Acoustic and bottom-sampling control across the Laurentian Channel and western Grand Banks of Newfoundland map area.

which is towed at a speed of 6 kt approximately 50 m above the seabed. An outgoing signal is transmitted in 1-ms pulses at 1-s intervals. The acoustic beam has a horizontal and vertical width of 1.5 and 20°, respectively. The system has a slant range of 750 m each side of the fish. Most of the side-scan information was obtained over the shallower areas due to limitations of the system. The data were displayed on a split helix wet paper recorder, and a small amount of the information was recorded on magnetic tape for later processing and playback (Josenhans et al. 1978). On several early cruises, a Simrad hull-mounted fish-finding sonar was used in an unconventional manner. It was obliquely trained on the seabed in shallow depths to provide information on the surface distribution of deposits of sand and gravel. An interpretation of the side-scan data has been symbolized and appears on Map 4015-G (in pocket). In the study area, 2222 km (1200 mi) of side-scan data were collected.

A van Veen sediment grab was used to collect approximately 700 surficial sediment samples. The sample positions were chosen to be representative of the acoustic stratigraphic units identified on the basis of the echograms. When echogram data were lacking, samples were taken where the seabed morphology indicated a possible change in sediment type. The samples were studied by size analysis and their color and lithology described.

Several piston cores were collected in the study area and analyzed radiographically to recognize any internal structures. Subsamples were taken for textural and paleontological analysis. Bottom photographs of the seabed were collected with EG & G Model 650 underwater cameras from a height of 1 m. Some of these photographs are included in this report.

PHYSIOGRAPHY

The study area is divided into two major physiographic regions (Fig. 3): the Canadian Appalachians and the submerged Atlantic Coastal Plain (King 1972; Williams et al. 1972). The Appalachian region is subdivided into the Atlantic Uplands and the Carboniferous–Triassic Lowlands.

The Atlantic Uplands physiographic division is the largest geomorphic unit of the Appalachian Region (Williams et al. 1972). In Newfoundland and Nova Scotia, the Atlantic Uplands dips gently to the southeast and is developed across igneous and metamorphic rocks. Within the map area, this zone, for the most part, coincides with areas of acoustic basement. On the Scotian Shelf, the submerged upland zone generally borders the Cape Breton coast and extends offshore to include the southern part of St. Anns Bank (map in pocket). A minimum depth of 22 m (12 fath) occurs on St. Anns Bank and the rough undulating bottom surface is controlled mainly by the close proximity of the underlying bedrock to the seabed. The upland zone (Fig. 3) also parallels the south coast of Newfoundland and generally coincides with areas of rough topography, some of which results from extensive local overdeepening through glacial erosion. For example, Fortune Bay (Fig. 1) occurs within the submerged upland zone and is a linear isolated depression, 30 km (16 mi) wide and 93 km (50 mi) long, northwest of the Burin Peninsula. Depths of over 512 m (280 fath) occur in the depression, and sills with depths of 110 m (60 fath) occur where the bay joins with St. Pierre and Hermitage channels.

The Carboniferous–Triassic Lowlands, the largest lowland area of the Appalachian Region, is developed mainly on rocks of those ages. Several isolated banks occur within this lowland area. Rose Blanche Bank is hook-shaped and projects from the southwestern corner of Newfoundland. It trends easterly, has a minimum depth of 126 m (69 fath), and a rough undulating surface. It differs from the other bank areas within the study area in its rough surface morphology and greater depths. Burgeo Bank is rectangular and occurs at the junction of Hermitage and Laurentian channels. Its shallowest point is 70 m (38 fath), and its southwestern side grades steeply to the floor of Laurentian Channel. Glacial erosion has also been extensive in the lowland zone. Hermitage Channel between St. Pierre and Burgeo banks possesses the typical geomorphic characteristics of a hanging valley, and trends northeasterly, perpendicular to Laurentian Channel. The average width is 37 km (20 mi), and a sill, with a minimum depth of 291 m (159 fath), occurs at its mouth where it joins Laurentian Channel. Two linear isolated depressions with a maximum depth of 382 m (209 fath) occur in the

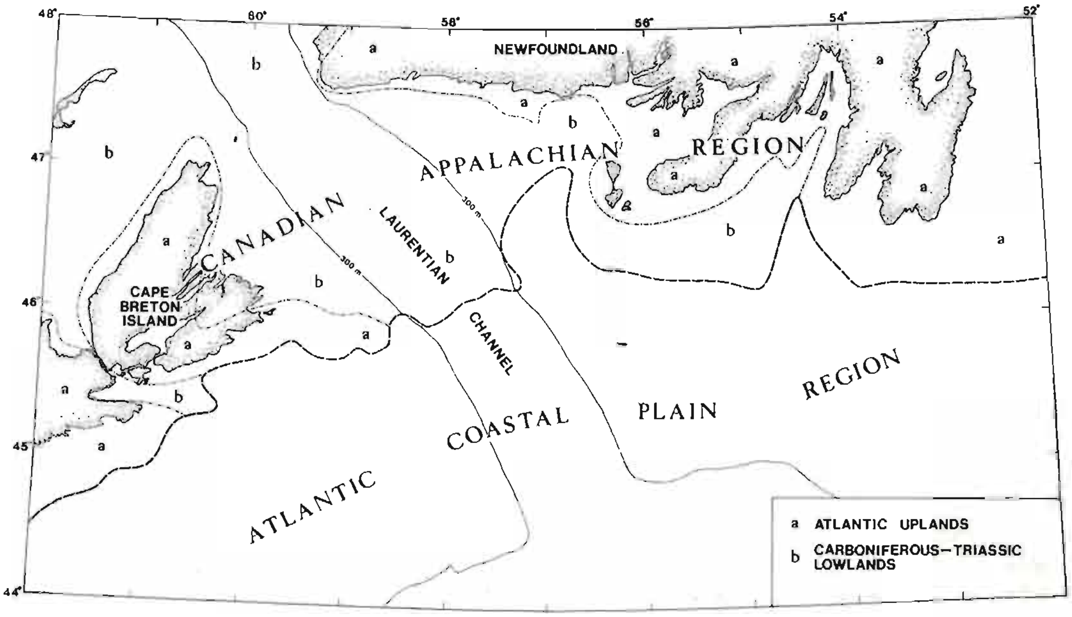

FIG. 3. Physiographic regions of the study area (modified after Williams et al. 1972).

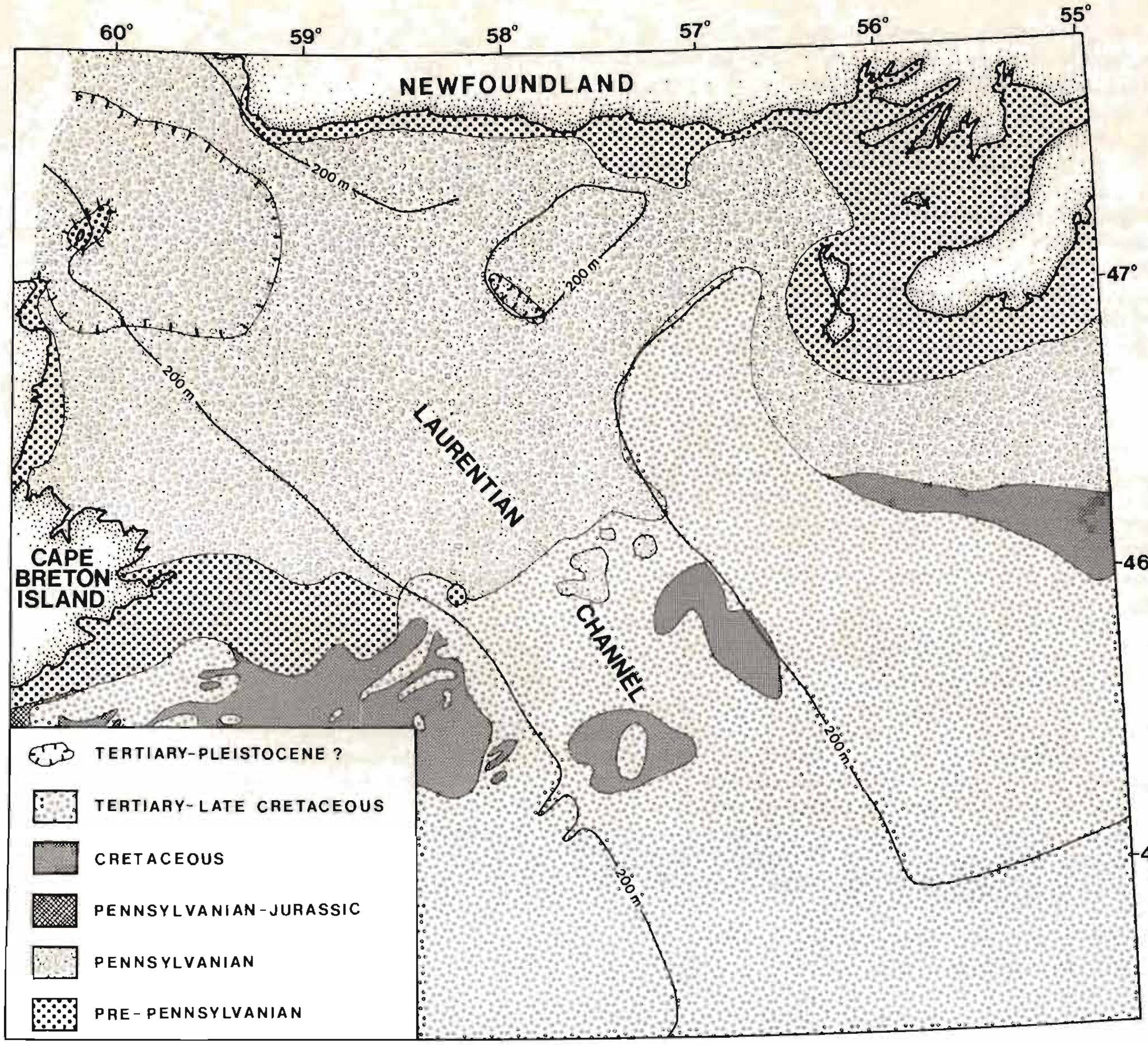

FIG. 4. Bedrock geology of the study area (from King and MacLean 1976).

inner part of Hermitage Channel which appears to be a seaward extension of Hermitage and Connaigre bays.

The second geomorphic region, the Atlantic Coastal Plain (Fig. 3, 4), is underlain for the most part by Mesozoic and Cenozoic coastal plain sediment (King and MacLean 1976). The boundary between the Carboniferous–Triassic Lowlands to the north and the Coastal Plain Province cuts across Laurentian Channel south of St. Anns Bank to the northwestern edge of St. Pierre Bank. The landforms that developed across this surface (mesas, cuestas, and deep incised valleys) were formed in response to periods of subaerial erosion and represent a coastal plain surface. St. Pierre Bank, the largest in the map area, is triangular in shape and covers an area of 13 720 km^2 (4000 mi^2). The shallowest point (31 m (17 fath)) occurs in the northwestern area of the bank. Halibut Channel is an extension of Placentia Bay to the north and lies to the east of St. Pierre Bank, separating it from Green Bank (Fig. 1).

Laurentian Channel, which cuts across both physiographic divisions, is the major morphologic feature in the map area. It is a fiordlike depression (Shepard 1931) extending from the St. Lawrence River valley through the Gulf of St. Lawrence, across the continental shelf between Nova Scotia and Newfoundland, and terminating at the shelf edge. The sides of the channel are relatively straight, and it has an average width of 93 km (50 mi). The deepest part occurs in an isolated depression with a depth of 538 m (294 fath), north of Cabot Strait. Another isolated depression with a depth of 485 m (265 fath) lies to the south of the mouth of Hermitage Channel. At the mouth of Laurentian Channel, where it crosses the shelf break, a sill with a minimum depth of 364 m (199 fath) projects from the southwestern corner of St. Pierre Bank and extends three-quarters of the way across the channel mouth. Numerous slump features lie seaward of the sill over the shelf edge. A conspicuous bottom ridge occurs on the floor of Laurentian Channel west of the mouth of Hermitage Channel. It trends in a northerly direction and is also defined by a change in bottom sediment type on Map 4015-G. Additional contours for the floor of Laurentian Channel have been interpolated from Canadian Hydrographic Charts 801 and 802.

The presence of fluvial erosional systems in the subsurface of Laurentian Channel (King and MacLean 1970a) indicates that a subaerial drainage system was formed as far back as Late Cretaceous time. The system was extensively developed on the Scotian Shelf, and a coastal plain landscape of mesas, cuestas, and stream valleys evolved. On the Scotian Shelf, subsequent glacial erosion was moderate in nature with local overdeepening of the previous subaerial surfaces (King et al. 1974). In the study area, glaciation was more intense and the ancestral Laurentian Channel drainage system was widened, overdeepened, and straightened to its present configuration.

Glacial erosion was more extensive in the northwestern areas of Laurentian Channel. Evidence of the previous fluvial drainage system has also been removed. The distribution of Tertiary sediment on both sides of Laurentian Channel indicates that the channel may have contained a substantial amount of this sediment. However, it is difficult to separate the relative degrees of erosion by Late Tertiary fluvial systems and the various glaciations that have occurred in the area.

OCEAN CIRCULATION

A generalized ocean circulation pattern over the study area is shown in Fig. 5. This pattern results from the influence of the Labrador current, and the Gulf Stream current with tidal effects superimposed (Dinsmore 1972). The Labrador current has the greatest effect adjacent to Newfoundland. It flows southerly along the east coast of the island and has an influence over a large area of the Grand Banks of Newfoundland. The current continues westerly around the Avalon Peninsula and passes the southeast coast of Nova Scotia. The Labrador current divides into two segments at approximately 50° latitude and flows along the eastern edge of the Grand Banks of Newfoundland along the 200-m contour and through the Avalon Channel at velocities usually <0.5 m/s. The latter current flows in a southwesterly direction and is deflected by shallow St. Pierre Bank, which redirects the flow through Halibut Channel to the south and through St. Pierre Channel to the west toward Cabot Strait. Flow velocities along the south coast of Newfoundland are generally thought to be <0.5 m/s.[1] The tidal component in this area is significant and locally reverses the direction of flow. The westerly flowing tidal component has a duration 25% longer which results in a residual circulation to the west. Near the coast and in the deep isolated fiordlike bays along the south coast of Newfoundland, tidal forces control the dominant local currents.

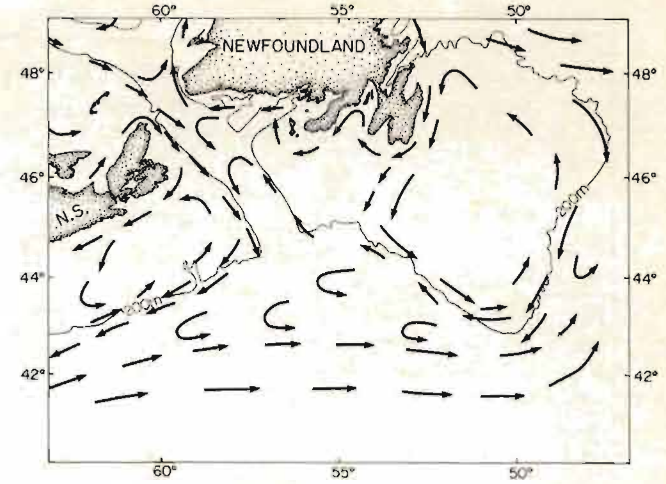

FIG. 5. Generalized ocean circulation pattern of the Scotian Shelf and Grand Banks of Newfoundland (from Dinsmore 1972).

In the Cabot Strait area, the Labrador current divides. One component flows to the northwest through the strait and into the Gulf of St. Lawrence. Detailed current measurements (Trites 1971) indicate that the cold Labrador water mass is concentrated on the eastern side of the strait throughout the entire water column. The maximum flow occurs between depths of 100 and 200 m. To balance this incoming watermass through Cabot Strait, a stronger current flows seaward along the western side of the strait at a velocity of 0.2–0.4 m/s. This current is shallow and does not extend to the bottom of Laurentian Channel. It flows southeasterly over the shelf off Cape Breton Island to St. Anns Bank where it mixes with the southwestward flowing Labrador current. The net direction of water movement is out of the Gulf of St. Lawrence with approximately $75 \times 10^4\ m^3 \cdot s^{-1}$ inflowing and $84 \times 10^4\ m^3 \cdot s^{-1}$ outflowing (Trites 1971).

The Gulf Stream flows along the southern edge of the Grand Banks of Newfounland during the winter and extends over their southeastern regions during the summer. Within the Gulf Stream, current velocities are variable; rates in excess of 0.5 m/s have been observed in a northeast direction. At the boundary between the Gulf Stream and the Labrador current along the southern margin of the Grand Banks, an area of mixed water and counterclockwise gyres is developed.

BEDROCK GEOLOGY

A description of the bedrock geology of the map area is included to define the bedrock units found on the cross sections on the map and show the relationships between bedrock lithology, seabed morphology, and the

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[1] *Sailing Directions, Newfoundland*, Sixth Edition, 1980, Fisheries and Oceans Canada, Ottawa.

thickness and texture of the overlying surficial sediments. This brief discussion is based on a map and report by King and MacLean (1976), who studied the bedrock geology of the Scotian Shelf and adjacent areas, and on data collected during this study. Figure 4 shows the distribution of bedrock units within the map area. The geology was interpreted from a study of seismic reflection profiles, seismic refraction data, gravity and magnetic information, samples obtained with an electric rock core drill, and adjacent land geology.

The oldest rocks of the map area (Table of Formations) occur in a zone along the northeast and south coasts of Cape Breton Island and along the south coast of Newfoundland including the Burin Peninsula (map unit 1); they appear on cross sections GH, and IJKL of map 4015-G (in pocket). These rocks are termed "acoustic basement" because the seismic energy derived from the airgun is reflected from the surface of these rocks and subsurface reflections do not occur on the seismic profiles. The rocks are pre-Pennsylvanian in age and their lithologies are assumed to be similar to the adjacent land because of their close proximity. They consist of Precambrian volcanic, sedimentary, and plutonic rocks and a suite of Cambrian–Devonian high grade metamorphic and granitic rocks. The Scatarie basement ridge, an acoustic basement high, extends offshore from the southeast coast of Cape Breton Island and trends easterly (Fig. 4). It extends almost to the edge of Laurentian Channel and includes the southern part of St. Anns Bank and Scatarie Bank. Further to the east it is overlain by Pennsylvanian and Tertiary strata. The unit may locally contain younger volcanic rocks.

TABLE OF FORMATIONS.

Era	Period or Epoch	Surficial Formations[a]	Lithology	Thickness (m)
Cenozoic	Quaternary	Sable Island Sand and Gravel (10). *Time equivalent of map unit 9.*	Clean, reddish- to greyish-brown, fine- to coarse-grained well sorted sand, grading laterally to subrounded coarse gravels and large boulders. Bedrock frequently outcrops at the seabed.	0–20 (generally thin)
		LaHave Clay (9). *In part time equivalent of upper portions of map units 7 and 8; mostly younger.*	Dark greyish-brown to olive silty clay, grading locally to clayey silt and silty clayey sand.	0–30
		Sambro Sand (8). *Lowermost part of section may be time equivalent of map unit 7.*	Dark greyish-reddish brown, fine- to coarse-grained, sublittoral silty and clayey sand grading to sandy silty gravel. Represents modified glacial till and Emerald Silt.	0–20 (generally thin)
		Emerald Silt (7). *Lowermost part of section may be time equivalent of map unit (6).*	Dark greyish-brown to olive-brown, poorly sorted, clayey and sandy silt, grading to a silty and clayey sand with angular gravel; proglacial.	0–120
		Scotian Shelf Drift Newfoundland Shelf Drift (6).	Dark olive-grey to reddish-brown, poorly sorted, cohesive glacial till; includes angular fragments of pebble to boulder sized material, sand-, silt-, and clay-sized sediments; occurs in morainal deposits and may include minor stratified drift.	0–115
			Unconformity.	
	Tertiary and latest Cretaceous	(5)	Nearby well samples consist of grey siltstone, mudstone, and thin glauconitic sandstone.	—
Mesozoic				
	Cretaceous	(4)	Nearby well samples consist of argillaceous sandstone, shale, siltstone conglomerate, and limestone.	—
Paleozoic and Mesozoic			Unconformity.	
	Pennsylvanian–Jurassic	(3)	Undifferentiated sedimentary rocks.	—
			Unconformity.	
	Pennsylvanian	(2)	Drill cores consist of conglomerate, sandstone, shale, coal, and minor limestone.	—
Paleozoic and Older			Unconformity.	
	Pre-Pennsylvanian	(1)	Acoustic basement (undifferentiated); includes Precambrian to Devonian volcanic, sedimentary, high grade metamorphic and granitic rocks. Locally may include some younger sedimentary and volcanic rocks.	

[a] Numbers in parentheses refer to map units.

The area between Cape Breton Island and the southwest coast of Newfoundland, known as the Sydney Basin, is underlain by Pennsylvanian sediments (map unit 2). They represent an offshore continuation of coal-bearing strata that occur on Cape Breton Island and extend across Laurentian Channel to within 9–19 km (5–10 mi) of the Newfoundland coast (cross sections AB, CD, and GH). They also occur to the south and east of the Burin Peninsula and underlie most of Placentia Bay. These rocks flank the northern side of the Scatarie acoustic basement ridge and continue southward where they underlie Cretaceous and Tertiary sediments in the southern part of Laurentian Channel. Pennsylvanian sediments are composed of conglomerate, sandstone, shale, coal, and minor amounts of limestone. These rocks dip gently into the central part of the basin, which occurs beneath Laurentian Channel east of Cape Breton Island.

Jurassic rocks (map unit 3) occur at the seabed in the western part of the map area, south of Cape Breton Island, as the easternmost extension of Pennsylvanian–Jurassic strata that occur in Chedabucto Bay (Fig. 1) to the west. These sediments are bounded by high angle faults along the Glooscap fault system (King and MacLean 1976) within the Orpheus Basin which lies to the south of the Scatarie basement ridge, and extends from Chedabucto Bay across the northeast section of the Scotian Shelf and into Laurentian Channel. This basin is associated with a negative gravity anomaly arising from a thick sequence of low density strata and a thick section of salt (King and MacLean 1976). Cretaceous and Tertiary sediments overlie the Jurassic sediments to the east. Jurassic strata in Laurentian Channel locally may occur at the bedrock surface in association with salt piercement structures (Keen 1970; Webb 1973).

Cretaceous rocks (map unit 4) are exposed at the seabed along much of the central Scotian Shelf north of Banquereau; they appear as two isolated deposits in the southern part of Laurentian Channel (cross sections EF and GH). Cretaceous strata are overstepped by a thin sequence of Tertiary sediments in Laurentian Channel and outcrop on the shelf south of Newfoundland in the northern area of Halibut Channel. Samples obtained from nearby wells on the Scotian Shelf consist of argillaceous sandstone, shale, siltstone, conglomerate, and limestone.

Tertiary and Late Cretaceous rocks (map unit 5) occur as a thin veneer on the inner shelf and thicken seaward to at least 2 km at the shelf edge (cross sections EF and GH). The sediments commonly overstep the underlying Cretaceous rocks and in Laurentian Channel overlie Pennsylvanian strata. At the shelf edge Tertiary rocks form progradational sequences. Fluvial drainage systems interpreted from the presence of numerous channels occur within the Tertiary sequences and represent an extensive unconformity that connects with areas of submarine canyon development near the edge of the shelf. Possible outliers of Tertiary (?) or Pleistocene sediment occur in the Cabot Strait area of Laurentian Channel and southwest of Burgeo Bank (cross sections AB, CD, and EF). These sediments overlie Pennsylvanian rocks, but because of their depth of burial beneath thick surficial cover, samples were not collected.

SURFICIAL GEOLOGY

Previous Studies

Two opposing schools of thought have developed on the extent of the Wisconsinan glaciation of Newfoundland and its surrounding marine areas. Early studies by Fernald (1925) and Coleman (1926) emphasized limited glaciation of the island by Wisconsinan ice which took the form of small localized ice sheets and valley glaciers. In contrast, MacClintock and Twenhofel (1940) concluded that Newfoundland was extensively glaciated during the Wisconsinan and that it probably supported its own ice cap. Widmer (1950) postulated that Wisconsinan ice advanced to the Grand Banks where it deposited large moraines, and during a late Wisconsinan readvance, glacial lakes were developed in Fortune and Placentia bays. Jenness (1960) proposed a sequence of deglaciation for the eastern area of Newfoundland which included a separate ice cap on the Avalon Peninsula, and freshwater lakes at Baie d'Espoir and in Fortune and Bonavista bays during deglaciation. Tucker (1976) provided a comprehensive study of the Quaternary literature of Newfoundland.

Brookes (1969, 1970a, b, 1977) studied the glacial chronology of the southwest coast of Newfoundland in detail. From an examination of the coastal cliff sequences adjacent to Cabot Strait, he postulated an ice advance perpendicular to the coast 14 000 years B.P., followed by marine overlap and a later ice readvance 12 600 years B.P. His chronology of glacial events in western Newfoundland was in agreement with the views held by MacClintock and Twenhofel (1940) of extensive Wisconsinan glaciation.

Henderson (1972) described the surficial geology of the Avalon Peninsula and its glacial and postglacial history in detail. He suggested that a separate, vigorous ice cap formed over the Avalon early in Wisconsinan time and that this local ice cap diverted the easterly flowing major ice front to the northeast and southwest, down Trinity and Placentia bays. This ice cap radiated south from a center over St. Marys Bay and was blocked by ice in Laurentian Channel. He also noted the absence of postglacial raised beaches on the Avalon Peninsula.

Grant (1971) proposed that an ice cap located on the continental shelf off southern Cape Breton Island moved onshore in a northward direction. He also speculated on the existence of a Wisconsinan ice dome centered on the Grand Banks of Newfoundland with movement to the northwest across Placentia Bay and the Burin Peninsula. His general pattern of late Wisconsinan glaciers (Grant 1977) supports the limited Wisconsinan view and depicts numerous small ice cap complexes in Newfoundland, which moved no further than to the 100-m contour off the coast.

Shearer (1973) studied the bedrock geology and surficial sediments in the northeastern Gulf of St. Lawrence using seismic reflection survey data. From an assessment of the distribution of glacial till he suggested that the northern gulf was covered by glacial ice during the Wisconsinan, and an absence of till in depths less than 100 m was due to reworking associated with a lower postglacial sea level and subsequent marine transgression. To the northwest of the map area, in the Gulf of St. Lawrence, Loring and Nota (1973) described and mapped the surficial sediments and concluded that Wisconsinan glaciations have been the most important factor in controlling the dispersal pattern of terrigenous material in the gulf.

Müller and Milliman (1973) studied the surficial sediments on the southwestern Grand Banks of Newfoundland and concluded that neither glaciers nor their melt waters extended south on the Grand Banks during the last glaciation. In contrast, Slatt (1974, 1977), from a study of the surficial sediments in the same area, concluded that the ice cap did lap on the western edge of the Grand Banks of Newfoundland. The rugged topography of the edge of the Grand Banks probably acted as a barrier to the easterly flow of ice. Sen Gupta and McMullen (1969), from a study of foraminiferal and textural distributions on the Grand Banks, proposed that an easterly limit of coarse sediment represented the maximum seaward extension of the continental ice sheet, placing the boundary farther southeast. Sediments seaward of the gravel occurrences probably represented reworked proglacial materials.

Slatt and Gardiner (1976) studied the petrology of the gravel and sand-sized fractions of sediments from Conception Bay, Placentia Bay, and Halls Bay, Newfoundland. They concluded that most of the material in the sediments of these bays is derived from local bedrock and a minor component results from ice rafting or bottom currents. Stehman (1976) studied the sediments in northern Placentia Bay using acoustical and sedimentological techniques. He observed the preservation of glacial tills in shallow depths above a Pleistocene low sea-level terrace and suggested a protected existence beneath grounded ice or an ice shelf, or a low energy environment during the Holocene transgression to explain the preservation.

More recently, Tucker and McCann (1980) proposed a sequence of events for the Wisconsinan glaciation of the Burin Peninsula based on a study of stratigraphy and distribution of the surficial deposits. They proposed that late Wisconsinan glaciers were of limited extent and that Early Wisconsinan ice covered most of the Newfoundland area. A third glacial event, which originated from an offshore source to the south, moved in a northwest direction across the Burin Peninsula; this idea supports a proposal by Grant (1975) for similar ice movement.

Sea-Level Changes

Knowledge of the late and postglacial eustatic and isostatic history from adjacent areas provides a preliminary insight into this map area which can help identify and interpret the lithostratigraphic surficial units.

On the Scotian Shelf, King (1970) and MacLean and King (1971) recognized the position of a former low sea-level stand at a depth of 115–120 m (63–65 fath). The position of this low sea-level terrace across the shelf area prior to the Holocene transgression is critical to the distribution of the surficial lithostratigraphic units. The low sea-level position on the Scotian Shelf was identified on the basis of a terrace interpreted from echograms, sediment textural characteristics above and below the terrace, and the distribution of glacial till relative to the terrace. On many of the echogram profiles across the shelf, a knickpoint is developed at 115–120 m (63–65 fath) below present sea level; this was interpreted as a low stand of sea level. Samples from above this terrace do not contain silt- and clay-sized sediment, and are composed entirely of clean sands and rounded gravels. Samples from below the terrace contain from 10 to 15% silt- and clay-sized sediment and are characterized by this fine fraction. Thick deposits of glacial till in the form of end moraines and ground moraine occur below the level of the terrace. Above the terrace very little glacial till exists, except in deep bedrock channels, and where it is found, its surface is modified. An anomalous occurrence of glacial till on the Scotian Shelf above the terrace was mapped in Chedabucto Bay (MacLean et al. 1977). Local late glacial ice originating from Cape Breton Island may have covered the glacial till and protected it from further erosion by the transgressing Holocene sea, or local isostatic rebound may have raised the deposit to its present position above the terrace. The consistent depth of occurrence of the terrace on the Scotian Shelf and its lateral continuity indicate that rebound was more or less complete before sea level began to rise, little differential rebound had occurred since its formation, the ice sheet had retreated from the shelf area before its formation, and the age of the terrace was probably the same across the shelf. During the Holocene transgression, previously deposited glacial materials above the terrace were reworked, and the winnowed fines deposited in the adjacent depressions. The transgression was a very effective mechanism for sorting the seabed materials above the terrace.

To determine accurately the depth of the terrace across the map area, numerous closely spaced samples were collected on the inner shelf and at the edges of the offshore banks. Recognition of the terrace on the inner shelf south of Newfoundland is difficult. The area is characterized by deep narrow depressions, bedrock ridges, and rugged topography, which make accurate surficial sampling difficult. Because of the steep slopes, resolution of the seismic systems is also limited. However, in the offshore areas, along the flanks of Burgeo, St. Pierre, and St. Anns banks, the topography is less undulating and the terrace more easily studied. Textural information from samples taken in these areas together with an interpretation of the echograms and high resolution seismic reflection profiles indicate that the terrace usually occurs at a depth of 115–120 m (63–65 fath), similar to the depth of occurrence on the Scotian Shelf to the west. An exception occurs east of the Burin Peninsula where thick continuous glacial till occurs in depths as shallow as 91 m (50 fath), and represents a maximum depth of occurrence for the terrace in this area.

The shallowest point on Rose Blanche Bank is 128 m (69 fath). The bank is covered with iceberg-furrowed glacial till; however, in its shallow areas, the furrows are slightly infilled and the surface of the seabed is smoothed. This sediment distribution and surface morphology arose in response to the sublittoral processes present during the low sea-level stand over the bank area, and indicate that prior to the Holocene transgression, Rose Blanche Bank was not emergent.

In the Bay of Fundy and adjacent areas, raised marine strand lines were attributed to late glacial ice that isostatically depressed the region much longer than on the adjacent Scotian Shelf (Fader et al. 1977). Subsequent isostatic rebound raised the position of the 115-120-m (63-65-fath) terrace to a depth of 37 m (20 fath). Along the southeast coast of mainland Nova Scotia and Cape Breton Island, no evidence exists on land for a postglacial marine limit higher than the present shoreline. However, along the southwestern coast of Newfoundland, elevated marine features are common and dates of these deposits cluster at approximately 14 000 years B.P. (Brookes 1977).

A map of Newfoundland with isobases drawn on equal elevations of isostatic rebound is shown in Fig. 6 (Wightman and Cooke 1978). The zero isobase parallels the south coast of Newfoundland, several kilometres offshore, and continues subparallel to the axis of Placentia Bay northeastward across the Avalon Peninsula.

Side-scan sonar data collected in the map area have provided additional information on the texture, distribution, and morphology of the surficial sediments. This enhances our understanding of sea-level changes and isostatic rebound, and will be discussed in detail in later sections. King (1976), from a study of side-scan sonograms in the Halibut Channel area, recognized iceberg furrows and interpreted them as relict features (Fig. 7). The furrows do not occur in depths shallower than 105 m (57 fath) and were probably formed shortly after sea level began to rise along the 115-120-m (63-65-fath) terrace, 14 000-15 000 years B.P. King also identified bedforms in close association with the former shoreline at 115-120 m (63-65 fath) that include sand and gravel patches, megaripples, and sand waves (Fig. 8, 9). These bedforms were interpreted as forming at an early stage of the Holocene transgression when water depths were less and currents stronger.

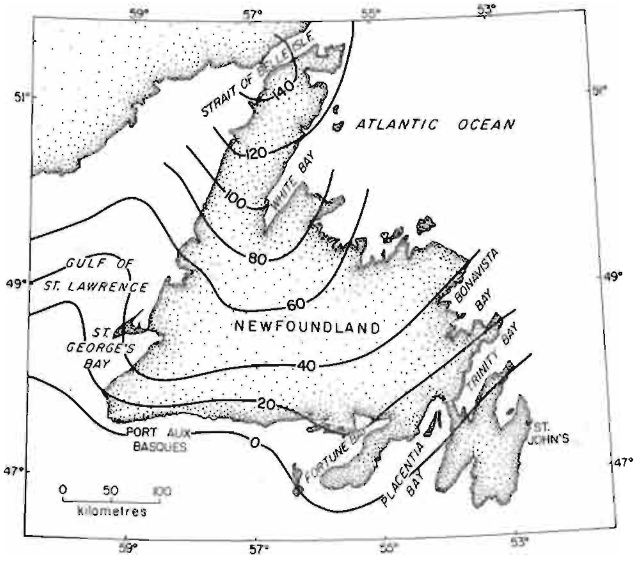

FIG. 6. Isobases of the Island of Newfoundland (from Wightman and Cooke 1978).

Surficial Formations

Five surficial formations, recognized and mapped by King (1970) on the Scotian Shelf, are found in the map area (*see* Table of Formations). These formations, Scotian Shelf-Newfoundland Shelf Drift, Emerald Silt, Sambro Sand, LaHave Clay, and Sable Island Sand and Gravel, are formal rock units that were defined and described by King (1980). They consist of glacial till, proglacial silt, sublittoral sand, recent mud, and basal transgressive sand and gravel. Figure 10 is a diagrammatic section of the surficial succession across the Scotian Shelf off Halifax, and illustrates the stratigraphic relationships between formations. The surficial formations are remarkably uniform and continuous over large areas of the shelf. In some areas they are defined by sharp boundaries with adjacent formations, and in others the relationships are gradational. Figure 11 is a location map for the profiles illustrated throughout the report.

Scotian Shelf Drift-Newfoundland Shelf Drift (Map Unit 6) — The Scotian Shelf Drift (map unit 6) was described by King (1970) as the material deposited beneath glaciers on the Scotian Shelf. Its equivalent within the map area on the western Grand Banks is the Newfoundland Shelf Drift. It is an olive-grey to reddish-brown, poorly sorted till, composed of sand, silt, and clay, that contains various amounts of pebbles, cobbles, and boulders. The coarse rock fragments in the till are subrounded to angular and often faceted. Photographs of the seabed over glacial till reveal many cobbles and boulders protruding from a matrix of sandy mud (Plates I, II).

The glacial till can occur as a thin blanket of ground moraine, as infillings in old subaerial bedrock erosional channels, or in thick morainal ridges. Within the map area, the till outcrops at the seabed from Rose Blanche Bank to Burgeo Bank, and occurs at the mouth of Hermitage Channel as a sill, along the Burin Moraine, east of St. Pierre Bank, and in the Gabarus and Scatarie moraines on the Scotian Shelf southeast of Cape Breton Island. The till underlies most other parts of the map area as a thin discontinuous sheet of ground moraine. The extent of glacial till in the subsurface of the bank areas is not well known.

In areas below and adjacent to the submarine ter-

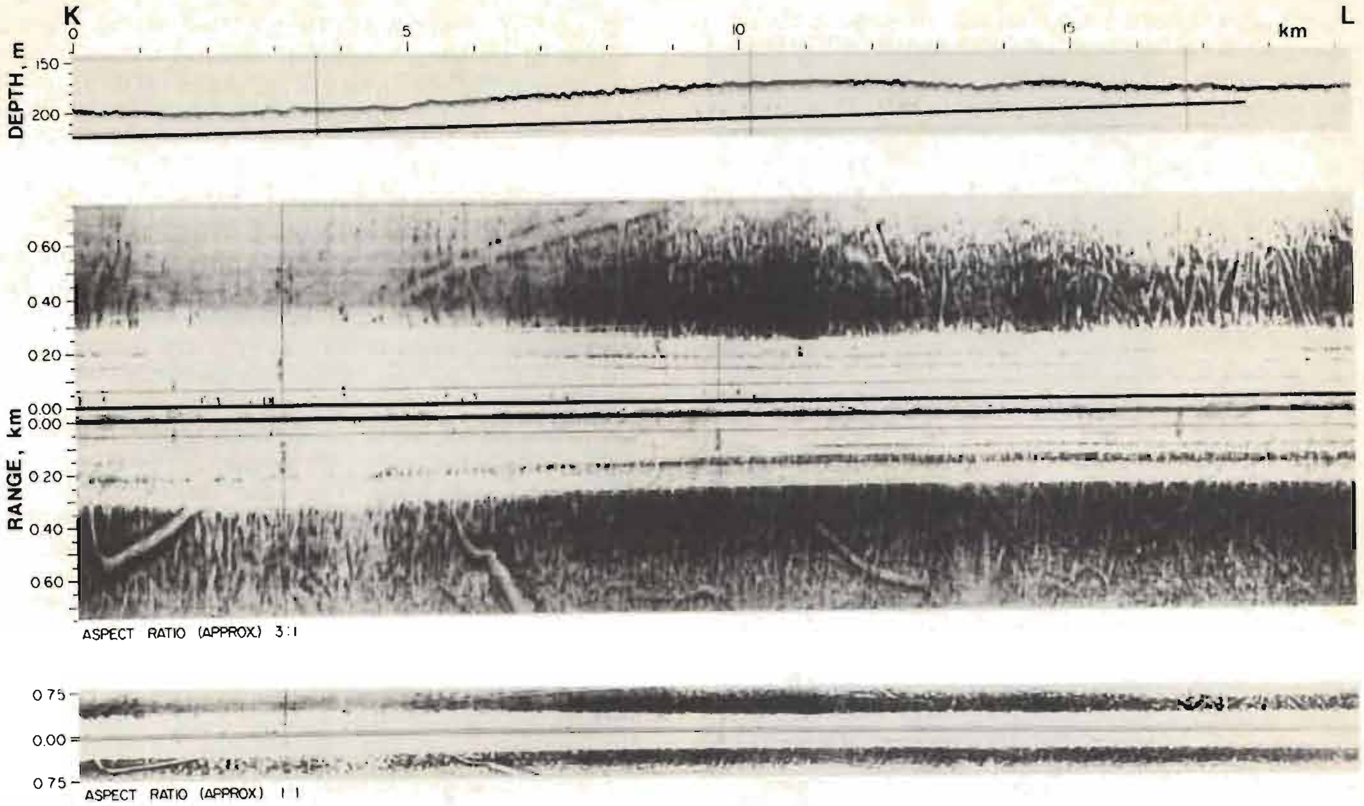

FIG. 7. Side-scan sonograms and echogram profile run parallel to the western edge of Laurentian Channel across an area of iceberg furrows developed on Sambro Sand. On the upper sonogram the furrows are partially buried from the 1- to 7-km marks.

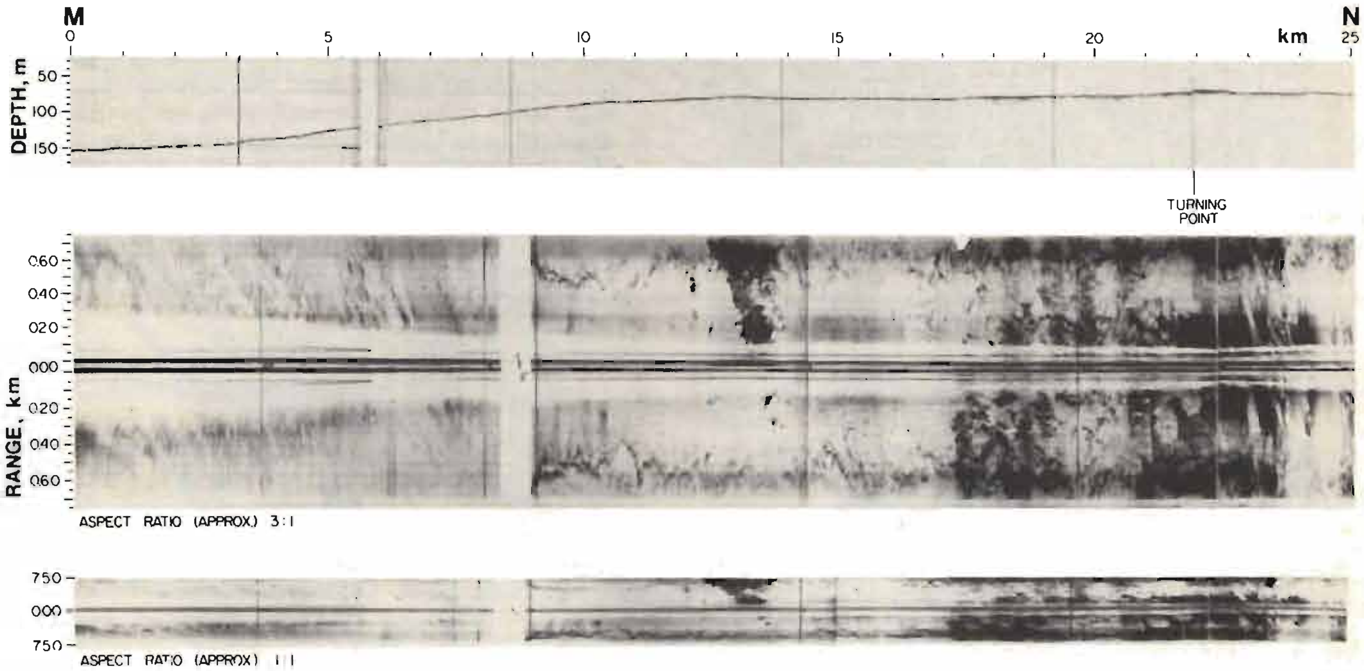

FIG. 8. Side-scan sonograms and echogram profile from Halibut Channel showing iceberg furrows and various relict bedforms near the 115–120-m (63–65-fath) terrace. Areas of gravel occur at the 21–24-km marks and are represented as dark tone on the sonograms in contrast to the light-toned sand areas.

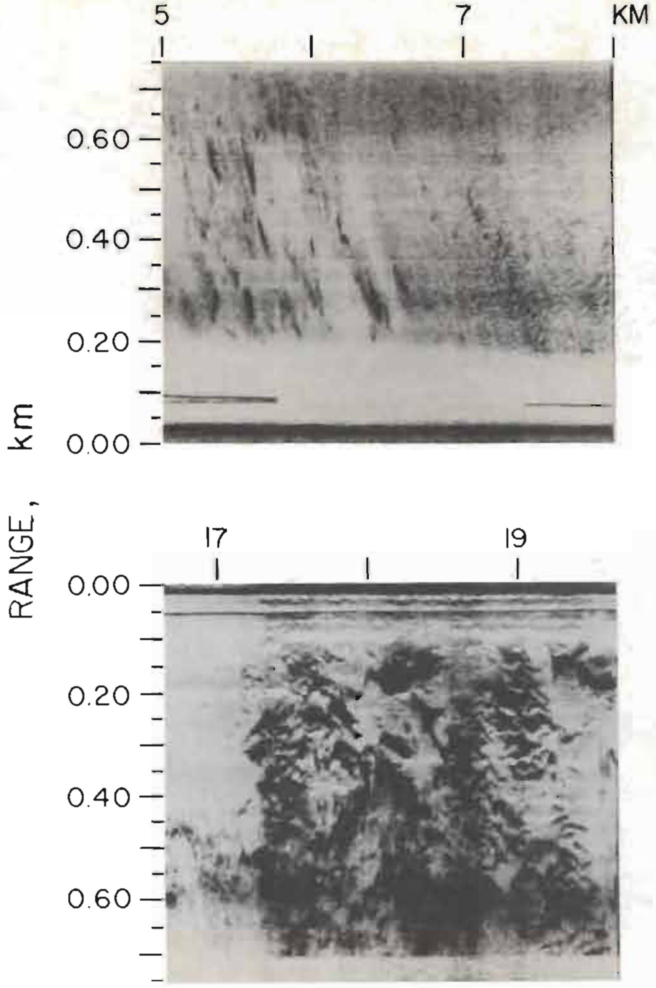

FIG. 9. Upper sonogram — enlarged section of upper sonogram, Fig. 8, between 5 and 8-km marks. The rims of partially buried iceberg furrows which appear as discontinuous dark lineations, and short wavelength sand waves occur immediately below the 115–120-m (63–65-fath) terrace.

Lower sonogram — enlarged section of lower sonogram, Fig. 8, between the 17- and 19.5-km marks. Relict megaripples occur at the seabed.

race at 115–120 m (63–65 fath), glacial till grades laterally to modified till (Sambro Sand). During the low stand of sea level, sublittoral sediment transport processes modified the surface of the glacial till through winnowing of the fine surface sediment and infilling of the depressions on the till surface. The residual material formed a lag deposit composed of gravel and local deposits of sand. The boundary between the glacial till and Sambro Sand is gradational and acoustically difficult to define. The glacial till can easily be distinguished from the overlying and interbedded deposits of proglacial Emerald Silt, and the contacts between the formations are normally defined by sharp boundaries on the acoustic profiles, which are consistent over large areas.

Glacial till has a characteristic acoustic signature that varies according to the frequency of the seismic reflection system used. The pulse emitted by an echo sounder cannot penetrate it. The surface is rough and undulating, and pulse stretching is pronounced. The energy from the Huntec (DTS), however, will penetrate through glacial till and even define bedrock surfaces beneath thick till (<50 m) deposits (Fig. 12, 13). Airgun seismic reflection systems can easily penetrate several hundred metres of glacial till, but because of limited resolution within the bubble pulse, thin deposits (<12 m) cannot be accurately delineated. On the acoustic profiles glacial till does not exhibit internal coherent reflections.

Glacial till was recognized on the Scotian Shelf by King (1967a, b) on the basis of its irregular undulating surface and acoustic impenetrability on echogram profiles. Its occurrence was confirmed by bottom sampling, and lithologic studies showed that the submarine till was very similar to the till found on mainland Nova Scotia. The origin of the surface irregularities on glacial till was not completely known until the development of sidescan sonar systems; the undulating surface, however, was used as an identification parameter. King (1976) has shown that these small-scale undulations on the glacial till surface have resulted from scour by grounded icebergs. Surveys of the Scotian Shelf indicate that most

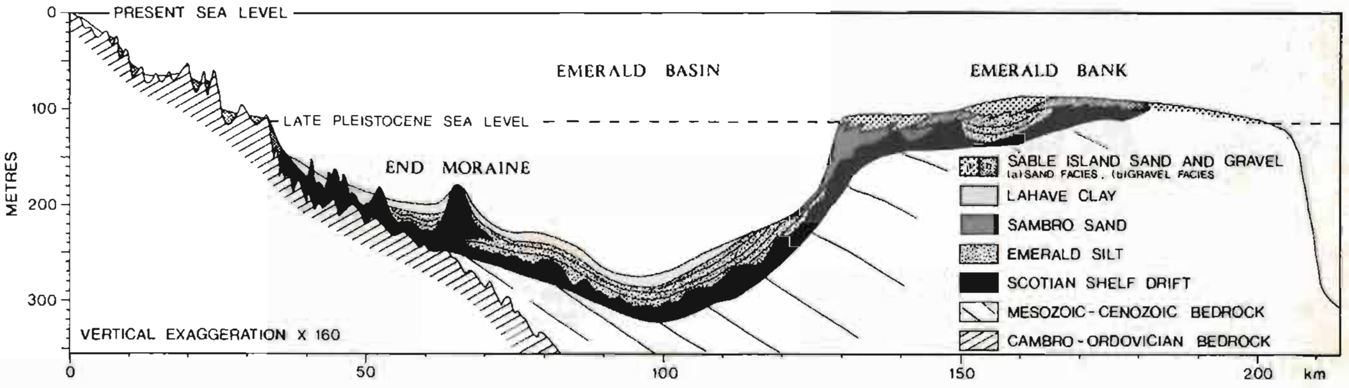

FIG. 10. Diagrammatic section of the Scotian Shelf surficial succession showing the interpreted stratigraphic relationships between formations and their relationships to the underlying bedrock, topography, and present and former sea levels (after King 1979.)

ERRATA

FADER, G.B., L. H. KING, AND H. W. JOSENHANS. 1982. Surficial geology of the Laurentian Channel and the western Grand Banks of Newfoundland. Mar. Sci. Pap. 21: 37 p.

The following figure is a replacement for the one found on page 13.

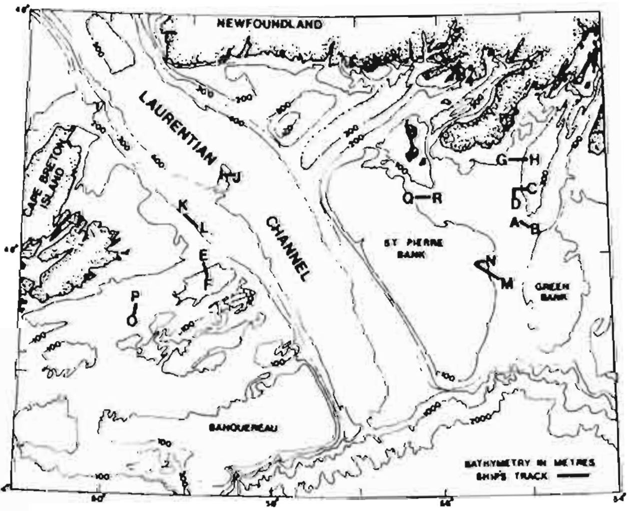

FIG 11. Location map for the study area showing generalized bathymetry and an index for the side-scan sonograms; echo-sounder, airgun, seismic, and Huntec (DTS) profiles illustrated in the report.

glacial till surfaces exposed at the seabed are furrowed and that iceberg furrows appear to be confined to seabeds composed of glacial till. Because these furrows are only found on glacial till, they must have been formed in early postglacial times and therefore are relict.

Within the present map area, an interpretation of side-scan data has shown that all the surficial formations, including the youngest, are furrowed to varying degrees. This probably resulted from late Wisconsinan glaciers along the south coast of Newfoundland, which provided large icebergs to the shelf area through the numerous deep fiords that indent the southern coast, and from icebergs originating from the Gulf of St. Lawrence. A similar situation may exist today on the Labrador Shelf and in other northern areas. Thus, the use of morphology as a sediment classification parameter is limited, and must be supplemented with seabed samples, side-scan sonograms, and high resolution seismic reflection data.

Iceberg furrows on the till vary greatly in size and have an average depth of 2-3 m. The deepest furrow in the map area occurs on the edge of Laurentian Channel west of Burgeo Bank and is 20 m deep. The width of the furrows averages 30-50 m; two of the widest furrows are 80 and 110 m. Furrows on glacial till buried beneath thin deposits of glaciomarine and recent sediment can impart an undulating morphology to these overlying sediments. The formation of iceberg furrows is an important process for overturning and mixing of the upper several metres of sediment, especially on glacial till surfaces. King (1976) envisaged a mechanism for furrowing of glacial till. The grounded moving ice would bulldoze the glacial till surface, creating turbulence in the sediment and water column directly ahead of the iceberg. This results in sorting of the disturbed material with removal of the fines into suspension, and deposition of coarser material. The coarse fraction would then be pushed aside to form gravel rims. Further sorting and deposition of fines that adhered to the gravel would occur and fill the furrows created with an increase in the relative gravel content of the rims. The floor of the depression would be smoothed through compression of the coarse fraction into the substrate.

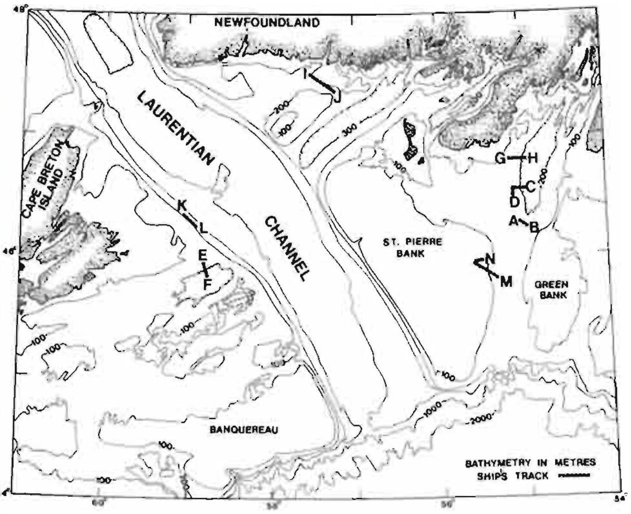

FIG. 11. Location map for the study area showing generalized bathymetry and an index for the side-scan sonograms; echosounder, airgun seismic, and Huntec (DTS) profiles illustrated in the report.

A study of the lithology of the coarse fractions from the glacial till samples has provided information on the source areas of the till deposits. The till on Rose Blanche Bank and adjacent areas differs from the glacial till in the Burin Moraine. From a study of 25 seabed samples, the average distribution of particle sizes in the Rose Blanche Bank deposits is 22% gravel, 53% sand, 15% silt, and 10% clay-sized sediment compared to 38% gravel, 38% sand, 20% silt, and 5% clay-sized sediment in 22 samples from the Burin Moraine deposit. The higher percentage of sand-sized sediment on Rose Blanche Bank reflects a local origin for the till through erosion of the underlying Pennsylvanian sandstone bedrock. The sand-sized fraction of the till is composed of iron-stained quartz grains, feldspar grains, rock fragments, dark minerals, and some coal fragments. The gravel fraction of the Rose Blanche Bank deposit of till contains granitic, metasedimentary, and sandstone fragments with minor amounts of limestone and volcanic fragments. These particle types are similar to the rocks found on land in the southwestern area of Newfoundland. The gravel fraction of the Burin Moraine contains metasedimentary, granitic, and volcanic rocks that are similar to the rocks of the Burin Peninsula to the northwest, and indicates glacial transport from there.

The survey of the map area using the Huntec (DTS) was limited and thus most measurements of the till thickness were made from airgun seismic reflection profiles. The thickness of the till varies considerably and is generally related to the morphology of the underlying bedrock surface, except in areas where end moraines occur. Areas underlain by sedimentary bedrock with a smooth surface are generally mantled with a more continuous deposit of till. Rough, undulating metamorphic and igneous terrain is usually covered with thinner discontinuous till. On the inner shelf south of Newfoundland, the till is usually less than 5 m thick. Little glacial till occurs in Hermitage and Fortune bays as is typical on land where valley glaciers rarely leave much ground moraine. The thickest deposits of glacial till (>50 m) occur in the moraines.

The Scotian Shelf end moraine system is represented in the map area by the Gabarus and the Scatarie moraines (King et al. 1972), which occur as a series of partially buried ridges of glacial till southeast of Cape Breton Island. The morainic system extends westward across the Scotian Shelf to the Gulf of Maine and probably joins with the New England Moraine at Cape Cod. The Scatarie Moraine consists of two major lobes at least 68 km long, 9 km wide, and 115 m thick (Fig. 14). The northern lobe is 6 km wide and forms a ridge 50 m thick. The Gabarus Moraine comprises a series of parallel lobes. The southwestern lobe is 7 km wide and

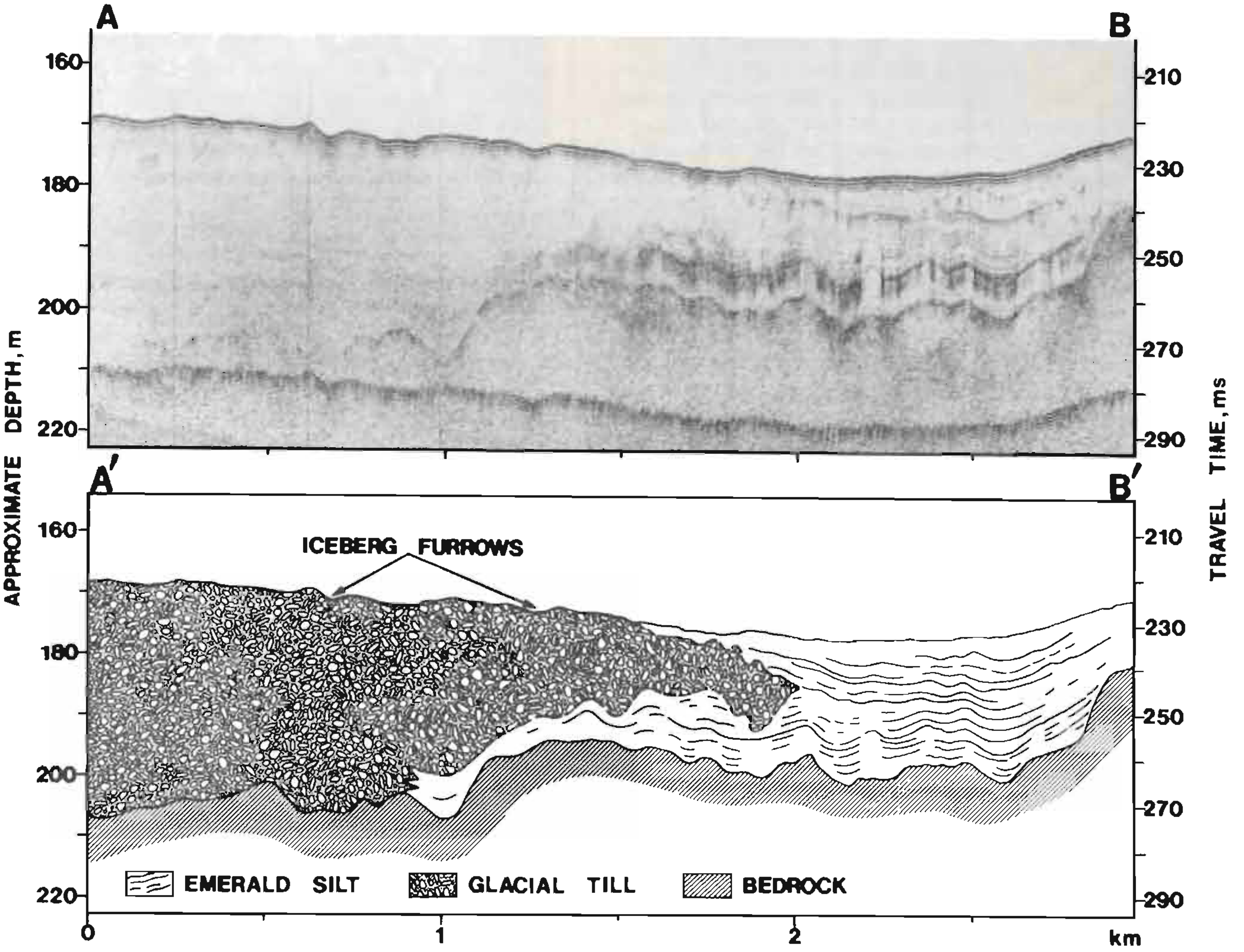

FIG. 12. Huntec (DTS) profile from the eastern side of the Burin Moraine. The glacial till is interbedded with the Emerald Silt, and iceberg furrows, interpreted from side-scan sonograms up to 3 m in depth, occur across the surface of the till.

82 m thick and the other minor lobes are a series of ridges about 20 m thick. The distal side of the Scatarie Moraine is much steeper than the proximal side and seaward the moraine is overlain by proglacial deposits of Emerald Silt.

The Laurentian Moraine occurs as a subsurface deposit of glacial till in Laurentian Channel northeast of St. Anns Bank. The feature trends in a northerly direction and is slightly arcuate. The moraine is overlain by Emerald Silt on its eastern side and Emerald Silt and LaHave Clay at its western edge. Glacial till in the moraine reaches a maximum thickness of 30 m and the feature is 30 km wide and over 70 km long. In cross section the moraine is wedge-shaped and the steeper eastern edge produces a prominent escarpment across the floor of Laurentian Channel, up to 30 m high. Huntec (DTS) profiles across the steeper distal side show an interbedded relationship between the till and the Emerald Silt (Fig. 12). This relationship also occurs at the front of the Burin Moraine. King (1970) recognized interbedding between Emerald Silt and glacial till on the Scotian Shelf, in the Halifax–Sable Island map area (Fig. 10). Recent studies on the Scotian Shelf (King 1979) and the eastern Grand Banks of Newfoundland using the Huntec (DTS) have shown that this is a common relationship.

Side-scan sonograms from the front of the Laurentian Moraine show that iceberg furrows cover the surface of the seabed (Fig. 15). Subsurface furrowing has also been interpreted from the seismic sections based on morphological comparisons. The relict buried furrows together with those developed at the seabed indicate a complex pattern. However, the glacial till surfaces appear to be furrowed the most. The subsurface furrows on the till are often mimicked in the overlying silt and clay. Thin discontinuous deposits of LaHave Clay occur across various areas of furrowed Emerald Silt overlying the moraine. These localized deposits are difficult to map because of their limited extent. The clay overlying the moraine increases in thickness to the west.

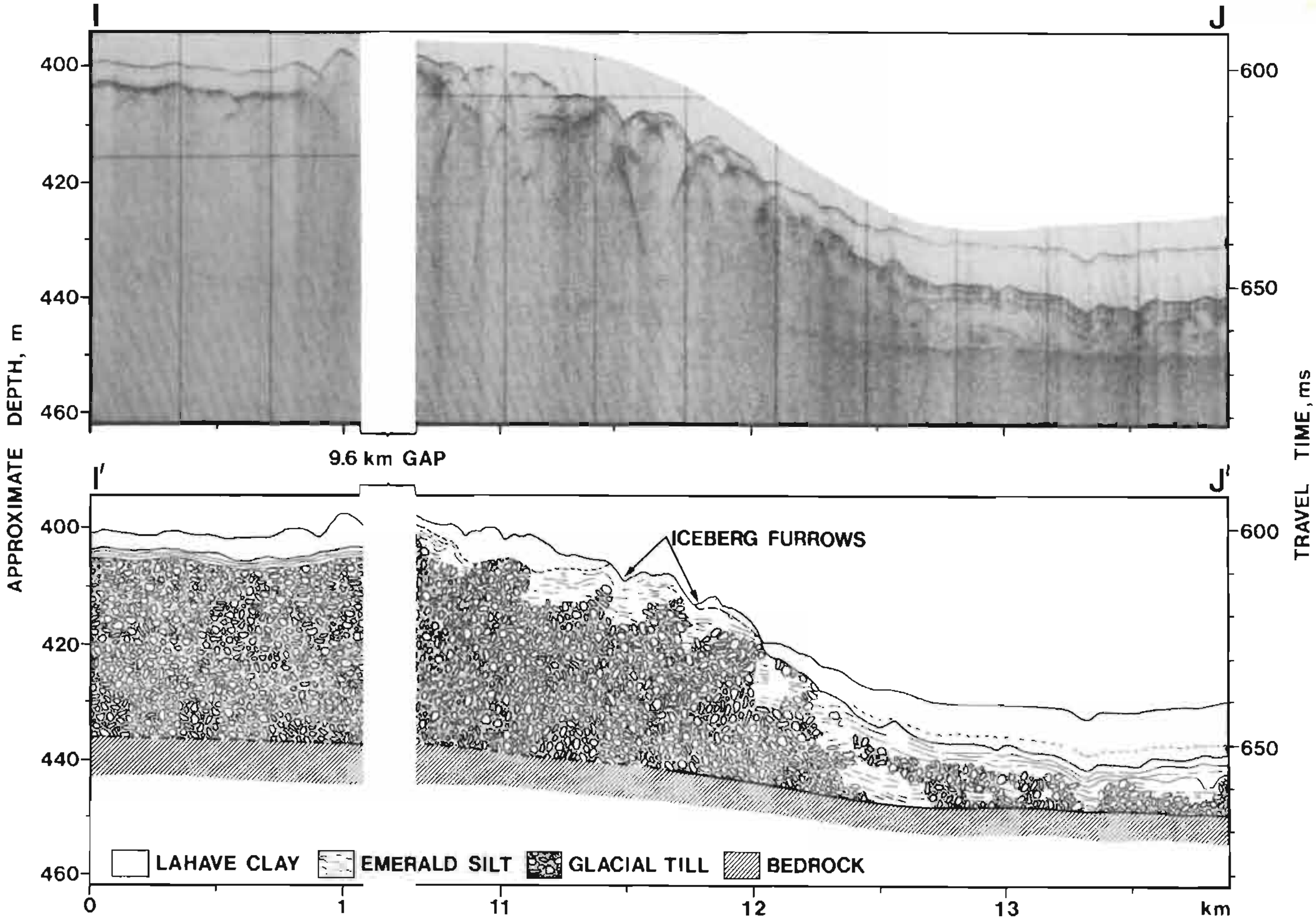

FIG. 13. Huntec (DTS) profile in Laurentian Channel at the eastern side of the Laurentian Moraine. Intensive furrowing from the 11-12-km marks has disturbed the coherent reflections within the Emerald Silt overlying the moraine. The section to the west shows the undisturbed stratigraphy. Figure 15 is a side-scan sonogram and interpretation from the same area.

The distribution of the Laurentian Moraine appears to be related to the morphology of the bedrock surface. The eastern edge of the moraine closely parallels the 439-m (240-fath) contour, and the entire feature is confined to a shallow, bedrock-controlled sill that separates the large basin of Cabot Strait from another basin to the southeast. This distribution of till together with the interbedded relationship between Emerald Silt and till at the distal side of the deposit suggest that the moraine may have been formed beneath a floating ice shelf in Laurentian Channel where the ice was sufficiently thick to contact the seabed in the shallow areas. On the flanks of Laurentian Channel and in other areas of the channel floor, the transition between glacial till and Emerald Silt occurs at similar depths. Minor variations in the present depth of the transition zone of glacial till and Emerald Silt can be accounted for by variations in the ice thickness at the time of deposition. The Laurentian Moraine therefore does not necessarily represent the easternmost limit of the Wisconsinan ice sheet in Laurentian Channel, but may only represent a zone where an ice shelf was grounded.

The Burin Moraine is continuous for at least 97 km (60 mi) along the western flank of Placentia Bay and may continue further to the northeast. It consists of a series of morainic ridges of glacial till connected by a thinner continuous sheet of ground moraine (Fig. 14). The moraine is 42 m thick at its highest point and its surface is covered with iceberg furrows (Fig. 16). In several areas within the moraine, bedrock highs protrude through the till surface. Unlike the Scatarie and Gabarus moraines of the Scotian Shelf, the Burin Moraine is not mantled with glaciomarine sediments or pockets of recent mud in depressions on its surface. At the southeastern boundary of the moraine, the glacial till is interbedded with proglacial Emerald Silt (Fig. 12). The high resolution seismic profiles show a well defined contact between these two formations; the interbedded relationship between glacial till and Emerald Silt probably occurs along a zone where the ice sheet became buoyant. These interbedded relationships at the front of the moraine together with lithologic correlations between the coarse fraction of the till in the Burin Moraine and the bedrock of the Burin Peninsula, indicate that the ice

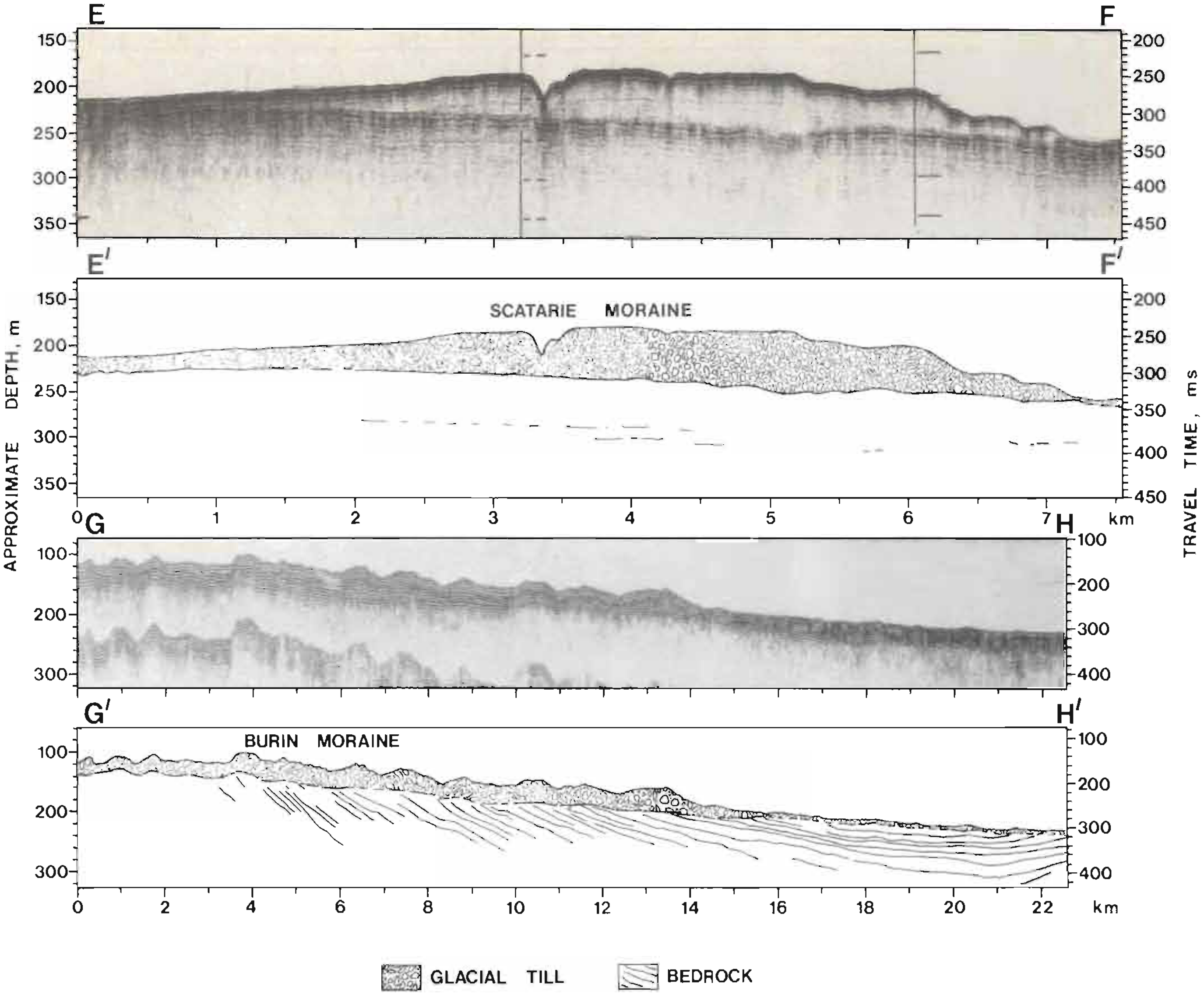

FIG. 14. Airgun seismic reflection profiles and interpreted sections across E-F Scatarie Moraine, Scotian Shelf, and G-H Burin Moraine, western Placentia Bay.

sheet that deposited the Burin Moraine did not move from an ice dome centered on the western Grand Banks of Newfoundland (Grant 1975; Tucker and McCann 1980).

A ^{14}C age of 22 200 ± 1450 years B.P. (GSC-2866) determined from the total organic carbon of Emerald Silt immediately overlying the Burin Moraine indicates that the moraine was fully developed before this time. This is in agreement with ages for deposition of Emerald Silt on the Scotian Shelf (King 1979), part of a program in progress to study the regional extent of the Wisconsinan ice sheet in the Maritime Provinces and the mechanism of marine glacial deposition on the continental shelf.

The Scotian Shelf moraines and the Burin Moraine appear to line up along a common front across the Scotian Shelf and western Grand Banks of Newfoundland. In the adjacent area of the Laurentian Channel, evidence suggests that the ice sheet was largely buoyant over most of the channel and was only grounded over a bedrock high where it deposited the Laurentian Moraine. To the west of the Burin Moraine, on St. Pierre Bank, a zone of isolated hummocks that may represent erosional remnants of a moraine that existed on St. Pierre Bank occurs, but was largely removed and modified during the Holocene transgression. The lateral continuity of the moraines on the Scotian Shelf and the shelf south of Newfoundland indicates that the ice that formed the moraines must have had a broad regional extent.

Emerald Silt (Map Unit 7) — Emerald Silt (map unit 7) is a term proposed by King (1970) for a proglacial silt that overlies the glacial till, and in the lower part of the

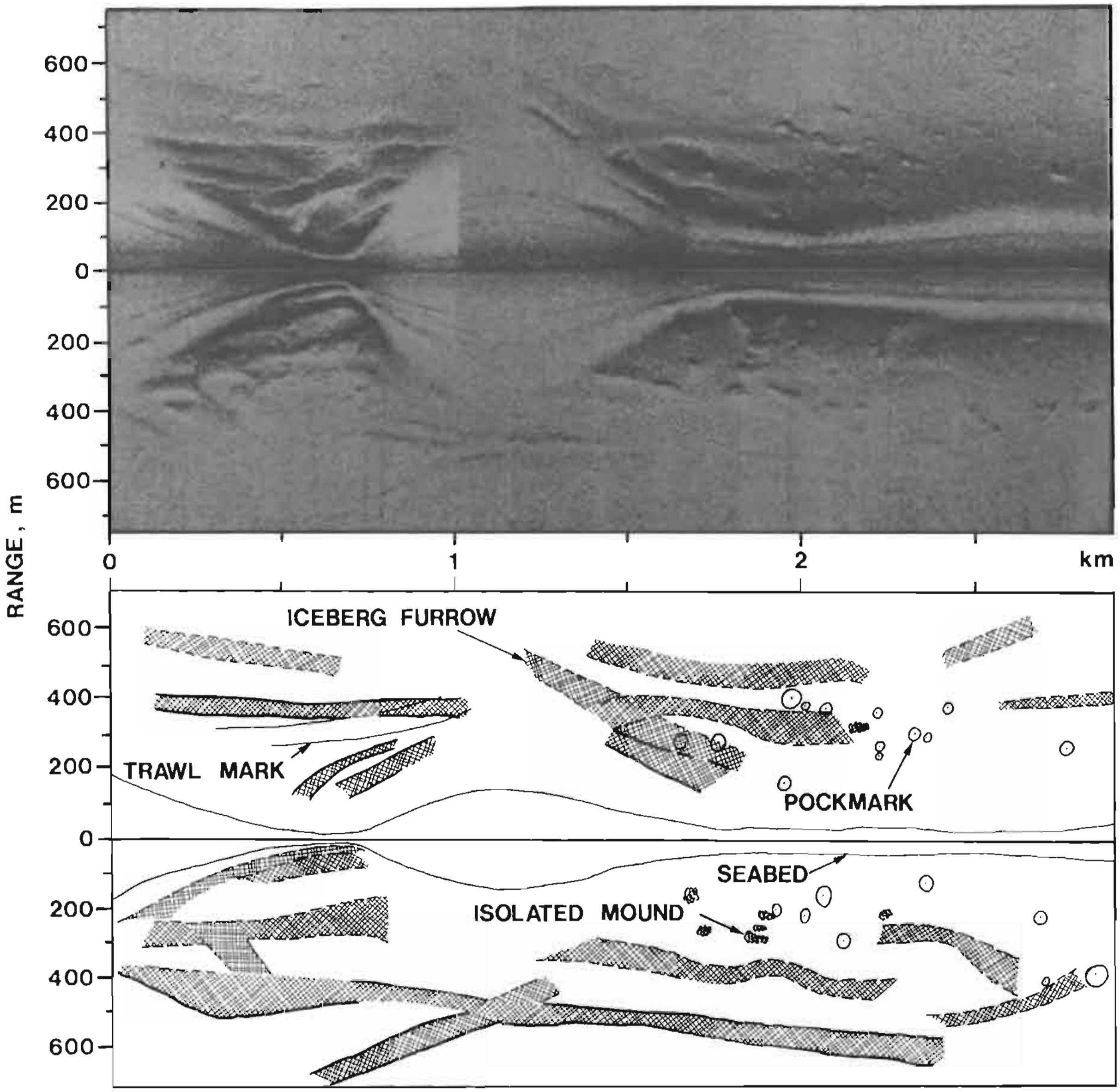

FIG. 15. Side-scan sonogram and interpretation from the eastern side of the Laurentian Moraine. Large iceberg furrows occur in the Emerald Silt overlying the moraine. At the 2-km mark along the profile isolated depressions, "pockmarks," range in size up to 60 m across, and may have formed by ascending gas or water from the underlying bedrock.

section interfingers with the till (Fig. 12, 13). It is a dark greyish-brown to greenish-brown, clayey and sandy silt (7a) that grades locally to a silty and clayey sand with minor angular gravel (7b). Plate III is a bottom photograph of an outcrop of the Emerald Silt from the Scatarie Moraine area.

Emerald Silt outcrops at the seabed in localized depressions on the Gabarus and Scatarie moraines. It overlies the Laurentian Moraine at the bottom of Laurentian Channel and occurs in depressions on the inner shelf between Burgeo Bank and the south coast of Newfoundland. It also outcrops at the mouth of Laurentian Channel, in Hermitage and Fortune bays, and south of the Burin Moraine. In the deeper basins, the Emerald Silt is frequently overlain by continuous deposits of LaHave Clay. In the subsurface, Emerald Silt occurs in Hermitage Channel, Fortune Bay, and the outer part of Hermitage Bay where it is very extensive and thick (up to 120 m). East of Cape Smokey, Cape Breton Island, Emerald Silt lies in a bedrock depression but its surface is modified and a thin layer of sand overlies the deposit. Most of Laurentian Channel is underlain by Emerald Silt in the subsurface. It also occurs in the subsurface of northeastern St. Pierre Bank but has been transgressed, eroded, and overlain with deposits of sand and gravel. The extent of Emerald Silt above the terrace on the outer bank areas is not well known, but recent studies on the eastern Grand Banks of Newfoundland with the

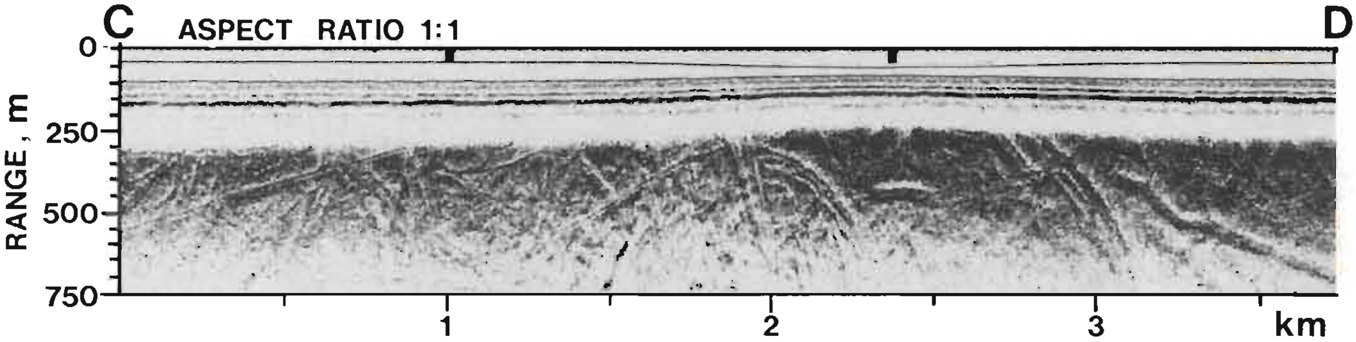

FIG. 16. Side-scan sonogram over an area of iceberg furrows across the Burin Moraine.

Huntec (DTS) indicate the presence of isolated pockets. In all cases these deposits of silt are overlain by a thin veneer of sand or gravel, and the surface of the silt is often defined by a marked erosional unconformity.

On the echo sounder profiles, Emerald Silt is represented by a small amount of pulse stretching followed by a deeper diffuse grey zone, representing a scattering of the acoustic energy from internal reflections. Emerald Silt, unlike the glacial till, is easily penetrated by the energy of the echo sounder, and continuous subbottom reflections occur within the formation. On the Huntec (DTS) profiles, Emerald Silt appears as a well stratified unit with many continuous coherent parallel reflections that are consistent over large areas. Figure 12 is a DTS profile from the southeastern front of the Burin Moraine. The silt is interbedded with glacial till, and this relationship is characteristic of the distal side of the entire moraine complex. Emerald Silt is difficult to interpret from airgun seismic reflection profiles because of the lower resolution; however, thick deposits appear as weak continuous coherent reflections. The Emerald Silt surface is generally smooth with gentle undulations. In areas where the formation is thin and overlies a rough surface of glacial till, the morphology of the till surface is mimicked by the surface of the silt. Unlike the Scotian Shelf, where only the glacial till surface is covered with iceberg furrows, Emerald Silt is extensively furrowed in the map area, especially on the shelf south of Newfoundland. From an interpretation of the side-scan sonograms, the furrows appear to be very similar to those developed on glacial till. Figures 13 and 15 show iceberg furrows developed on Emerald Silt in Laurentian Channel overlying the Laurentian Moraine. The furrows are up to 10 m deep and disrupt the coherent reflections developed in the upper section of the formation.

King (1970) interpreted the depositional history of the Emerald Silt on the Scotian Shelf and concluded that the formation was deposited from floating ice in front of a grounded ice sheet. Variations in texture were attributed to the influence of such factors as proximity of the ice front, topography of the seafloor, and oceanographic conditions. The texture of the Emerald Silt close to deposits of glacial till is very similar to that of the till, and high resolution seismic data are essential to differentiate the two. Where the silt is overlain by LaHave Clay, it is easily distinguished from the clay, which is acoustically transparent in contrast to the numerous continuous coherent reflections that occur within the silt. Close to the 115-120-m (63-65-fath) terrace, the surface of the silt has been modified, and local sand deposits are developed across its surface.

The occurrence of gas-charged zones (acoustic masks) within Emerald Silt has been interpreted at numerous localities indicated on the map. The high resolution seismic profiles over these areas show reflector terminations, inhibited acoustic penetration, and reflector pulldowns, all of which are acoustic anomalies usually associated with gas-charged sediment. The major occurrences are south of the Scatarie Moraine and in the nearshore zone of the fiords that indent the southern coast of Newfoundland. Figure 17 is a Huntec (DTS) profile across an area of gas-charged sediment at 45°31′N, 59°40′W. On the Scotian Shelf, the gas-charged sediments usually occur overlying relict subaerial drainage channels cut into bedrock in which thick deposits of glacial and postglacial sediment have accumulated. Airgun seismic reflection profile systems will penetrate the zones and resolve seismic events at depth. Often the gas-charged sediment appears as an anomalously strong reflector on the seismic reflection profiles, and the presence of gas along particular horizons can enhance the reflectivity locally. No samples of the gas were obtained within the map area but similar gas-charged sediments from the Grand Banks of Newfoundland to the east contain methane (King and Fader 1976). The gas-charged zones occur at various depths within the surficial formations, but on average at about a 10-m depth. Gas-charged zones also occur within the LaHave Clay.

Sambro Sand (Map Unit 8) — Sambro Sand is a term proposed by King (1970) for a sand formation below the submarine terrace at 115-120 m (63-65 fath). It is a dark, greyish-brown, fine- to coarse-grained sediment containing some silt- and clay-sized particles, and gravel (see Plate IV). Areas with less than 10% gravel are designated as map unit 8a, and as 8b with more than 10%. Sambro Sand is easily differentiated from samples of Sable Island Sand and Gravel since the latter does not

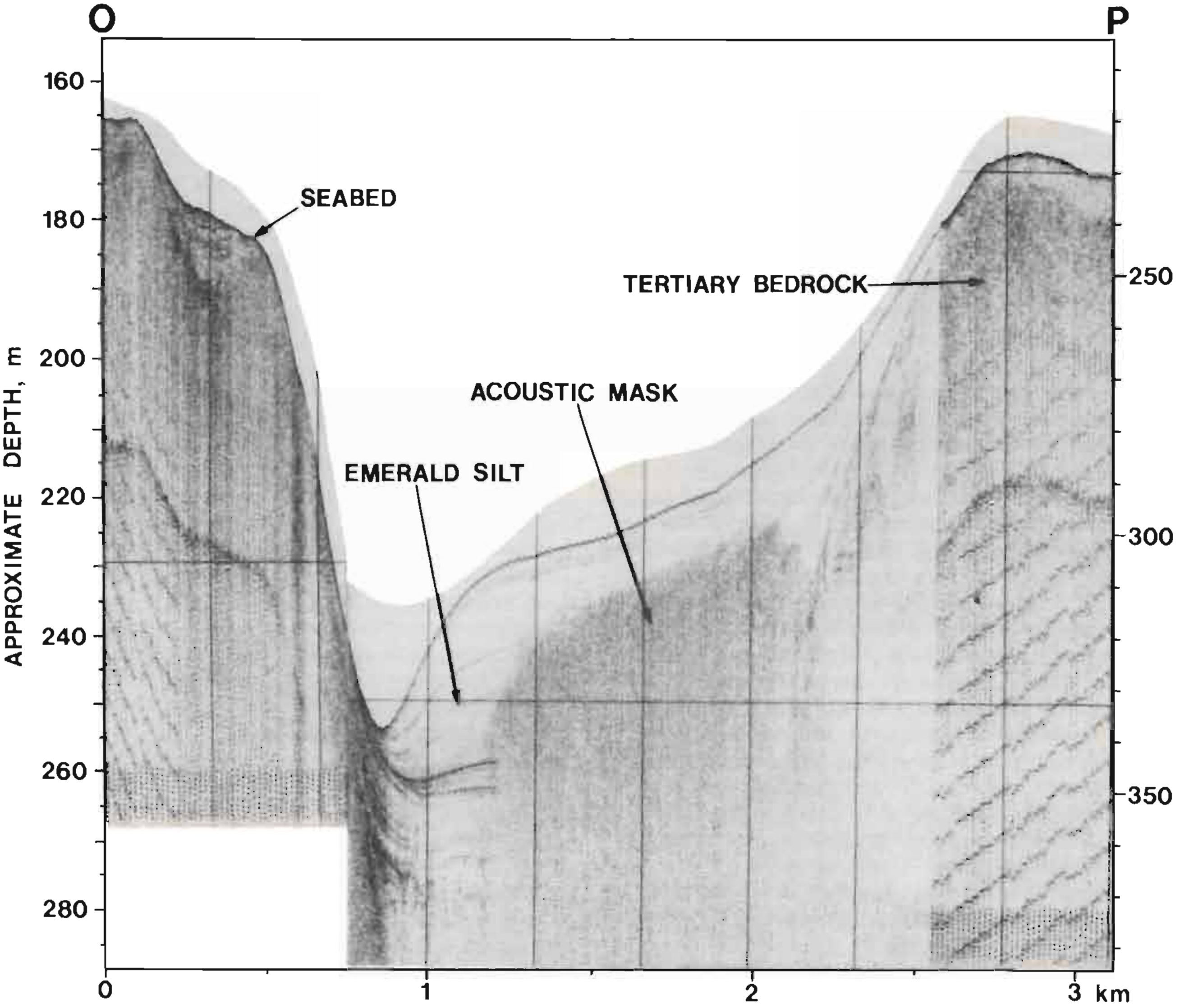

FIG. 17. Huntec (DTS) profile across a zone of gas-charged sediment in a relict bedrock channel. The gas appears on the profile as a diffuse grey zone and prevents the resolution of geological events at depth. Reflections within the Emerald Silt, terminate at the edge of the "acoustic mask."

contain silt- and clay-sized sediment. Foraminiferal tests, sponge spicules, radiolaria, and broken shell fragments occur in abundance within the sand-sized fraction.

For the most part, Sambro Sand fringes the bank and nearshore zones and occurs along the edge of Laurentian Channel. Where the seabed has a gentle slope, the formation is developed over large areas, such as in Halibut Channel. In some areas it is derived through erosion of the underlying glacial till or Emerald Silt and constitutes a thin lag deposit. In other areas it is a depositional formation of substantial thickness. Sambro Sand often consists of a veneer deposit, and is usually less than 0.3 m thick as determined from the Huntec (DTS) profiles; however, it can thicken locally to 11 m to form sand wave fields. Adjacent to the south coast of Newfoundland, where the seabed is very rough, bedrock sometimes outcrops through a thin Sambro Sand cover.

Acoustically, Sambro Sand is recognized by a high degree of pulse stretching on echograms and a lack of penetration. Figure 18 is a Huntec (DTS) profile across a 4-m thick deposit of Sambro Sand, south of the Burin Peninsula. On this profile, the Sambro Sand is represented by continuous coherent reflections. Because the sand normally occurs as a very thin veneer, samples or reflectivity measurements are needed for identification. The boundary between Sable Island Sand and Gravel and Sambro Sand occurs at the 115–120-m (63–65-fath) contour, except in the eastern part of the Burin Moraine, several nearshore areas along the south coast of Newfoundland, and off the southeast coast of Cape Breton Island. In these areas, localized late glacial ice either affected the isostatic history and raised the level of the terrace, or prevented its formation. The boundary between the LaHave Clay and the Sambro Sand is gradational.

Iceberg furrows occur across many areas of Sambro Sand and are concentrated on the flanks of Laurentian Channel. The occurrence of these furrows is attributed to late glacial ice in the Gulf of St. Lawrence and along the south coast of Newfoundland; this ice was the source of many icebergs in the study area during the early Holocene transgression. The symbolized side-scan interpretation on the map shows the distribution of furrows along the survey tracks. Figure 7 is a side-scan profile and echogram over an area of Sambro Sand at the western edge of Laurentian Channel; it shows the intensity of furrowing. In areas where the Sambro Sand is heavily furrowed, it is difficult to differentiate the Sambro Sand from the glacial till, especially on the echograms, and therefore bottom samples or Huntec (DTS) data are essential to identify the formations. MacLean and King (1971) mapped several areas along the edge of Laurentian Channel as glacial till, from echograms that we now interpret as Sambro Sand. Many of the furrows on Sambro Sand do not appear as fresh as those on glacial till and are slightly modified through infilling and partial burial. Often, only the coarse rims of the furrows remain as evidence of furrowing. In an area adjacent to St. Paul's Island, iceberg furrows are numerous but appear to be slightly buried and modified. Numerous fresh furrows occur along the edge of St. Anns Bank. Areas of Sambro Sand that are not furrowed appear on side-scan sonograms as patches of sand and gravel.

In Halibut Channel, Sambro Sand occurs in a saddlelike depression between Green and St. Pierre banks. Much of the deposit is modified Emerald Silt that contains little gravel-sized sediment. Numerous sand waves occur across the seabed with a maximum height of 8 m, and wavelengths as long as 305 m. The sand waves shown on Map 4015-G are concentrated in the central area of Halibut Channel. They have been interpreted mainly from echogram profiles and limited side-scan sonar control and may be more extensive than indicated. The largest sand waves of Sambro Sand lie east of Banquereau Bank at the mouth of Laurentian Channel, and have a maximum height of 11 m.

The Sambro Sand north of the Burin Moraine has a high gravel content which results from erosion of the surface of the glacial till. The Sambro Sand that fringes Burgeo Bank has a high sand content (62%), and originates from reworked local till derived from the underlying sandstone bedrock. In this area sandstone fragments dominate the lithology of the gravel-sized fraction of the Sambro Sand. These textural and lithological comparisons illustrate the relationships between the underlying bedrock and the glacial and modified glacial products.

On St. Anns Bank, east of Cape Breton Island, Sambro Sand represents modified glacial till and in some areas, Emerald Silt. Several samples close to shore off Cape North, Cape Breton Island, are mica-rich sands, while most others contain a large amoung of red, iron-stained quartz fragments.

LaHave Clay (Map Unit 9) — LaHave Clay (map unit 9) is a term proposed by King (1970) for a formation of silty clay (9a) and clayey silt (9b). In the present map area, a coarse facies of the clay (9c) contains more than 20% sand-sized sediment. This sand-sized fraction may contain up to 40% biogenic material including fora-

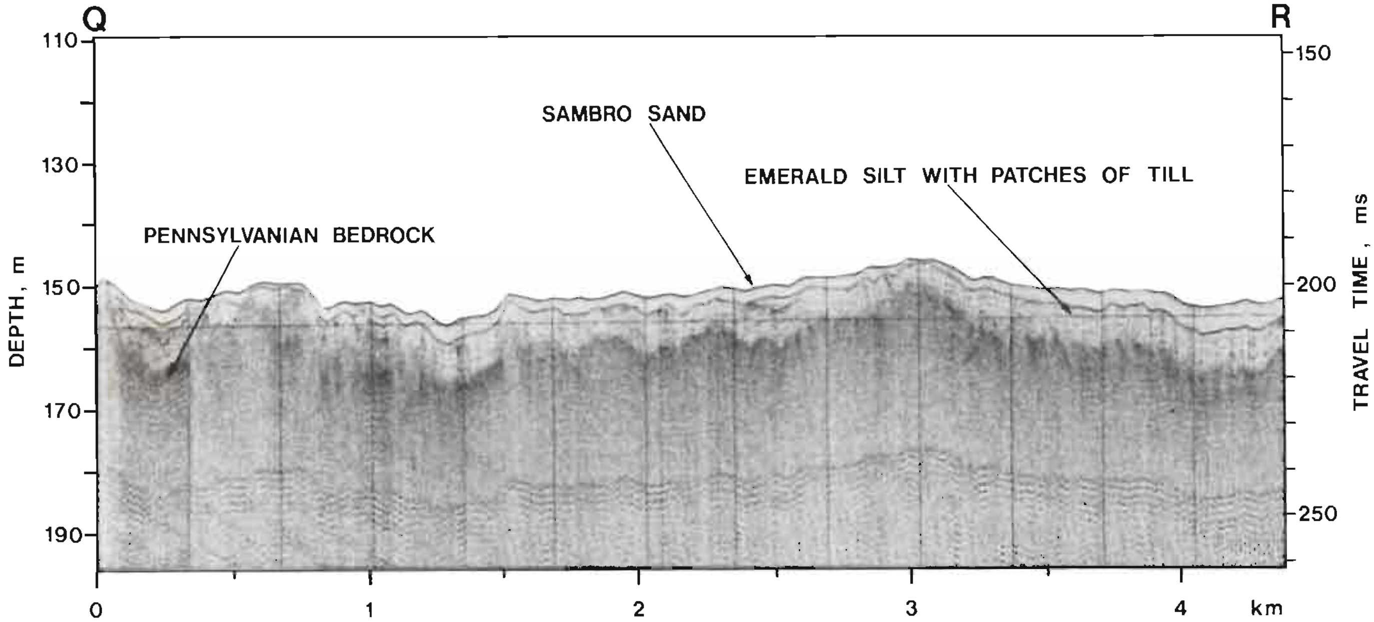

FIG. 18. Huntec (DTS) profile across a 4-m thick deposit of Sambro Sand overlying Emerald Silt and glacial till adjacent to the Burin Moraine.

miniferal tests, sponge spicules, diatoms, radiolaria, fecal pellets, and shell fragments. Within the map area the formation is mainly a clayey silt that grades to a sandy silt (Plate V). LaHave Clay is dark greyish brown to dark olive, and remarkably homogeneous. It is mainly confined to the basins and local depressions on the shelf. It is the dominant surficial formation exposed at the bottom of Laurentian Channel and occurs in a trough between Burgeo Bank and the south coast of Newfoundland, in Hermitage Channel and Bay, and floors much of Fortune Bay. Along the south coast of Newfoundland, LaHave Clay is found very close to the shoreline and probably extends inland within the numerous fiords. On the Scotian Shelf, it occurs in the deep depressions between the inner and outer shelf, and is ponded in depressions developed on the surface of the moraines. In Laurentian Channel, over the Laurentian Moraine, small localized deposits of LaHave Clay overlie the Emerald Silt but are of such limited extent that they cannot be mapped. LaHave Clay reaches a maximum thickness of 30 m in the Cabot Strait area and several cores of it were taken in Laurentian Channel. Core number 351 (46°34′N, 58°24′W) penetrated 5.5 m of LaHave Clay overlying 4 m of Emerald Silt. The average composition of LaHave Clay was 8% sand-, 30% silt- and 62% clay-sized sediment. In some samples the sand fraction consisted of up to 50% foraminiferal tests and pyrite in the form of worm tube infillings.

LaHave Clay is characterized on echogram profiles by its acoustical transparency and lack of internal reflections, and the return pulse from the seabed shows limited pulse stretching. The surface of the formation is generally flat, and subbottom horizons beneath the clay can be delineated on the echograms. On the Huntec (DTS) profiles (Fig. 13), LaHave Clay is acoustically transparent with weak continuous parallel reflections, and contrasts against the strong continuous coherent reflections of the Emerald Silt.

LaHave Clay overlies the Emerald Silt and the glacial till, and is a time equivalent of the Sable Island Sand and Gravel. Where LaHave Clay occurs close to the terrace at 115-120 m (63-65 fath), the contact between the clay and the Sambro Sand is gradational. Near the terrace, adjacent to the moraines, and in the deep depressions along the south coast of Newfoundland, the clay is also coarser. It was derived during the Holocene transgression from the erosion of Emerald Silt and glacial till that had been previously deposited on the shallow banks and nearshore areas. A minor component is derived from river systems that drain the adjacent land areas and from erosion along the present shorelines.

The LaHave Clay surface is generally flat, but may be undulating where the clay is thin and overlies rough surfaces of Emerald Silt or glacial till. Unlike the surface of the clay on the Scotian Shelf, iceberg furrows occur in Hermitage Channel and on the inner shelf north of Burgeo Bank. The distribution of iceberg furrows in the clay may be more extensive than indicated as a result of the limited side-scan coverage over deep LaHave Clay deposits. The greatest concentration of furrows in LaHave Clay occurs north of Burgeo Bank where they are up to 6 m deep. The distribution of iceberg furrows on the LaHave Clay, especially in the inner trough north of Burgeo Bank, indicates that the icebergs originated from late glacial ice on Newfoundland as no icebergs now occur in this area. The numerous deep fiords that indent the south coast may have funneled the icebergs to the shelf areas. Little modification of the furrows has taken place since their formation as they are not infilled. This also suggests that the LaHave Clay was deposited before the ice retreated from the coastal areas of Newfoundland.

In several large basins on the western Scotian Shelf, numerous cone-shaped depressions (pockmarks) occur in LaHave Clay and Emerald Silt, and have been identified and described by King and MacLean (1970b) and Josenhans et al. (1978). Pockmarks are thought to be formed by ascending gas or water from the underlying sediments and appear to be confined to areas overlying sedimentary bedrock. Within the study area, pockmarks occur on the LaHave Clay in front of the Laurentian Moraine at the bottom of Laurentian Channel. Figure 15 is a side-scan sonogram and interpretation of these pockmarks, which are 20-60 m in diameter. Side-scan sonar data are essential for positive identification of pockmarks because in cross section they resemble iceberg furrows. In the deepest part of Cabot Strait between Cape Breton Island and Newfoundland, a large area of depressions (some over 20 m deep) occurs in LaHave Clay. It is unlikely that these depressions result from iceberg furrowing because they occur only in the deepest area of Cabot Strait and not on the flanks. Side-scan data are lacking because of the great depths; therefore the geometry of the depressions is not known. The depressions are concentrated in the Cabot Strait area where current flow is restricted and velocities are higher; therefore, they may be the result of erosion of LaHave Clay.

Gas-charged zones (acoustic masks) occur within the LaHave Clay in the fiords and inner bays along the south coast of Newfoundland. On the seismic reflection profiles, the gas-charged sediments appear similar to the gas-charged zones of Emerald Silt (Fig. 17).

Sable Island Sand and Gravel (Map Unit 10) — Sable Island Sand and Gravel is a term proposed by King (1970) for a basal transgressive sand and gravel formation that occurs in water depths of less than 115-120 m (63-65 fath), above the submarine terrace. The formation occurs mainly across the bank areas and inner shelf zones. It consists of clean reddish to greyish-brown, fine- to coarse-grained, well sorted sand that grades locally to coarse, well rounded gravel with large boulders.

Sable Island Sand and Gravel is divided into two members: 10a, sand with less than 50% Gravel (Plate VI); and 10b, gravel with less than 50% sand (Plate VII). Texturally, the formation is easily distinguished from the sublittoral Sambro Sand which contains up to 15% silt- and clay-sized sediments, whereas in areas of

Sable Island Sand and Gravel the fine fraction is absent.

Side-scan sonar data have been particularly helpful in mapping the distribution of the sand and gravel deposits and their associated bedforms. Because of the depth limitations of the system, most of the side-scan information has been collected in the shallower areas where the sand and gravel deposits occur. The interpretation of the sand and gravel distributions has been symbolized on the map along the track lines of the collected data.

Acoustically, Sable Island Sand and Gravel is characterized on the echograms by a high degree of pulse stretching and no penetration or resolution of subbottom events. On the echograms, the gravel and sand cannot be differentiated and must be supplemented with samples and side-scan sonar information. On the side-scan sonograms, gravel contrasts well with sand. The gravel areas show as uniformly dense, dark patches as opposed to much lighter toned areas for the sand (Fig. 8). Sable Island Sand and Gravel is generally less than 15 m thick. In some areas, it occurs as a thin lag overlying glacial till and Emerald Silt deposits that were not completely removed during the Holocene transgression. This situation occurs in isolated depressions such as buried drainage channels, and on some areas of the outer banks. The Holocene transgression was a very effective mechanism for eroding and sorting materials deposited above the 115–120-m (63–65-fath) terrace on the inner shelf, and in most places the glacial till was completely removed. On the bank areas, the seabed is generally flat with little relief. On the inner shelf, the seismic reflection profiles indicate that in areas of high relief, the slope of the seabed is mainly controlled by the morphology of the underlying bedrock, and the gravel and sand deposits occur as infillings between adjacent highs.

The surface of Banquereau Bank consists of clean, light grey sands composed of well rounded and well sorted quartz grains (MacLean and King 1971). Glauconite is found in amounts from 2 to 4% and was probably derived from the underlying bedrock. St. Anns Bank is overlain by approximately equal distributions of sand- and gravel-sized sediments. The gravel-sized fraction consists of subrounded fragments of buff to red sandstone, with lesser amounts of granitic, volcanic, and metamorphic rocks. Most gravels are subangular to subrounded, and occur in the pebble to cobble size range. Shell fragments are numerous across the bank. Bedrock outcrops at the seabed in a nearshore zone off Cape Smokey and in the Scatarie Bank area. Numerous large boulders have been interpreted from side-scan sonograms near Scatarie Bank. The greatest density of sand patches lies northeast of Sydney near the seaward edge of the bank. The sand patches are interpreted as isolated lenses overlying a gravel lag. A field of large sand waves with a period of 100 m and a maximum height of 3 m, occurs on the southern part of St. Anns Bank. Smaller sand waves occur close to the shore north of Point Aconi, Cape Breton Island, and to the east of Aspy Bay. Near the seaward edge of St. Anns Bank and along the western side of Laurentian Channel, remnant rims of iceberg furrows are interpreted from the side-scan sonograms, and occur on Sable Island Sand and Gravel. They are few in number, partially buried, and probably resulted from furrowing by late glacial ice in the Gulf of St. Lawrence.

Adjacent to the south coast of Newfoundland, Sable Island Sand and Gravel occurs in a narrow zone, the width of which is limited by the steeper gradients of the shelf. The gravel fraction of the samples consists of granitic, volcanic, and metasedimentary rocks.

Shell material can constitute up to 50% of the sand- and gravel-sized fraction of some samples (Plates X, XI). On the shelf east of Cape Breton Island and south of Newfoundland, the gravel-sized fraction is frequently coated with *Lithothamnia*, a pink calcareous bryozoan (Plate VII). Ninety per cent of the gravel fraction from the surficial samples of Burgeo Bank was coated with *Lithothamnia*. Burgeo Bank is covered with well rounded gravel that consists of fragments of red sandstone with minor granitic and metasedimentary material. Broken calcareous shell debris constitutes up to 50% of many of the samples from Burgeo Bank.

The largest deposit of Sable Island Sand and Gravel in the map area occurs on St. Pierre Bank. From an interpretation of the side-scan sonograms across the bank, much detail can be obtained on the relative distributions of the sand and gravel deposits. The samples alone do not define the complex distributions. Sand deposits are mainly confined to the eastern and southeastern area of the bank (Plate IX) and gravel occurs along its central and western portions. Sand waves and megaripples with wavelengths of between 1 and 200 m occur across St. Pierre Bank and are concentrated in the eastern and southeastern areas. The underwater photographs (Plates VI, VIII) show detailed variations in texture across individual bedforms. Many of the troughs of the sand waves contain coarser sediment and shell debris (Plate X). The bedforms on the western side of St. Pierre Bank have wavelengths of up to 200 m, much larger than the average of 10 m on the eastern side of the bank.

Lunate asymmetrical megaripples (Fig. 8, 9) occur on the edge of St. Pierre Bank adjacent to Halibut Channel. These megaripples are barchanlike in shape (King 1976). In the same area, the rims of relict iceberg furrows occur just above the terrace on the edge of the bank. Although somewhat modified, their preservation associated with the terrace indicates that little modification of the seabed has occurred since their formation. This also supports the idea that the megaripples and sand waves in similar depths are also relict, and were formed by strong tidal currents when eustatic sea level was much lower.

In the shallow areas of the banks and on the inner shelf where Sable Island Sand and Gravel deposits occur, it is difficult to determine whether the materials are relict or modern. Detailed bottom current information is lacking, and a better understanding of the sedimentary environment is needed. From a study of the numerous bottom photographs over areas of sand waves, it appears that in the shallowest depths the sediments are being modified in response to the present hydrodynamic regime. However, the degree of modification is not fully understood.

GLACIAL AND POSTGLACIAL HISTORY

On the Scotian Shelf, glacial erosion was moderate and only locally modified the preexisting subaerial bedrock surfaces. The Laurentian Channel and western Grand Banks of Newfoundland map area underwent extensive glacial erosion as evidenced by the fiordlike character of Laurentian Channel with its straight parallel sides, hanging valley tributaries such as Hermitage Channel, and extensively overdeepened depressions adjacent to the south coast of Newfoundland. However, the degree of glacial modification is difficult to establish because the detailed configuration of the pre-Pleistocene erosional surface is not known. It is also difficult to separate the effects of earlier glaciations. The surficial sediments that resulted from deposition during previous glacial periods have been largely redistributed by the most recent glaciation.

An end moraine complex, with a more or less straight common front from the Scotian Shelf to the western Grand Banks, marks the limit of the grounded ice sheet during the Wisconsinan glacial period. A ^{14}C age of 22 200 years B.P. derived from proglacial sediments directly overlying the moraine south of the Burin Peninsula, indicates that the ice sheet was fully developed by this time and in a stage of retreat. The Laurentian Moraine occurs at the bottom of Laurentian Channel over a bedrock sill and the till is interbedded with the proglacial Emerald Silt. On the basis of regional studies on the extent of the Wisconsinan glaciation and the distribution of the glacial till and Emerald Silt, we think that the Late Wisconsinan ice sheet was largely buoyant over most of Laurentian Channel and only touched the seabed over topographic highs. This suggests that the configuration of the glacial morphology of Laurentian Channel was formed by earlier glaciation. It also explains the isolated existence of the Laurentian Moraine on the bedrock sill. The limit of ice advance on St. Pierre Bank cannot be accurately established because the subsequent Holocene transgression removed much of the evidence for its existence.

Beneath the grounded ice sheet a near continuous cover of glacial till was emplaced. As the ice sheet retreated, the surface of the glacial till was heavily furrowed by icebergs, and the proglacial Emerald Silt was deposited from floating ice over the glacial till. Milliman and Emery (1968) indicated that eustatic sea level reached its lowest point at 15 000 years B.P. and from the consistent depth at which the low sea-level terrace occurs in the study area, it appears that the ice had receded from most of the shelf area, and that isostatic rebound had occurred before this time. During the low sea-level stand, the Sambro Sand was developed in the adjacent sublittoral zone through reworking and deposition on the glacial till and Emerald Silt. As sea level rose, the bank and inshore areas were transgressed, and the glacial till and Emerald Silt previously deposited above the low sea-level stand were largely eroded. Lag deposits of well rounded gravel and well sorted sands (Sable Island Sand and Gravel) developed, and in some areas of the inner shelf bedrock was partially exposed. The winnowed fines were deposited in the adjacent basins to form the LaHave Clay.

All the surficial formations in the map area are furrowed to varying degrees, unlike the Scotian Shelf to the west where iceberg furrows are confined to glacial till surfaces. The presence of furrows on all formations is attributed to late glacial ice from Newfoundland, parts of Cape Breton Island, and the Gulf of St. Lawrence. The late glacial icebergs had easy access to the shelf through the numerous fiords that occur along the south coast of Newfoundland. The undulations developed by iceberg furrowing impart unique characteristics to the structure, morphology, and texture of the surficial formations.

The presence of raised marine deposits (possible lateral equivalents of the Emerald Silt) along the south coast of Newfoundland dated at 13 500 ± 210 years B.P. (GSC-1200) (Brookes 1977), also indicates the existence of late glacial ice on Newfoundland. This ice delayed isostatic rebound of the coastal areas unlike the adjacent offshore where removal of the ice and subsequent rebound occurred much earlier. This late ice may have extended offshore and in some areas prevented the formation of the terrace. Later isostatic rebound concurrent with ice removal raised the position of the terrace developed during the low sea-level stand in the coastal areas. This may account for some of the difficulties in determining the depth of the terrace from sample and seismic control along the south coast of Newfoundland.

The presence of the most recent relict iceberg furrows indicates that the distribution of the surficial formations has changed little during at least the last 10 000 yr except in the very shallow areas where the Sable Island Sand is being modified in response to the modern hydrodynamic regime. The occurrence of these furrows and lack of sediment infill on LaHave Clay also indicate that little deposition of sediment has occurred since their formation.

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REFERENCES

Brookes, I. A. 1969. Late glacial-marine overlap in western Newfoundland. Can. J. Earth Sci. 6: 1397-1404.

1970a. The glaciation of southwestern Newfoundland. Ph.D. thesis, McGill Univ., Montreal, Que.

1970b. New evidence for an independent Wisconsin-age ice cap over Newfoundland. Can. J. Earth Sci. 7: 1371-1382.

1977. Radiocarbon age of Robinson's Head moraine, west Newfoundland, and its significance for postglacial sea level change. Can. J. Earth Sci. 14: 2121-2126.

Coleman, A. P. 1926. The Pleistocene of Newfoundland. J. Geol. 34: 193-222.

Dinsmore, R. P. 1972. Ice and its drift into the North Atlantic Ocean, p. 89-127. *In* Symposium on Environmental Conditions in the Northwest Atlantic. 1960-1969. Int. Comm. Northwest Atl. Fish. Spec. Publ. 8.

Fader, G. B., L. H. King, and B. MacLean. 1977. Surficial geology of the eastern Gulf of Maine and Bay of Fundy. Mar. Sci. Pap. 19; Geol. Surv. Can. Pap. 76-17: 23 p.

Fernald, M. L. 1925. Persistence of plants in unglaciated areas of Boreal America. Am. Acad. Arts Sci. Mem. 15, No. 3: 237-342.

Grant, D. R. 1971. Glaciation of Cape Breton Island, p. 115-120. *In* Report of Activities, Part B. Geol Surv. Can. Pap. 71-1B.

1975. Glacial features of the Hermitage-Burin Peninsula area, Newfoundland, p. 333-334. *In* Report of Activities, Part C. Geol. Surv. Can. Pap. 75-1C.

1977. Glacial style and ice limits, the Quaternary stratigraphic record and changes of land and ocean level in the Atlantic Provinces, Canada. Geog. Phys. Quat. XXXI: 247-260

Henderson, E. P. 1972. Surficial geology of Avalon Peninsula, Newfoundland. Geol. Surv. Can. Mem. 368: 121 p.

Hutchins, R. W. 1974. Computer simulation of a transiently excited underwater sound projector. Ocean '74, p. 115-119. Proc. Inst. Electr. Electron. Eng. Int. Conf. Eng. Ocean Environ., Halifax, N.S. Vol. 2. Institute of Electrical and Electronic Engineers, Inc., New York, NY.

Hutchins, R. W., D. L. McKeown, and L. H. King. 1976. A deep tow high resolution seismic system for continental shelf mapping. Geosci. Can. 3: 95-100.

Jenness, S. E. 1960. Late Pleistocene glaciations of eastern Newfoundland. Geol. Soc. Am. Bull. 71: 161-180.

Jollymore, P. G. 1975. A medium range side-scan sonar for use on coastal waters. Design criteria and operational experiences, p. 108-114. Proc. Inst. Electr. Electron. Eng. Int. Conf. Eng. Ocean Environ., Halifax, N.S. Vol. 2. Institute of Electrical and Electronic Engineers, Inc., New York, N.Y.

Josenhans, H. W., L. H. King, and G. B. Fader. 1978. A side-scan sonar mosaic of pockmarks on the Scotian Shelf. Can. J. Earth Sci. 15: 831-840.

Keen, M. J. 1970. A possible diapir in the Laurentian Channel. Can. J. Earth Sci. 7: 1561-1564.

King, L.H. 1967a. Use of a conventional echo sounder and textural analyses in delineating sedimentary facies: Scotian Shelf. Can. J. Earth Sci. 4: 691-708.

1967b. On the sediments and stratigraphy of the Scotian Shelf, p. 71-92. *In* E. R. W. Neale and H. Williams [ed.] Collected papers in geology of the Atlantic Region. Geol. Assoc. Can. Spec. Pap. 4.

1970. Surficial geology of the Halifax-Sable Island map area. Mar. Sci. Pap. 1: 16 p.

1972. Relation of plate tectonics to the geomorphic evolution of the Canadian Atlantic Provinces. Geol. Soc. Am. Bull. 83: 3083-3090.

1976. Relict iceberg furrows on the Laurentian Channel and western Grand Banks. Can. J. Earth Sci. 13: 1082-1092.

1979. Aspects of regional surficial geology related to site investigation requirements — Eastern Canadian Shelf. International Conference, Offshore Site Investigation. The Society for Underwater Technology, London, Preprint: 34 p.

1980. Aspects of regional surficial geology related to site investigation requirements — Eastern Canadian Shelf. *In* Offshore Site Investigation Graham Trotman Ltd., London.

King, L. H., and G. B. Fader. 1976. Application of the Huntec deep tow high-resolution seismic system to surficial and bedrock studies — Grand Banks of Newfoundland, p. 5-7. *In* Report of Activities, Part C. Geol. Surv. Can. Pap. 76-1C.

King, L. H., and B. MacLean. 1970a. Origin of the outer part of the Laurentian Channel. Can. J. Earth Sci. 7: 1470-1484.

1970b. Pockmarks on the Scotian Shelf. Geol. Soc. Am. Bull. 81: 3141-3148.

1976. Geology of Scotian Shelf and adjacent areas. Mar. Sci. Pap. 7; Geol. Surv. Can. Pap. 74-31: 31 p.

King, L. H., B. MacLean, and G. Drapeau. 1972. The Scotian Shelf submarine end moraine complex, p. 237-249. *In* Marine geology and geophysics; 24th Int. Geol. Congr., Sect. 8.

King, L. H., B. MacLean, and G. B. Fader. 1974. Unconformities on the Scotian Shelf. Can. J. Earth Sci. 11: 89-100.

Loring, D. H., and D. J. G. Nota. 1973. Morphology and sediments of the Gulf of St. Lawrence. Fish. Res. Board Can. Bull. 182: 147 p.

MacClintock, P., and W. Twenhofel. 1940. Wisconsinan glaciation of Newfoundland. Geol. Soc. Am. Bull. 51: 1729-1756.

MacLean, B., G. B. Fader, and L. H. King. 1977. Surficial geology of Canso Bank and adjacent areas. Mar. Sci. Pap. 20; Geol. Surv. Can. Pap. 76-15: 11 p.

MacLean, B., and L. H. King. 1971. Surficial geology of the Banquereau and Misaine Bank map-area. Mar. Sci. Pap. 3; Geol. Surv. Can. Pap. 71-52: 19 p.

McKeown, D. L. 1975. Evaluation of the Huntec ('70) Hydrosonde deep tow seismic system. Bedford Institute of Oceanography, Report Series, 75-4: 115 p.

Milliman, J. D., and K. O. Emery. 1968. Sea levels during the past 35,000 years. Science 162: 1121-1123.

Müller, J., and J. D. Milliman. 1973. Relict carbonate-rich sediments on southwestern Grand Bank, Newfoundland. Can. J. Earth Sci. 10: 1744–1750.

Sen Gupta, B. K., and R. M. McMullen. 1969. Foraminiferal distribution and sedimentary facies on the Grand Banks of Newfoundland. Can. J. Earth Sci. 6: 475–487.

Shearer, J. M. 1973. Bedrock and surficial geology of the Northern Gulf of St. Lawrence as interpreted from continuous seismic reflection profiles, p. 285–303. *In* P. J. Hood [ed.] Earth Science Symposium on Offshore Eastern Canada. Geol. Surv. Can. Pap. 71-23.

Shepard, F. P. 1931. St. Lawrence (Cabot Strait) submarine trough. Geol. Soc. Am. Bull. 42: 853-864.

Slatt, R. M. 1974. Continental Shelf sediments off eastern Newfoundland: a preliminary investigation. Can. J. Earth Sci. 11: 362-368.

1977. Late Quaternary terrigenous and carbonate sedimentation on the Grand Banks of Newfoundland. Geol. Soc. Am. Bull. 88: 1357-1367.

Slatt, R.M., and W. Gardiner. 1976. Comparative petrology and source of sediments in Newfoundland fiords. Can. J. Earth Sci. 13: 1460–1465.

Stehman, C. F. 1976. Pleistocene and recent sediments of northern Placentia Bay, Newfoundland. Can. J. Earth Sci. 13: 1386–1392.

Trites, R. W. 1971. The Gulf as a physical oceanographic system. *In* Second Gulf of St. Lawrence Workshop, Bedford Institute of Oceanography, Dartmouth, N.S., Nov. 30–Dec. 3, 1970. 32-63.

Tucker, C. M. 1976. Quaternary studies in Newfoundland; a short review. Marit. Sediments 12: 61-73.

Tucker, C. M., and S. B. McCann. 1980. Quaternary events on the Burin Peninsula, Newfoundland, and the islands of St. Pierre and Miquelon, France. Can. J. Earth. Sci. 11: 1462-1479.

Webb, G. W. 1973. Salt structures east of Nova Scotia, p. 197-218. *In* P. J. Hood [ed.] Earth Science Symp. on Offshore Eastern Canada. Geol. Surv. Can. Pap. 71-23.

Widmer, K. 1950. Geology of the Hermitage Bay area, Newfoundland. Ph.D. thesis, Princeton Univ., Princeton, NJ.

Wightman, D., and H. B. S. Cooke. 1978. Postglacial emergence in Atlantic Canada. Geosci. Can. 5, No. 2: 61-65.

Williams, H., M. J. Kennedy, and E. R. W. Neale. 1972. The Appalachian structural province, p. 181-261. *In* R. A. Price and R. J. W. Douglas [ed.] Variations in tectonic styles in Canada. Geol. Assoc. Can. Spec. Pap. 11.

PLATE I. Bottom photograph of the Scotian Shelf Drift (map unit 6). The glacial till consists of a mixture of angular fragments of pebble- to boulder-sized material in a matrix of sand and mud. Several sea urchins (*Strongylocentrotus*?) can be seen in the central and left side of the photograph. Numerous burrowing anemones are visible in the bottom and upper left-hand corners. Taken on the Burin Moraine at 46°32.2′N, 55°10.2′W, at a depth of 83 m (45 fath).

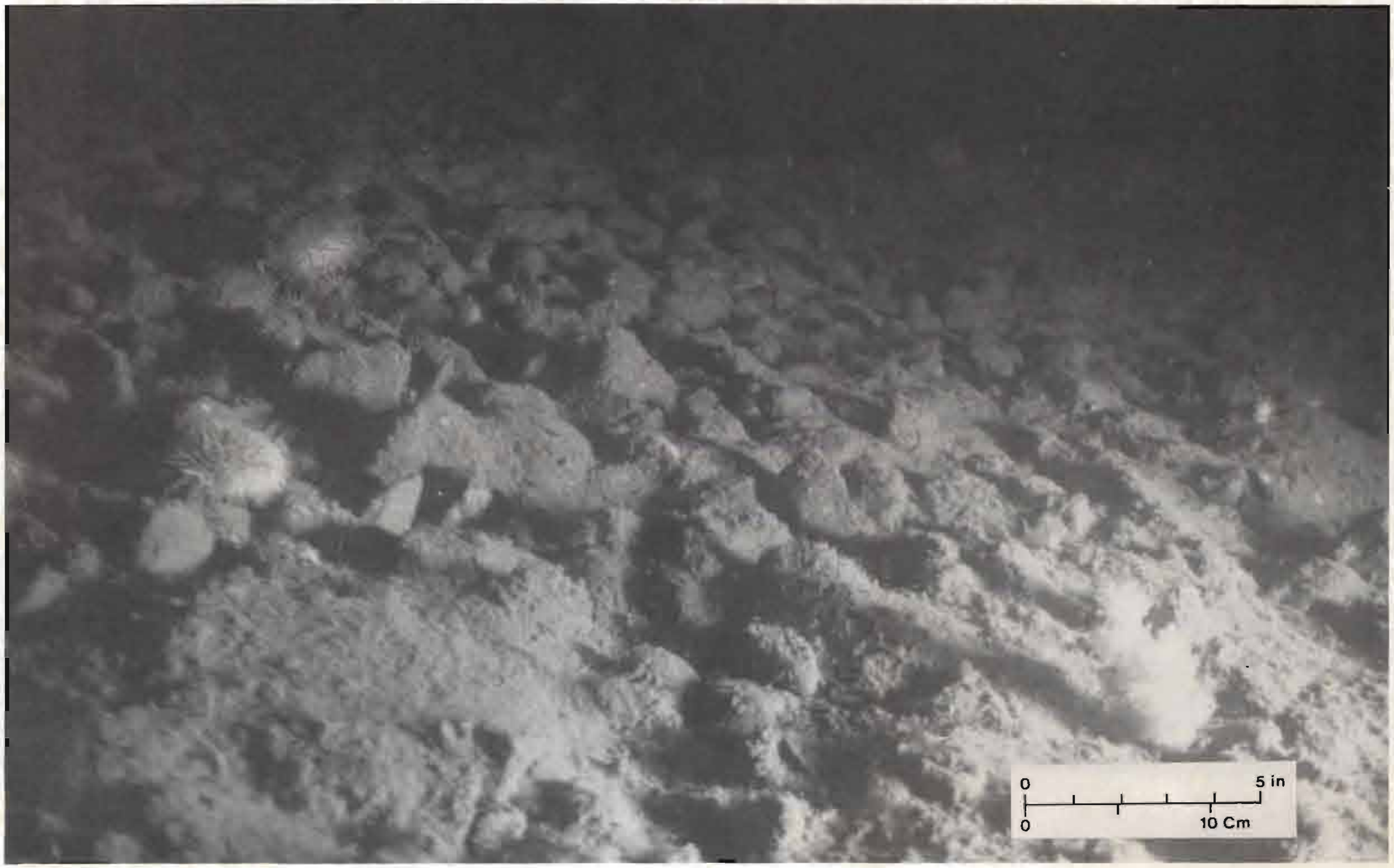

PLATE II. Oblique photograph of the Scotian Shelf Drift (map unit 6) over the Burin Moraine at the same position as Plate I. Sea urchins (*Strongylocentrotus*?) can be seen on the left side of the photograph and a seapen (*Pennatula*) occurs in the right bottom corner. The scale only applies to the foreground of the photograph.

PLATE III. Bottom photograph of the Emerald Silt (map unit 7), a soft mud similar in appearance to the LaHave Clay (Plate V). A brittle starfish (*Ophiuroidea*) occurs to the left of center of the photograph, and numerous tracks and holes of burrowing organisms are seen across the seabed. Taken in the area of the Scatarie Moraine at 45°45'N, 58°55.5'W, at a depth of 241 m (132 fath).

PLATE IV. Bottom photograph of the Sambro Sand (map unit 8a). Numerous tube worms (*Onuphis*) are scattered across the seabed, and some can be seen protruding from their tubes. Several burrowing anemones are found in the central area. A rock in the central left area is partially covered with a hydroid colony along with a small chiton. Taken east of St. Anns Bank, 46°06.02′N, 58°56.0′W, at a depth of 137 m (75 fath).

Plate V. Bottom photograph of LaHave Clay (map unit 9), similar to the Emerald Silt seabed (Plate III). The bottom consists of very fine silt- and clay-sized particles. Several stalked tunicates (*Boltenia*) occur in the top of the photograph, and numerous holes, tracks of unknown organisms, and small worm tubes are present. Taken in Hermitage Channel, 47°01.2′N, 57°06.2′W, at a depth of 307 m (168 fath).

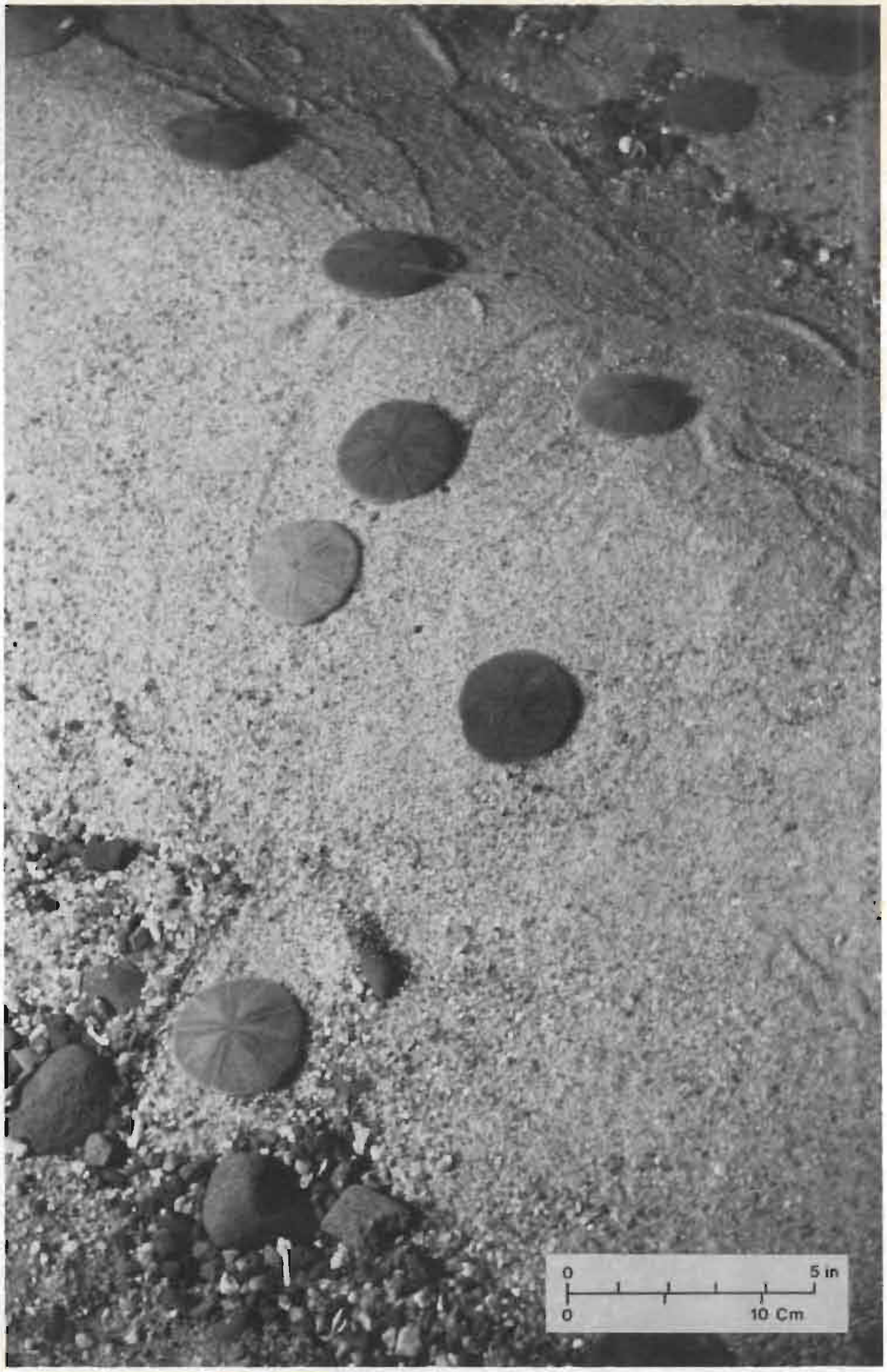

Plate VI. Bottom photograph of the Sable Island Sand and Gravel (map unit 10a), across an area of small sand waves. The troughs of the sand waves contain coarser material. Sand dollars (*Echinarachnius*) appear to be moving across the crest of the sand wave. A hermit crab is seen in the top right of the photo and several isopods are found in the lower left corner. Taken on northeastern St. Pierre Bank, 46°15.2′N, 56°12.6′W, at a depth of 64 m (35 fath).

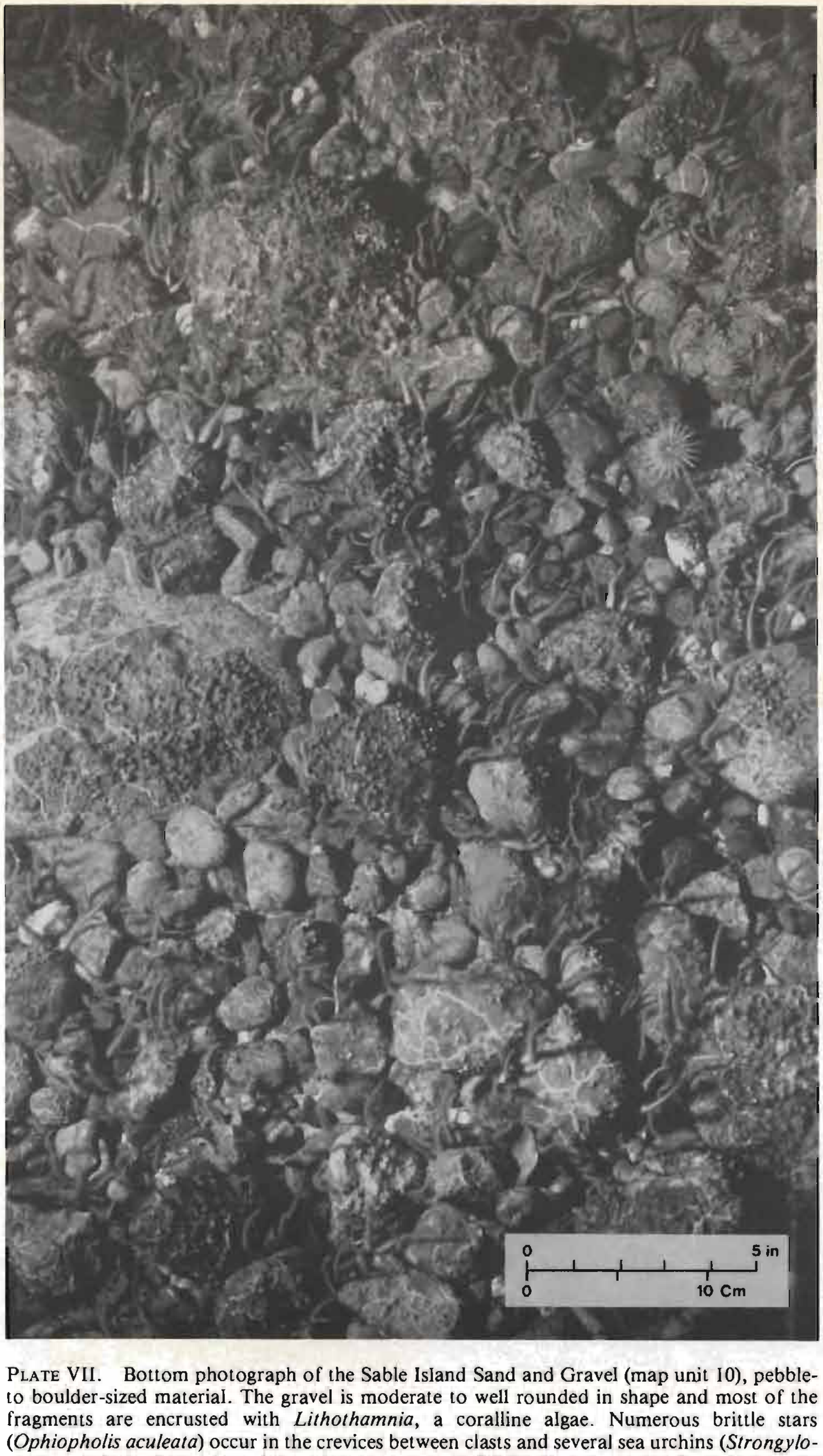

PLATE VII. Bottom photograph of the Sable Island Sand and Gravel (map unit 10), pebble- to boulder-sized material. The gravel is moderate to well rounded in shape and most of the fragments are encrusted with *Lithothamnia*, a coralline algae. Numerous brittle stars (*Ophiopholis aculeata*) occur in the crevices between clasts and several sea urchins (*Strongylocentrotus drobachiensis*) can be seen. Anemones and fanlike bryozoan colonies are scattered across the bottom. Taken on western St. Pierre Bank, 46°03.8′N, 56°35.6′W, at a depth of 42 m (23 fath).

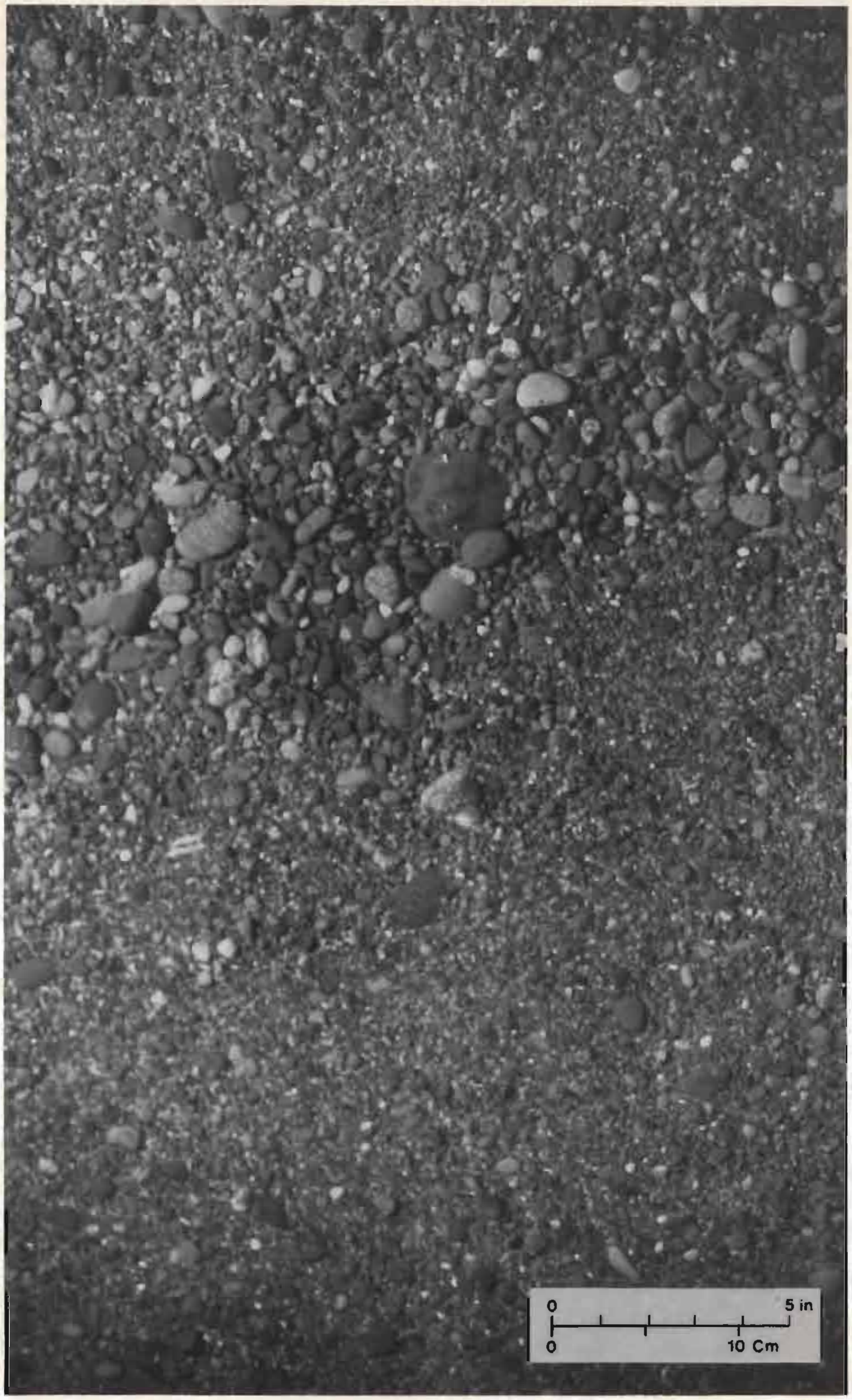

PLATE VIII. Bottom photograph of the Sable Island Sand and Gravel (map unit 10b), showing the distribution of gravel across an area of small gravel waves. The coarser well rounded gravel fragments are confined to the troughs of the waves. A few periwinklelike gastropods occur on some of the larger clasts. Taken on the northwestern part of St. Pierre Bank, 46°25.6′N, 56°59.2′W, at a depth of 37 m (20 fath).

PLATE IX. Bottom photograph of the Sable Island Sand and Gravel (map unit 10a), across a bottom of very fine well sorted sand. The numerous mounds may represent the shelters of burrowing organisms formed through the agglutination of sand grains. Taken in east-central area of St. Pierre Bank, 46°03.8′N, 55°44.5′W, at a depth of 64 m (35 fath).

PLATE X. Bottom photograph of the Sable Island Sand and Gravel (map unit 10b), across an area of well sorted fine gravel overlain by broken and whole shells, mostly clams (*Mya*). A tube worm (*Onuphis*) occurs in the bottom left of the photograph. Taken on southeastern St. Pierre Bank near Halibut Channel, 45°19.7′N, 55°35.6′W, at a depth of 48 m (26 fath).

PLATE XI. Bottom photograph of the Sable Island Sand and Gravel (map unit 10a), across an area of sand with minor amounts of fine gravel. Scattered across the bottom is broken shell material. Tube worms (*Onuphis*), whose tubes consist of linear arrangements of broken shell fragments can be seen in the central part of the photograph. Taken at the southeastern corner of St. Pierre Bank, 45°42.5′N, 55°40.5′W, at a depth of 60 m (33 fath).