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GEOLOGICAL STUDIES IN ST. MARGARET'S BAY, NOVA SCOTIA

D.J.W. PIPER
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Abstract

St. Margaret's Bay is a bedrock basin modified by glacial scouring, with a shallow sill at its entrance. Up to 100 m of sediment overlies bedrock; the acoustic properties of this sequence are often masked by multiples or by gas layers, but it is probably mostly till. Sheet till and drumlins, with different lithologies, have been distinguished. Sediment overlying till reaches local thicknesses of at least 40 m in basins. The nature of this deeply buried sediment is indeterminable, but acoustically it can be compared with the Emerald Silt and LaHave Clay.

A lake filled the central part of the bay shortly after deglaciation, when sea level was below the sill depth. Above the lake level, morphology is suggestive of subaerial erosion; below the lake level topography is rather smooth.

The surficial sediment distribution reflects present energy conditions. Erosion of till is the most important source of sediment at present. Sands are common near the sill, and have in part been washed in from the open continental shelf. Muds fill basins in the central bay. Sandy gravels and sandy gravelly muds are found in the shallower northern and eastern waters of the bay. In the central basin, sediment is accumulating at about 1. 5 mm/yr. ; of this at least half is resedimented from shallow water during storms. The mud is very rich in organic matter, which decomposes to methane. The methane forms a prominent sub-bottom acoustic reflector.

Maps of depth to bedrock, bedrock geology, drumlin distribution, and surficial sediment type are included in the report.

Résumé

La baie St-Margaret occupe un bassin dont la roche en place a été modelée par l'érosion glaciaire et dont l'entrée présente un seuil peu profond. L'épaisseur des sédiments qui recouvrent la roche en place peut atteindre jusqu'à 100 m. Des réflexions multiples ou des couches gazeuses dissimulent les propriétés acoustiques de ces sédiments qui sont probablement constitués surtout de till. L'auteur y distingue du till et des drumlins de composition lithologique différente. Dans les dépressions, les sédiments qui recouvrent le till atteignent localement une épaisseur minimale de 40 m. On ne peut déterminer la nature de ces sédiments profondément enfouis, mais du point de vue de l'acoustique, ils se comparent au silt Emerald et à l'argile LaHave.

Un lac a occupé la partie centrale de la baie peu après la déglaciation, alors que le niveau de la mer se trouvait sous le seuil. Au-dessus du niveau du lac, le relief laisse supposer l'existence d'une érosion subaérienne. Sous le niveau du lac, la topographie est plutôt régulière.

La distribution des dépôts meubles reflète les conditions énergétiques actuelles. Ainsi, l'érosion du till est actuellement la source la plus importante de sédiments. Près du seuil, on trouve du sable en grande quantité provenant en partie du large du plateau continental. Les dépressions du centre de la baie sont remplis de boues, alors que des graviers sableux et des boues sableuses contenant aussi du gravier reposent dans des zones moins profondes du nord et de l'est de la baie. Dans la dépression centrale, les sédiments s'accumulent au taux d'environ l, 5 mm par année, dont la moitié au moins est apportée des eaux peu profondes, lors des tempêtes. Les boues sont très riches en matière organique qui se décompose et forme du méthane, lequel constitue, sous le fond, un réflecteur acoustique remarquable.

Le présent rapport contient des cartes donnant la profondeur et la géologie de la roche en place, la distribution des drumlins et les types de dépôts meubles.

INTRODUCTION

St. Margaret's Bay (Fig. 1) is a large inlet on the Atlantic coast of Nova Scotia. It lies 40 km west of Halifax, between 44°27'N and 44°42'N, and 63°50'W and 63°04'W; it is approximately 16 km long, 10 km wide and has an area of 138 km^2. The central part is a basin up to 90 m deep, bounded by a 55-m-deep sill to the south, by shoals to the east and north, and by a steep scarp to the west. Prominent inlets extend from the bay in the north and northeast; islands stud the northeastern and eastern margins.

Several aspects of the geology of St. Margaret's Bay were investigated. We have mapped the bedrock form of the bay, and the distribution of the overlying glacial till. We have also studied the detailed geomorphology and the postglacial marine sediments in order to understand the processes that have shaped the bay over the last 13 500 years since deglaciation. It seems clear that these are related to changes in sea level. Grant (1970a) has suggested that, after the Wisconsin glaciation, sea level would have risen to the sill depth of 55 m by about 11 500 B.P. A freshwater lake would thus have existed between deglaciation and the encroachment of the rising sea. Furthermore, during the past two thousand years, the Atlantic coast of Nova Scotia, including the St. Margaret's Bay region, has been sinking at about 40 cm per century (Grant, 1970a), much more than the eustatic rise in sea level during this period (*see* for example, Flint, 1971).

The principal oceanographic features of St. Margaret's Bay have been described by El Din *et al.* (1970). Freshwater enters the bay principally at the northern end, so that although the main part of the bay does not freeze in winter, ice does develop extensively in the northeastern and northwestern inlets. Circulation in the bay, both at the surface and in deeper layers, is anticlockwise. Net inflow is through the surface layers, net outflow is through deeper layers. Tidal currents have maximum values of 21 cm/s at the entrance to the bay, but decrease towards the head. The anticlockwise residual current has a magnitude of 2 to 3 cm/s at the surface.

Nutrient levels in the water are high in winter, but are depleted rapidly in the phytoplankton bloom of the spring; they are gradually replenished during the summer and fall (Platt *et al.*, 1972; Sutcliffe, 1972). The growth of seaweeds below the intertidal zone is enhanced by the high winter nutrient levels (Mann, 1973). They are of much greater importance to the primary productivity of the whole bay than is the productivity of the phytoplankton.

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We thank many individuals who have helped us in this study. Mary Ann Annand, Jan Aumento, Neal Barnes, David Bevan, Don Bidgood, Dianne Crouse, Derek Davies, Winston Goodwin, Ruth Jackson,

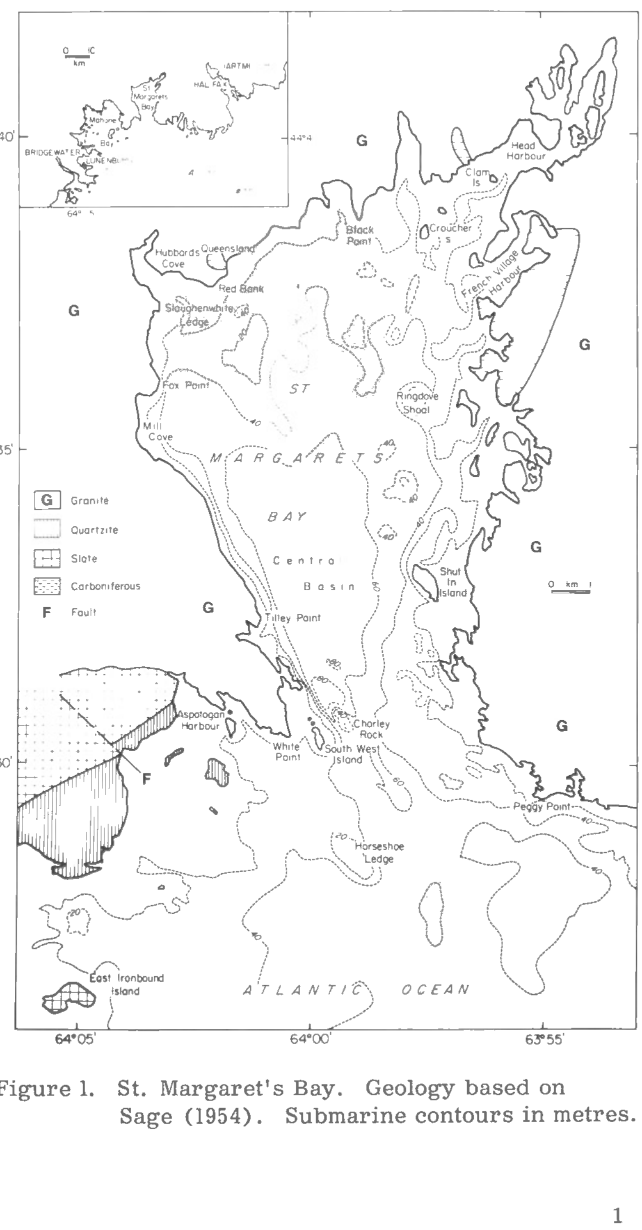


Figure 1. St. Margaret's Bay. Geology based on Sage (1954). Submarine contours in metres.

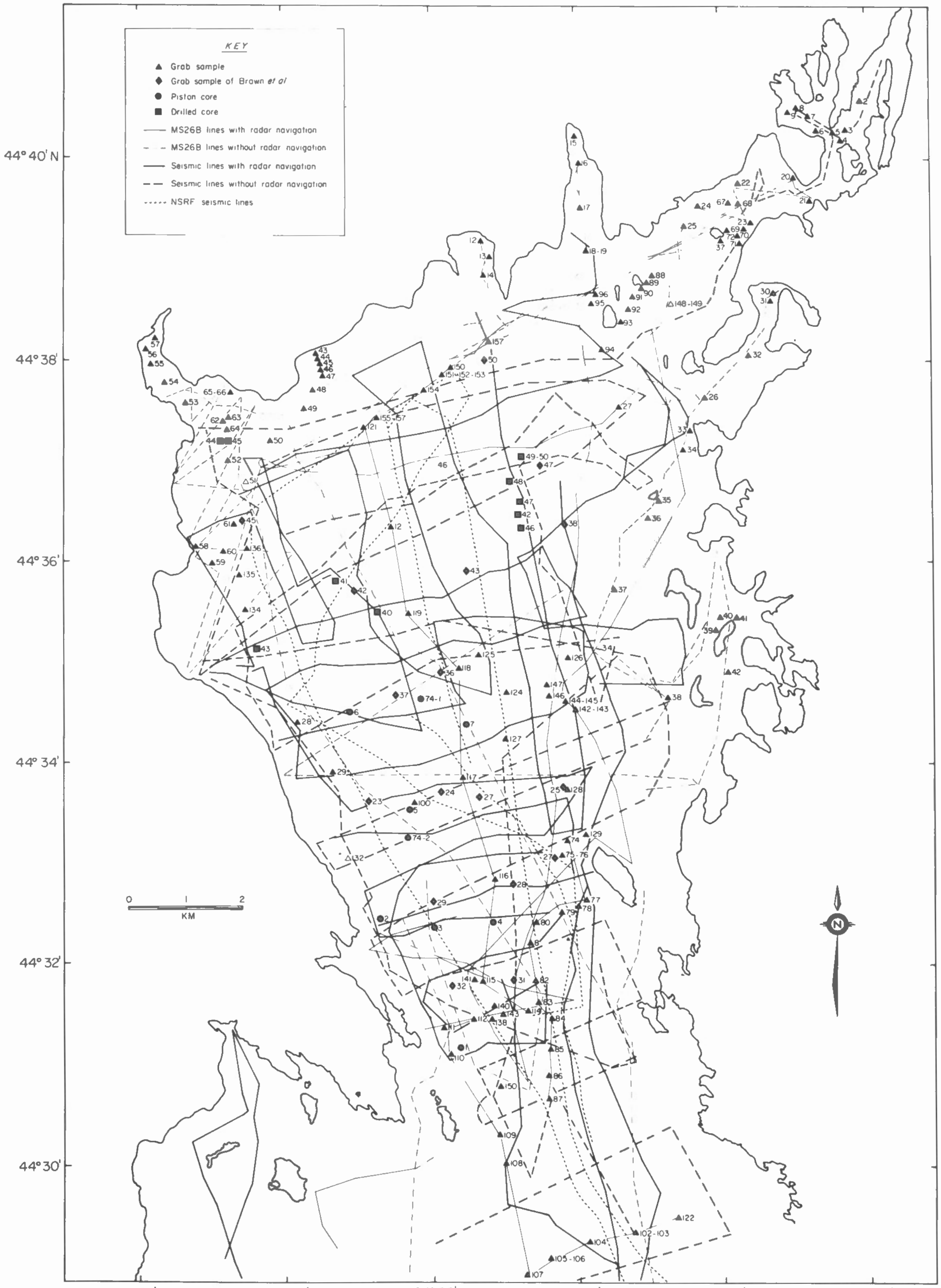


Figure 2. Map showing tracks and location of samples.

Charlotte Keen, Brant Laidler, Clive MacKay, Alison McCallum, Lauchie Meagher, Franco Medioli, Erik Nielson, Charles O'Reilly, Don Peer, Patricia Ryall and Lynn Smith.

METHODS

Field work for this project was carried out mainly in the summer of 1973. Some reconnaissance work done in 1972 has been incorporated, as have additional data obtained in 1974 and 1975. Figure 2 shows tracks and sample stations.

Navigation in 1973 and subsequent years was by means of radar ranges and azimuths determined at 5-minute intervals. Prominent points on land were used for fixes. Individual positions are estimated to be good to at least ±100 m. Earlier data were collected with poorer navigation, control which was based on making courses between points on the coast.

Three seismic reflection profiling systems were used: (1) A 1500-joule EG & G sparker; (2) A 200-joule Alpine sparker; (3) A Teledyne 200-800 joule sparker system. A Kelvin Hughes MS26B sounder was used to distinguish surficial sediment type. The sounder operates at 14 kHz and a repetition rate of 200 per minute.

Bottom samples were obtained using (1) a Van Veen grab on muddy bottoms, (2) a Dietz-LaFond snapper on sandy bottoms, and (3) a standard Ewing piston corer. Several drill core samples of till were supplied to us by the Metrology Group of the Atlantic Oceanographic Laboratory.

PHYSIOGRAPHY

Three main physiographic regions can be distinguished: the deep central basin, the southern sill, and the northern and eastern shoals and islands. We have contoured Hydrographic Service field sheets for the whole bay at 4-m intervals in order to recognize detailed topographic features: selected parts of our contour map are shown in Figures 3 and 4.

The Central Basin

The deep central basin has a fairly flat floor. Depths range from 51 m in the north to 91 m in the south. An east to west profile shows asymmetry with greatest depths in the west. There is a western, and sometimes an eastern, channel at the margins of the basin, which are extensions of similar features entering the basin in the northwest (from Hubbards and Mill Cove), and in a less regular fashion in the northeast and east (from the northeastern inlets and the eastern shoals).

The deepest part of the basin is at its southwestern end, where depths reach 91 m. This deep area is partially blocked from the main part of the basin by a northwesterly trending ridge (Fig. 3). Comparable submarine ridges extend into the basin from the shoals to the east and north (Fig. 4). A few topographic highs and lows disturb the rather flat floor of the basin in places; they rise above or fall beneath the general level in their respective areas by a few metres. The topographic highs are nearly buried hills of till.

The slopes at the margins of the basin are often steep. They appear steepest in the southwest, where the gradients may be higher than 1:10. The western margin is straight, by comparison with the other margins, which are irregular. On the north and northeast margins of the basin, a terrace is present at 53 to 59 m, bounded by steep slopes in water depths of 44 to 55 m (Fig. 4).

The Southern Sill

The southern sill has a maximum depth of 56 m. It separates the southern deep of the central basin from the open continental shelf. The northern flank of the sill is steeper than the southern flank.

The bathymetry of the sill is of great importance in understanding changes in circulation patterns and exposure to open ocean waves as sea level rose. Half the width of the present entrance to the bay is less than 20 m deep, and water more than 35 m deep is restricted to two very narrow channels. These join just south of the sill, and continue south as a slightly broader valley, which is nevertheless still deeply incised into the regional slope (Fig. 3).

The Northern and Eastern shoals and islands

Shoals and islands occupy the shallow waters of the northern and eastern margins of the bay. The shoals extend as irregular spurs into the central basin, and are bounded by submarine valleys with obvious connections to present river valleys (such as Hubbards River), or to basins with ponded sediments at depths of 35 to 50 m, which are themselves related to river valleys (such as Ingram River).

Some of the shoals are related to points on land constructed of till; an example is Red Bank and Slaughenwhite Ledge to the southwest (Figs. 1 and 4). Most of the shoals are underlain by till, and many seem to be associated with chains of drumlins. In contrast, the islands in the southern part of the bay, such as Shut-In Island, and Southwest Island, are formed of granite.

In the northern part of the bay, there appears to be a terrace at around 33 to 36 m. However, the prominence of this feature is accentuated by a large body of sediment ponded to that depth south of Queensland (Fig. 4). There is no pronounced terrace developed near present sea level.

BEDROCK

Local bedrock geology on land

Southern Nova Scotia is formed of lower Paleozoic Meguma Group slates and quartzites, and Devonian granite batholiths. Most of St. Margaret's Bay (Fig. 1) is surrounded by granite, but southwest of the bay, Meguma rocks outcrop in Aspotogan Peninsula.

On the east side of the bay, Mississippian Windsor limestones locally rest unconformably on the granite (Sage, 1954).

Bedrock of St. Margaret's Bay

Depth to bedrock in St. Margaret's Bay (Fig. 5) has been mapped with a 200-joule Alpine sparker, a 800-joule Teledyne sparker and a 1500-joule Edgerton sparker. Bedrock could be delineated reasonably well (Fig. 6a) except where obscured by multiples in very shallow water, and where obscured in water depths greater than 55 m by a reflective gas layer (referred to as the "two-metre" reflector) which is developed in basin muds in the bay (Keen and Piper, 1976). Penetration in the latter case could be achieved with the larger sparkers only, and then with only very poor resolution (Fig. 6d). No velocity measurements have been made in the sediments overlying bedrock.

Bedrock has a slightly asymmetrical form from west to east. Depths are generally deeper in the western part of the bay than in the east. Where bedrock topography on shore is steep, the bedrock topography offshore is also steep. The relatively steep hills of granite along the western shore are adjacent to steep gradients in bedrock offshore, and the gradient is also steep northwest of Shut-In Island. The sill at the entrance to the bay is formed of bedrock (Fig. 6b).

Bedrock highs appear to have controlled till deposition. An example is the bedrock high south of Red

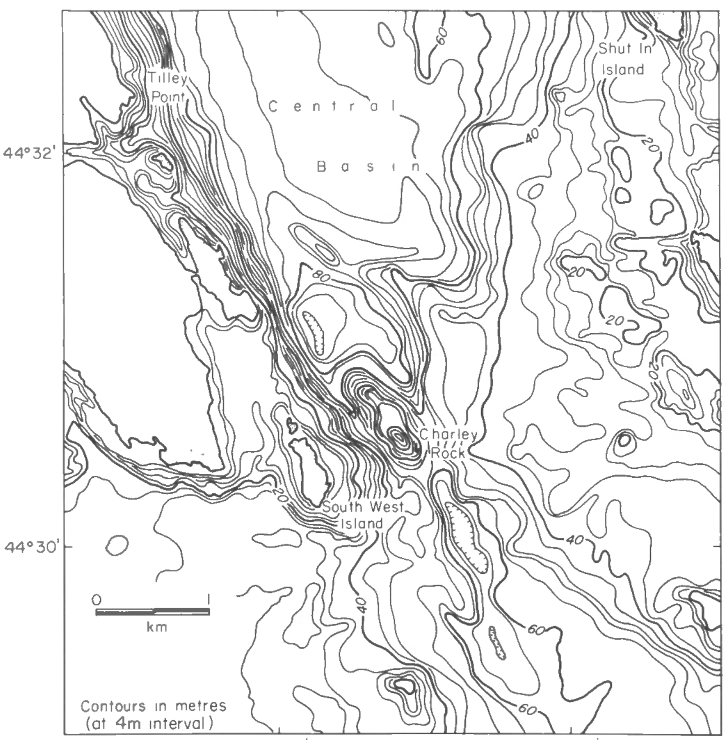


Figure 3. Detailed bathymetric map of entrance to St. Margaret's Bay. Contours at 4-m intervals based on fathom soundings on Hydrographic Service field sheets.

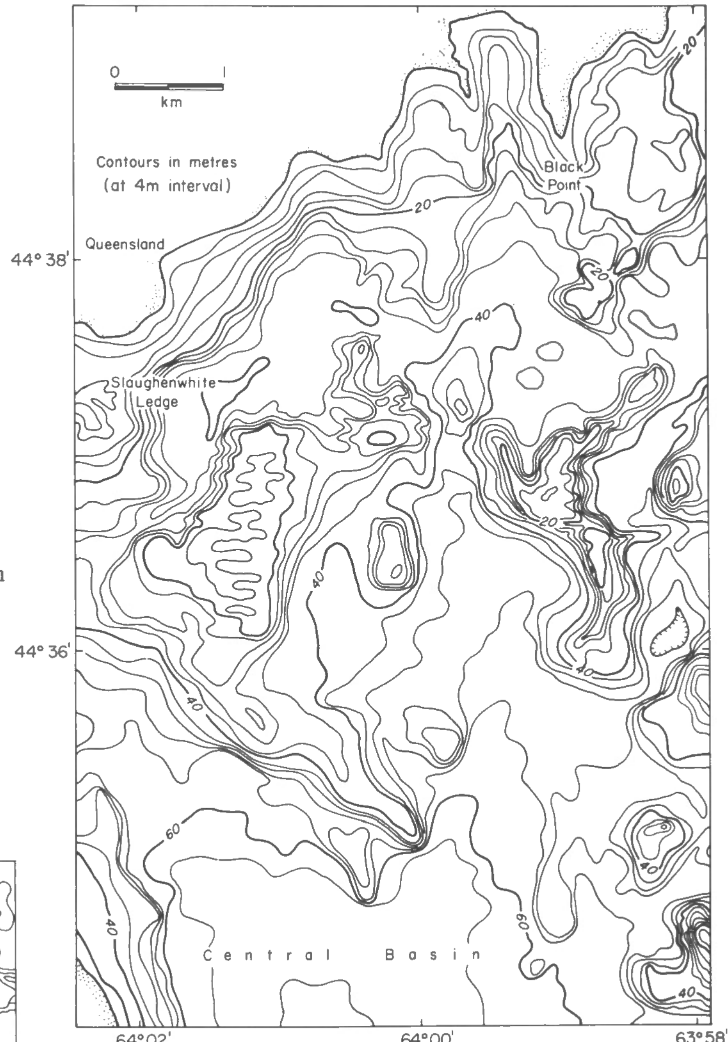


Figure 4. Detailed bathymetric map of north-central part of St. Margaret's Bay. Contours at 4-m intervals based on fathom soundings on Hydrographic Service field sheets.

Bank, a conspicuous drumlin on land. A smaller example is visible in Figure 6a. Bedrock also appears to have controlled the present morphology of the bay. For example, the channel of the submerged Hubbards River coincides approximately with the deep western basement trough.

Magnetic field observations suggest that the bedrock is granite throughout the bay, and that the Meguma is seen only outside the bay. We have no evidence of the extension into the bay of the scattered Carboniferous outcrops seen on land; in Mahone Bay we were able to detect Carboniferous bedrock with the NSRF Teledyne multi-tip sparker system (Barnes, 1976).

Bedrock geology off Aspotogan Peninsula

Rocks of the Meguma Group outcrop on the Aspotogan and Blandford peninsulas and can be traced offshore (Fig. 7). Bedrock off these peninsulas appears to control the submarine morphology to a considerable extent. For example, northwesterly bathymetric contours follow the trend of northwesterly faults observed on land.

We used magnetic field profiles (Fig. 8) to attempt to distinguish between granite on the one hand and slates and quartzites on the other. Observations at sea were controlled with profiles on land over known outcrops. The results were not unambiguous. Clear contrasts exist between (1) slates and quartzites and (2) slates and granites, but not between quartzites and granites.

Quartzites and slates in this region are folded in an anticline with a northeast-southwest axis truncated by the granite at the village of Aspotogan. Slates outcrop as the northern limb offshore on East Ironbound Island. The slates of the southern limb extend in

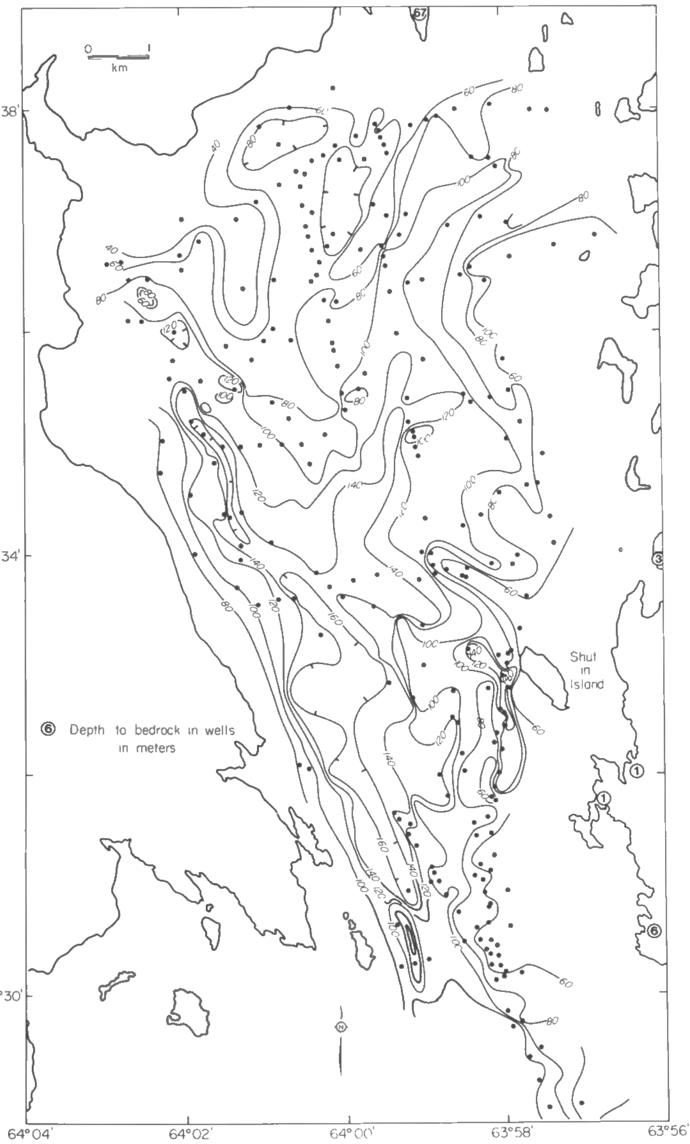


Figure 5. Map showing "depth" to bedrock, contoured in 2-way reflection time in milliseconds. Dots represent data points.

an easterly direction from East Ironbound Island to approximately two miles south-southwest of Peggy Point. There is no evidence which establishes extension of faulting from inside St. Margaret's Bay to the region south of the bay. However, this does not imply an absence of faulting.

GLACIAL TILL

Glacial till on land

No specific study has been made of the tills and drumlins of the St. Margaret's Bay region, although Grant (1963) mentioned them briefly. MacNeil (pers. comm.) mapped the distribution of drumlins (Fig. 9), eskers and kames around the bay. Nielsen (1976) has studied some of the tills around St. Margaret's Bay, as part of a broader study of the tills of Nova Scotia.

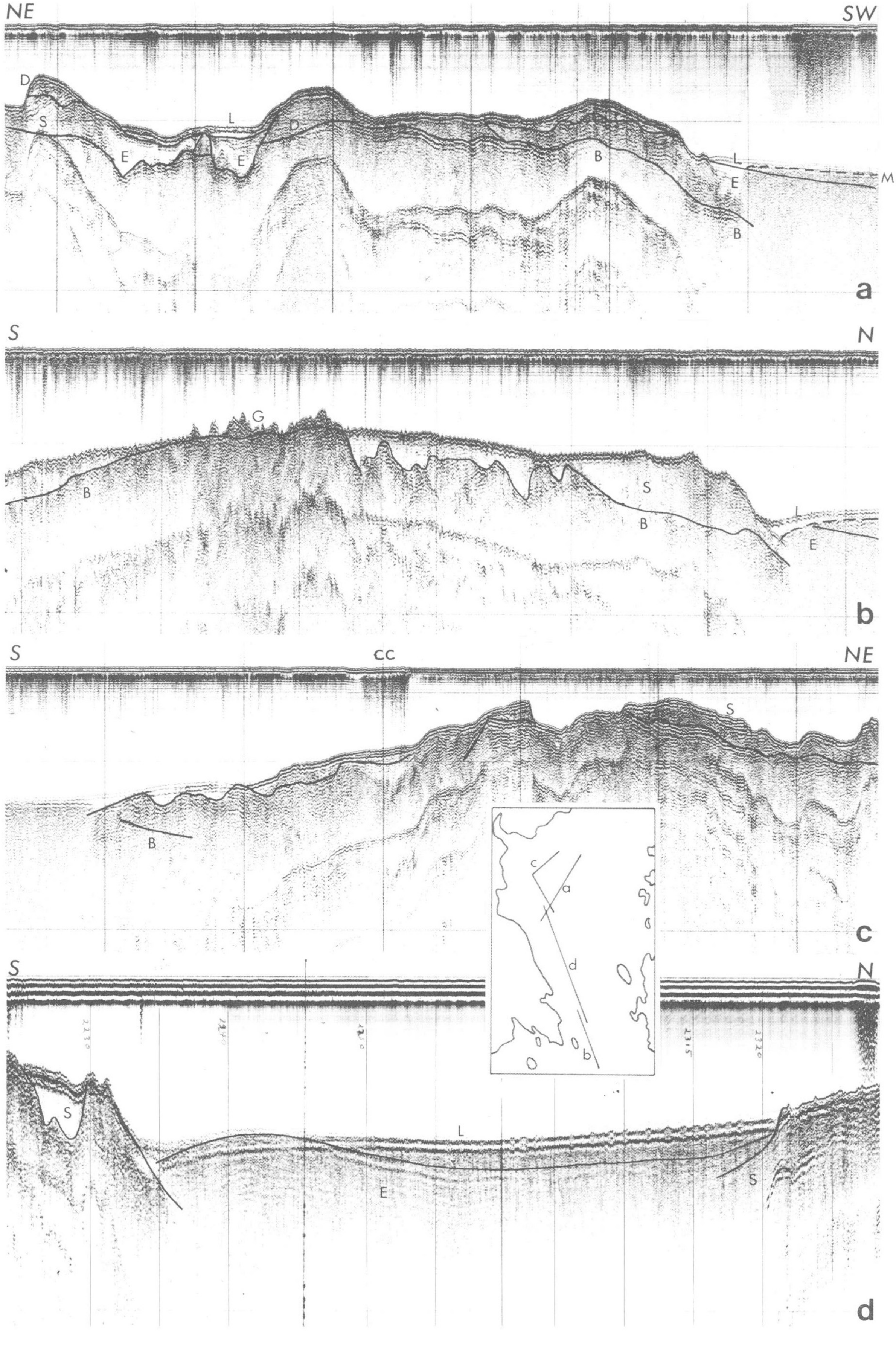
Several types of till are present in the St. Margaret's Bay region, but their stratigraphic relationships are poorly known. A compact till with slate and quartzite clasts is exposed around Halifax Harbour, and is overlain by a red till which forms prominent drumlins. This red till contains a wide variety of lithologies, including North Mountain Basalt, Triassic sandstones and siltstones, granite and Meguma slates and quartzites. However, southwest of Halifax in the Whites Lake area, the red till is overlain by a "hybrid" till, with mostly granite clasts but with some lithologies characteristic of the red till. Farther south, around Sambro, the "hybrid" till contains a higher proportion of red till lithologies, and rests directly on bedrock (Nielsen, 1976). Around the northern end of St. Margaret's Bay, a thick till with clasts almost entirely of granite is widespread, but nowhere are stratigraphic relationships with other tills visible. On Aspotogan Peninsula, there are thin loose tills with compositions similar to the local bedrock of slate, quartzite or granite.

Well records (H. Cross, pers. comm.) show thicknesses of till up to about 70 m around the northeast part of the bay but the records are insufficient to distinguish different types of till.

Glacial till distribution in the bay

1) Till bodies recognizable by seismic reflection profiling

Two types of till are recognized from seismic reflection profiling. Most of the bay is underlain by a relatively featureless till sheet (Fig. 6a, b), characterized by a lack of coherent seismic reflectors. However, in the area just north of the sill, and to the southwest of Shut-In Island, mound-like bodies with a similar acoustic signature are seen (Figs. 6a, 9). These probably are similar to the drumlins which occur in chains on the adjacent land and form many of the islands in the northeastern part of the bay. These mound-like till bodies often break through the surficial sediment cover to form slightly elevated topographic features, even in deep water. The trend of these features is similar to that of the adjacent drumlin chains.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2) Drilled cores of till

Drilled cores (Fig. 2) provide data on the lithology of the pebble component of submarine tills. Cores 44 and 45, from the northwest part of the bay, and 50, from northwest of Wedge Island, are of dominantly granitic till with some quartzite clasts. Cores 41 (from south of Slaughenwhite Ledge) and 42, 46, 47, and 48 (between Black Point and Ringdove Shoal) are polymict, with common red sandstone and limestone.

3) Lithology of surficial sediments

The lithology of the pebbles in the surficial sediments appear to be a good guide to the nature of the underlying till. For example, outer Hubbards Harbour is underlain by a sheet-like till body, and outcrops on the west side of the harbour suggest this is a granitic till. Pebbles in surficial sediments in the outer harbour consist entirely of granite, despite the proximity of rapidly eroding drumlins of polymict red till at Red Bank and Slaughenwhite Lodge. This suggests pebbles are not transported far from their original till. A further example is The Puddle, with no nearby drumlins, which also has entirely granitic pebbles.

The lithological data from the pebbles confirm our identification, from seismic reflection profiles, of drumlins occurring south from Croucher Island to south of Ringdove Shoal, and in the area south of Shut-In Island (Fig. 9).

SEDIMENTS OVERLYING TILL

Sediment thicknesses overlying till and bedrock locally reach thicknesses of 50 milliseconds (two way travel time). At least three seismic stratigraphic units can be recognized overlying till (Fig. 6).

Figure 6. (Opposite)

Seismic reflection profiles obtained with Nova Scotia Research Foundation Teledyne 200 joule sparker system with Aquadyne streamer.

B = bedrock, S = sheet till,
D = drumlin till, E = (?) Emerald Silt,
L = (?) LaHave Clay, G = (?) sand and gravel,
M = masking effect of "two metre" reflector.

Location of profiles shown on inset. Horizontal scale lines at 100 milliseconds, vertical at 5-minute (~0.75 km) intervals.

Profile a: Northwestern area of the bay, and northern part of Central basin. Note drumlins, and acoustic mask of "two metre" reflector in the central basin.

Profile b: Bedrock sill, with local sand and gravel. Note thick till to north, dropping off steeply to the Central basin.

Profile c: North Central basin and shoals south of Slaughenwhite Ledge.

Profile d: 800 joule record of Central basin penetrating the "two metre" reflector.

i) a unit with many parallel reflectors, often slightly oblique to the present sea floor. This is best developed in the central basin (Fig. 6d), although it is generally masked by the "two-metre" reflector. It probably also occurs in smaller basins in the northern part of the bay (Fig. 6a). It appears similar acoustically to the Emerald Silt of King (1970). Areas where this unit appears to approach the sea floor have a variety of surficial sediments: it is probably everywhere mantled by a thin veneer of younger sediment.

ii) an acoustically transparent unit, overlying the (?) Emerald Silt, and resembling the LaHave Clay of King (1970). This is rarely more than 10 milliseconds thick. It fills most of the basins in the bay. Cores from this unit indicate it is a mud, or locally a sandy mud.

iii) around the sill (Fig. 6b) is a rather opaque unit overlying bedrock, and with an acoustic signature subtly distinct from the usual tills. It may be a different type of till, or an accumulation of sandy and gravelly sediment.

SURFICIAL SEDIMENTS

Previous studies

Studies by Stanley in North West Arm, Halifax (Stanley, 1968) and by Slatt in Conception Bay, Newfoundland (Slatt, 1974) suggest that sedimentation in many sheltered bays in the Atlantic provinces of Canada can be explained in terms of "unmixing" of glacial tills by modern processes. Muds accumulate in sheltered areas, and residual gravelly sands remain in more exposed places. Holocene changes in sea level may produce an area of lag gravel which gradually submerges to become an area in which mud accumulates. Sand bodies may thus become relict as sea level rises.

The only earlier work on sediments of St. Margaret's Bay has been by Bartlett (1964) and Brawn *et al.* (1968). Bartlett occupied some 60 stations in the bay; these grain size analyses were reported for approximately 35. The stations were predominantly in shallow water in the north and northeast parts of the bay and as a consequence his conclusions concerning distribution of bottom sediments over the whole bay were not correct.

Benthonic foraminiferal assemblages were found by Bartlett to be typical of subarctic and cool temperature faunas, similar to those in Bedford Basin (Gregory, 1970). Bartlett distinguished four biofacies: intertidal; backbay, lagoonal and estuarine; nearshore; and open bay. Living Foraminifera were not found in water with salinity less than 16‰.

Brawn *et al.* (1968) studied sediments in St. Margaret's Bay in connection with a study of the bottom fauna. They divided sediments into six types and, using echo-sounder records as an aid, produced a map showing their distribution. The six sediment types are: boulders and gravels, gravels, sand, gravel and mud, compacted mud, and soft mud. The boulders and gravels, and gravels were associated with shoals, the soft muds with the deep central basin. Our work is in general agreement with that of Brawn *et al.* We have

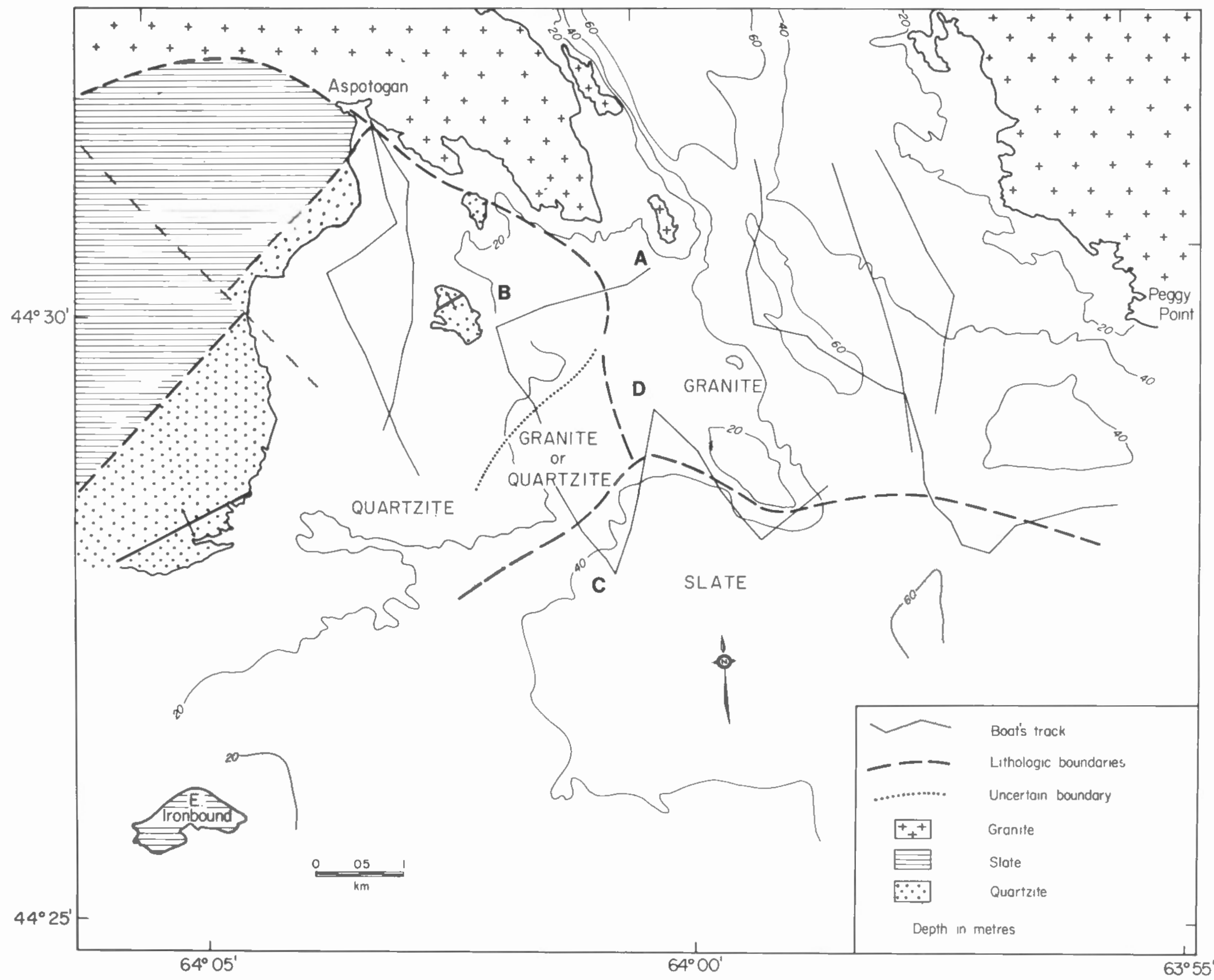


Figure 7. Inferred offshore geology south of Aspotogan, based on magnetometer profiles. Typical profiles shown in Figure 8. Land geology based on Sage (1954).

been able to extend the area covered to the outer part of the bay and to the shallow water of the eastern and northeastern part of the bay.

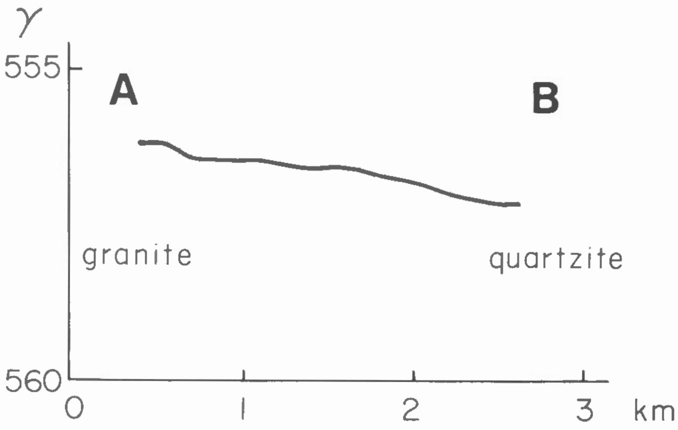
Paranjape *et al.* (1975) measured sedimentation rates using sediment traps in the deep central basin (at 70 m depth), and at a shallow water station (19 m) in the eastern shoals. In the deep basin, they determined a sedimentation rate of 0.17 $g/cm^2/yr$. They interpreted much of this as due to resuspension during storms, so that the net sedimentation rate at the sea floor would be lower.

Little of this sediment is of fluvial origin. The total area drained by streams discharging into the bay has been measured as 265 square miles by El Din *et al.* (1970) and as 320 square miles by us; the difference probably reflecting differences in deciding on the precise locations of watersheds. The water discharge of one river was gauged, so that the total river discharge to the bay can be estimated as 870 c.f.s. (assuming discharge is directly related to drainage area). Using sediment load data from gauged Nova Scotian rivers we calculate that the average rate of removal of sediment in suspension in mainland Nova Scotia at present is equivalent to a denudation rate 0.67 cm/1000 yr. Average rate of supply of suspended fluvial sediment to the bay is estimated by this method to be equivalent to a sedimentation rate of around 2 cm/1000 yr. spread uniformly over the bay. (Note that this calculation excluded bedload which is largely trapped in thalweg irregularities in the rivers.)

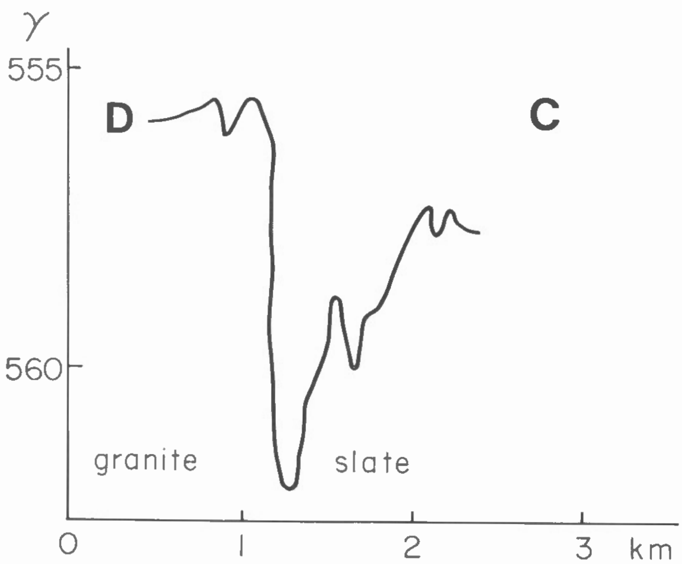
Bowen and his associates (1976, p. 156) have recently studied Queensland beach in detail. Otherwise, little is known of the beaches around the bay.

Laboratory analysis

We have made detailed grain-size analyses of 87 of our 157 surficial sediment samples; size distribution in the remainder has been estimated by comparison with analyzed samples. We have also used size analyses from our core samples, and from about 25 of the samples of Brawn *et al.* (1968).



Magnetic profile from granite (A) to quartzite (B).



Magnetic profile from granite (D) to slate (C).

Figure 8. Location of profiles shown in Figure 7.

The following analytical procedure was used. Labile organic carbon was removed by boiling with hydrogen peroxide, and Calgon was used to prevent clay flocculation. Samples were wet-sieved on a 63-micron screen, and the finer fraction was analyzed by standard pipette techniques. The sand fraction was dry-sieved at 1/2Φ intervals when there was sufficient sample. Folk's (1968) sediment nomenclature has been used. Heavy minerals have been separated from the 2 to 4Φ size-fraction of selected sands using tetrabromoethane (S.G. = 2.96). Light mineral petrology has not been studied in detail. Carbonate has been determined by weight loss on acidification, and water content by weight loss on drying. Organic carbon was determined on a Hewlett Packard CHN analyser.

Mapping of sediment type with MS26B profiles

The MS26B sounder has been used very successfully by King (1967, 1970) to map surficial sediments on the Scotian Shelf. In St. Margaret's Bay, we have applied this technique and have recognized four main types of bottom reflector (Fig. 10). Based on King's (1967) interpretations of similar reflector types, and our experience of bottom sampling in conjunction with the MS26B sounder in both St. Margaret's Bay and Halifax Harbour, we identify these reflectors as:

1) Flat acoustically transparent bottom is soft mud.
2) Less transparent bottom, usually flat, is sandy or gravelly mud.
3) Irregular bottom, strongly reflecting, is till (in some places perhaps reworked), or bedrock.
4) Strongly reflecting flat bottom is sand.

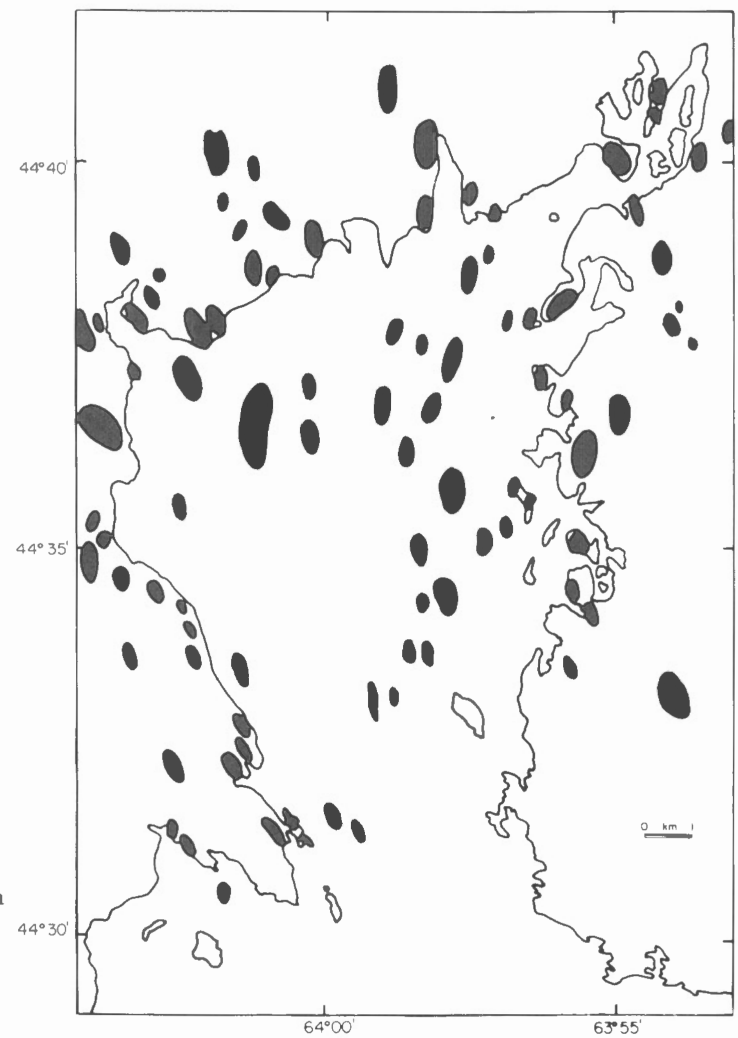


Figure 9. Distribution of drumlins in and around St. Margaret's Bay. Drumlins on land based on maps by R.H. MacNeil of Nova Scotia Research Foundation. Submarine drumlins based on bathymetry, seismic reflection profiles, and bottom samples.

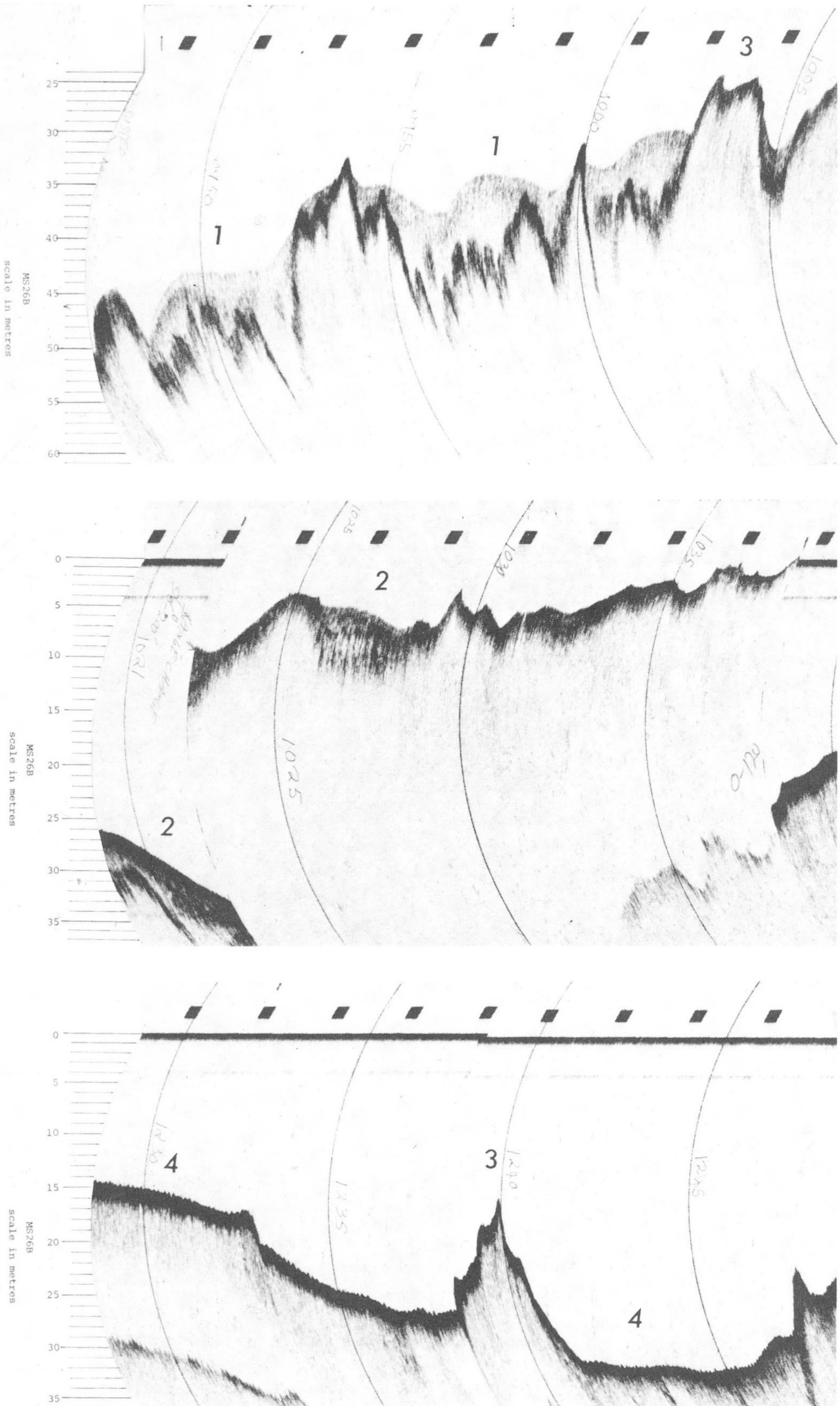


Figure 10.

MS26B reflector types.

1. Flat acoustically transparent – soft mud.
2. Less transparent – gravelly or sandy mud.
3. Irregular strongly reflecting – till or bedrock.
4. Flat strongly reflecting – sand.

Sediment types

Standard schemes of nomenclature for clastic sediments such as Folk's (1968) scheme used in this work have arbitrary boundaries between different classes of sediment. As a result, complete adherence to such nomenclatural schemes may mask real distribution patterns.

If sediment grain-size analyses are plotted on a gravel-sand-mud ternary diagram (Fig. 11), certain natural clusters of sediment type can be recognized, some of which overlap divisions of Folk's nomenclatural scheme. Some samples do not appear to fall in any particular cluster. Furthermore, replicate sampling at the same station commonly shows considerable variation in sediment type over a small area. Because of sampling problems with conventional grab samplers in gravelly areas, and the very large sample size required to obtain a representative sample of coarse grained sediments, the determined gravel content of our sediment samples is probably unreliable. We therefore use our natural clusters of sediment grain-size distribution as a basis for mapping and interpretation. The clusters are (using Folk's nomenclature):

1. Samples with more than 65% gravel; or areas in which single pebbles or no sample were recovered;
2. Sandy gravels and muddy sandy gravels;
3. Gravelly sands;
4. Gravelly muddy sands;
5. Sands and muddy sands with<30% mud (including "slightly gravelly" varieties);

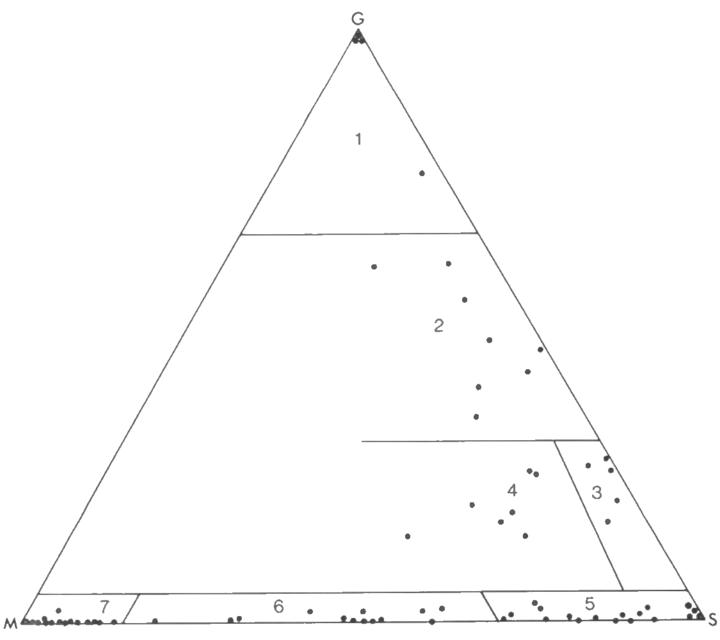


Figure 11. Grain size distribution of surficial sediment samples plotted on gravel-sand-mud ternary diagram. Numbers refer to sediment classes described in text.

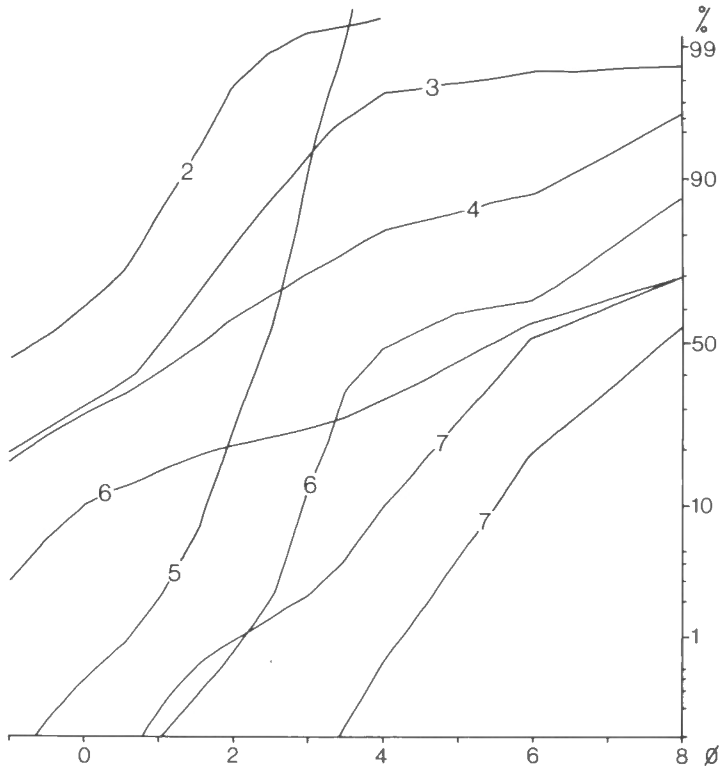


Figure 12. Grain size distribution of selected samples plotted as cumulative frequency curves on probability paper. Numbers refer to sediment classes described in text.

6. Sandy muds and muddy sands with 30-80% mud (including "slightly gravelly" varieties);
7. Muds.

Typical cumulative frequency size distribution curves for each type are shown in Figure 12.

Figure 13 is based on MS26B profiles and the sediment type determined from bottom samples, combined and interpreted to give a sediment distribution map of the bay. Sediment types 1 and 4 generally appear to directly overlie till on seismic reflection profiles. Type 5 may overlie bedrock directly or rest on till, on (?) Emerald Silt or on (?) LaHave Clay. Types 6 and 7 generally appear to be the surface expression of the LaHave Clay.

The only part of the bay for which long cores are available is the muddy central basin. Short cores (<50 cm) have been obtained from a number of other areas. Five cores, ranging from 3.5 to 9.5 m in length, are available (Nos. 73-003-3, 6 and 7; 74-021-1 and 2). They consist predominantly of mud similar to the surface muds. In addition, they contain thin beds of muddy silt, often associated with thin beds of mollusc shells (Fig. 14). These silty beds are coarser and contain more carbonate than the muds. There is no regular trend in grain size and carbonate with depth in the cores. However, water content, organic carbon and nitrogen all decrease systematically with depth

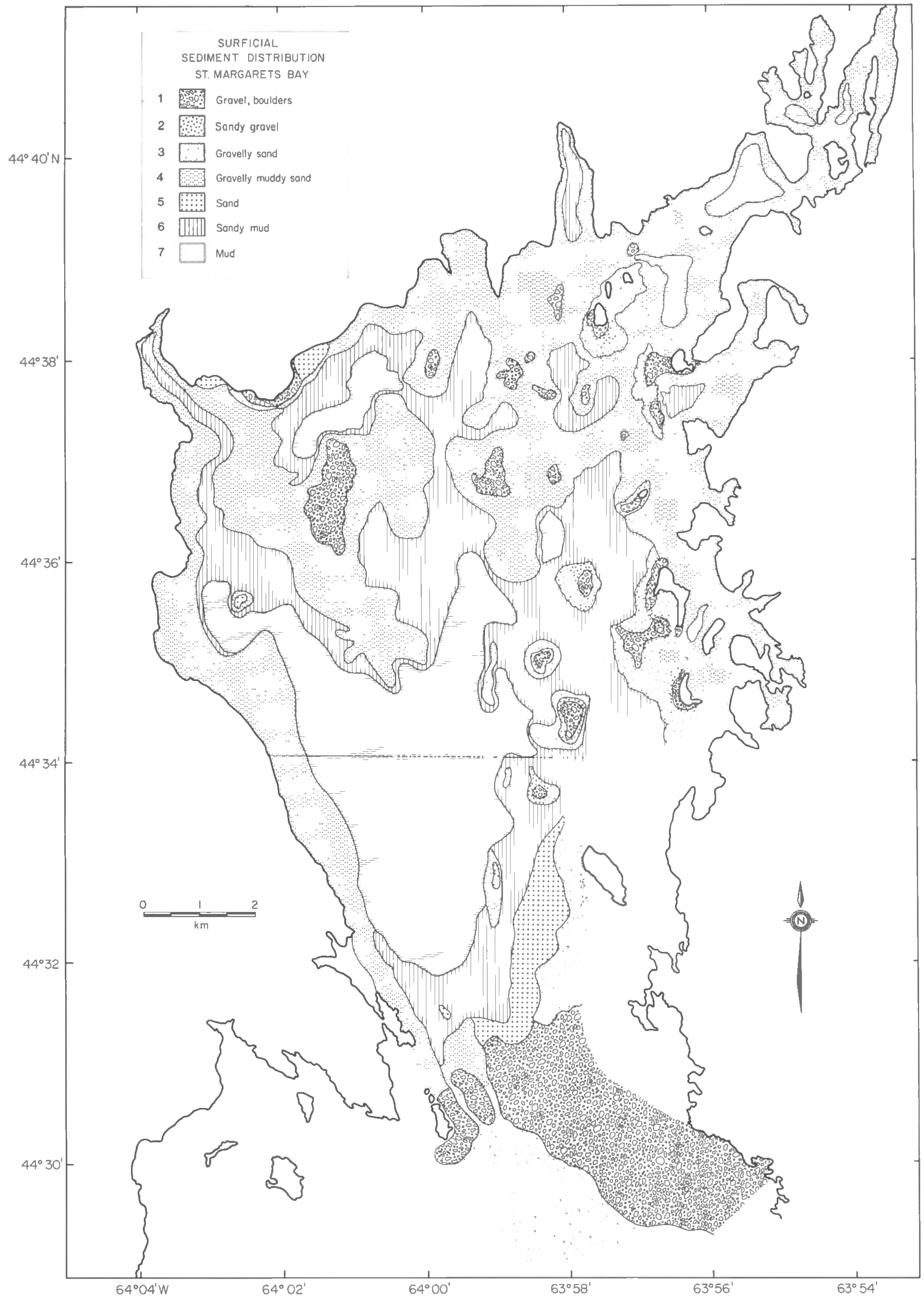


Figure 13. Distribution of surficial sediments in St. Margaret's Bay. Based on MS26B echo sounder profiles and surficial sediment samples.

(Keen and Piper, 1976). The carbon content decreases from almost 8% (dry weight) at the surface to around 2% at depth. An age determination by ^{14}C analysis of total organic carbon at 630 cm in core 74-021-1 gave a date of 3790 ± 250 B.P. All the cores recovered contain large amounts of gas, predominantly methane. This gas is presumably derived from the organic matter in the sediment. Its origin is discussed in more detail by Keen and Piper (1976).

Silty beds and laminae are recognizable only in X-radiographs. They frequently appear unbioturbated, and are often associated with shell layers that appear to be current-concentrated. They are commonest in cores from near the margin of the central basin, and also appear commoner deeper in the cores. Two mechanisms of formation appear possible: the beds may be *in situ* concentrates of coarser components of the muds, with finer sediment winnowed out by storm waves. Alternatively, storm waves may put sand, silt and shelf fragments into motion in shallower water, and transport them into deeper water. The presence of many sandy-bottom shallow water shells, notably *Mya arenaria* (Table 1) suggests the latter mechanism, although *in situ* concentration could also occur.

Mr. Brant Laidler (pers. comm., 1976) has made a detailed study of the foraminifera in cores from the central basin. There were no systematic changes in assemblage with stratigraphic level. Silty beds contain shallow water foraminifera such as *Islandiella islandica, Elphidium clavatum,* and *E. advenum*. They also have high concentrations of the large tests of *Globobulimina auriculata*. This further supports the hypothesis of transport of shallow water sediment as the origin of the silty laminae. However, foraminiferal assemblages very similar to those in the silty beds were also found in many homogenous muds, suggesting a similar origin for much of the mud in the central basin. Only samples with a large number of planktonic species may represent "background" conditions in the central basin. Bartlett (1964) has a little data on foraminifera found living in the deep basin: the principal species are *G. auriculata, Nonionellina labradorica* and *Elphidium bartletti;* these are also the three commonest dead species found in the cores. More work is needed on the foraminiferal assemblages.

The radiocarbon date suggests an overall sedimentation rate of about 0.15 cm/yr., equivalent to approximately 0.16 gm/yr. of dry sediment. Paranjape

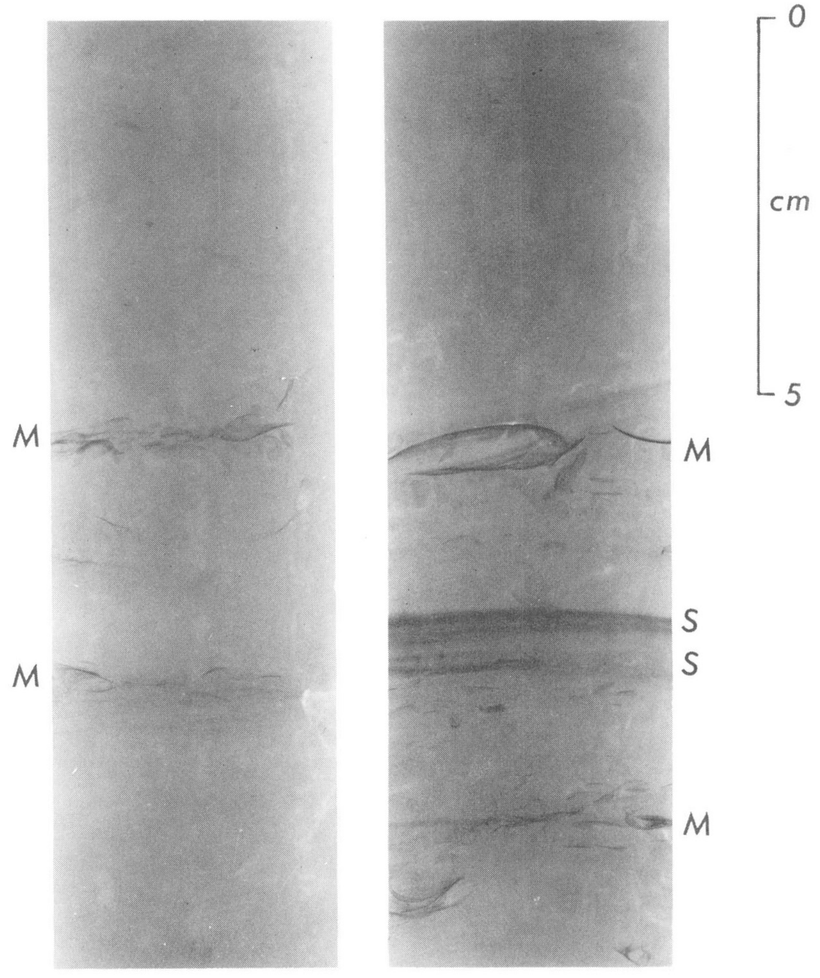


Figure 14. X-radiography of silty laminae in core 74-021-1.
S = silty laminae, M = mollusc shell concentrations

et al. (1975) determined a similar rate in traps placed on the sea floor which suggests that substantial resuspension of sediment, once it has reached the deep central basin, does not take place.

Table 1

Mollusc shells in cores 73-003-3, 6 and 7 from the central basin

	fragments	whole
Mya arenaria	33	11
**Yoldia thraciaeformis*	20	18
**Yoldia limatula*	5	-
Yoldia sapotilla	-	1
Yoldia sp.	39	-
Periploma leanum	-	6
Nucula tenuis	2	9
Nucula tenuisulcata	-	1
Serripes groenlandicus	-	1
**Thyasira gouldi*	-	1
Thracia sp.	-	6
Macoma balthica	-	2
Dentalium entale stimpsoni	-	1

*species found living on floor of Central Basin (G. Robert, pers. comm.)

Identifications by Mr. D. Davies, Nova Scotia Museum.

One short core (73-003-4) was taken near the margin of the sand body west of Shut-In Island, where the sand grades into the muds of the central basin. An irregular sub-bottom reflector is visible about 5 to 8 m below the surface. About 3 m of fine sand with thin beds of mud were recovered, but the core was highly disturbed. The alternation of mud and sand suggests that transport of sand into this area occurs only intermittently during storms.

Distribution of surficial sediment

Till outcrops, with a surface cover of pebbles, and local pockets of coarse sand, occur in shallow water where there is continual reworking by waves. In exposed areas south of the sill, till outcrops are found in water depths as great as 40 m; but in the more sheltered northern part of the bay, muddy sediments accumulate in water depths greater than about 10 m. Tills and gravels occur in intermediate depths around Shut-In Island. Bedrock probably outcrops in shallow water on some of the shoals south of the bay entrance, and perhaps off Shut-In Island. The lithology of the gravels varies rapidly, and correlates closely with underlying till, suggesting that most of the gravel is not moved far by the waves. Except on some isolated deep-water highs, pebbles are encrusted on all sides by coralline algae, suggesting that they are intermittently turned over during storms. Some deep-water highs with tills or gravels probably developed when sea level was lower; however, storm activity is now sufficient to keep them free of mud, but not to rework the gravel.

In Figure 13, we have attempted to distinguish three types of sediment with intermediate amounts of gravel: type 2 is sandy gravel (including some muddy sandy gravel), type 3 is gravelly muddy sand, and type 4 is gravelly sand. These sediment types usually occur in distinct geographic areas, but in places gravelly sediment distribution is variable, and no one sediment type predominates.

Sandy gravel and gravelly sand, commonly with an admixture of mud, occur in slightly deeper water than the till outcrops and gravel, and appear to be winnowed from eroding till. They are consequently most widespread near actively eroding coastal till cliffs. Submerged shoals, on the other hand, appear to supply much less sediment.

Gravelly muddy sand is the dominant sediment in water depths of 10 to 50 m in the central and northern parts of the bay. It is also widespread in very shallow sheltered waters in the northeast part of the bay. Pebble and gravel content tends to be highest near till outcrops. Similar sediments are widespread in North West Arm (Stanley, 1968) and Conception Bay (Slatt, 1974). They are interpreted as a mixture of lag sand and gravel eroded from underlying till, and winnowed mud (ultimately also eroded from till) deposited from suspension. The mixture of the two sediment types may be the result of:

a) formation of lag sands and gravels during storms, and accumulation of mud at times of fair weather,

b) formation of lag sands and gravels in shallow water, followed by accumulation of mud as sea level gradually rises.

Both processes are probably active. Our observations on the central basin muds suggests storm resuspension is likely the more important process.

Fine sand, with small amounts of both mud and gravel, is widespread in deeper water (mostly greater than 50 m) south of the entrance to the bay. It appears to grade into more gravelly sand in shallow water. The mud content is as high as 40 per cent in some areas, suggesting that sand is probably only moved during storms. Shell fragments are an important component of the sand. Similar deposits of sand and gravelly sand are found on the floors of the deep channels breaching the sill, where tidal current scour is probably also important. There is also an extensive sand sheet southwest and south of Shut-In Island, resting disconformably on underlying sediments. It grades from gravelly sand in shallow water (up to about 25 m) to muddy sand in deep water (around 60 m). There is a gradual decrease in mean grain size and an increase in mica content in sediment from shallow to deep water. The heavy mineral content of the sand is variable, suggesting a local source from a variety of till types. In addition, the alternation of sand and mud in core 73-003-3, and the storm transport of shallow-water shells to the central basin mud, both suggest this sand sheet is in equilibrium with present energy conditions, and is not relict sediment. Most of the sand is probably derived from till, although some may have been swept across the continental shelf during the Holocene transgression.

Sand sheets are developed in shallow water (<10 m) off the small sandy beaches in the northern part of the bay. They are similar to the sands found around both the till outcrops and the gravelly sands in the southern part of the bay. The sand appears to be derived primarily from the erosion of adjacent till headlands and its junction offshore with sandy gravelly muds is often quite sharp. Only small pocket beaches are found on the eastern and western shores of the bay.

There are two types of basin-filling sediment in the bay: sandy mud (locally including muddy sand), and mud. Muds fill the central basin, and some sediment ponds in the northern part of the bay. Sand content of the muds increases towards the basin margins. Extensive sandy muds are found wherever there is a nearby source of sand, notably between the Shut-In sand and the central basin mud, and in the former river valleys in the northern part of the bay. Both lithologies are acoustically transparent in MS26B profiles; gas reflectors are found in the muds, while some internal parallel reflectors are found in the sandy mud. Evidence discussed above suggests that much of this sediment is shallow-water sediment redeposited during storms. The concentration of sandy mud in the lower ends of the drowned river valleys of the northern bay suggests that some of the redeposition may be from density currents flowing near the bottom.

"Two-metre" reflector

The MS26B sounding records from the deep central basin show a prominent sub-bottom reflector at depths of 2 to 4 m below the sea floor. It is illustrated in Figure 15 and its distribution is shown in Figure 16. It is a sufficiently strong acoustic barrier to prevent penetration by low-powered acoustic sources in attempts to map bedrock (*see* seismic reflection profiles, Fig. 6a and 6c). A similar reflector occurs in some of the ponded mud basins in the northern part of the bay.

The principal anomalies in the distribution of the "two-meter" reflector in St. Margaret's Bay are (1) that it dips down at its margins, whether this be in association with an obvious topographic effect, or an obvious sub-bottom high (caused by till or bedrock nearly reaching the surface); (2) it is somewhat deeper beneath the sea floor to the south (in deeper water) than to the north; (3) it is absent in the most southerly, nearly isolated deep basin, and west of Shut-In Island (Fig. 16) and (4) the reflector is rather deeper in the shallow small basins in the northern part of the bay, where the sediment is rather sandier, and the total thickness of sediment is less.

We have recently investigated in detail the origin of the "two-metre" reflector (Keen and Piper, 1976). It is due to the generation of methane from the decomposition of organic-rich sediment. The gas layer is a result of the interaction of the reduced solubility of methane at low pressures, and the increasing viscosity of mud-water mixtures with depth.

The distinctive characteristics of its distribution can be explained by several circumstances: (a) If pressure increases (through water depth or increase in overburden) the solubility of methane increases, so that the level at which the amount of methane present exceeds the solubility will deepen; (b) If permeability increases, gas will be lost easily — this may happen northwest of Shut-In Island and immediately north of the sill where the surficial sediment is sandier; (c) If organic carbon production is low, or the products are

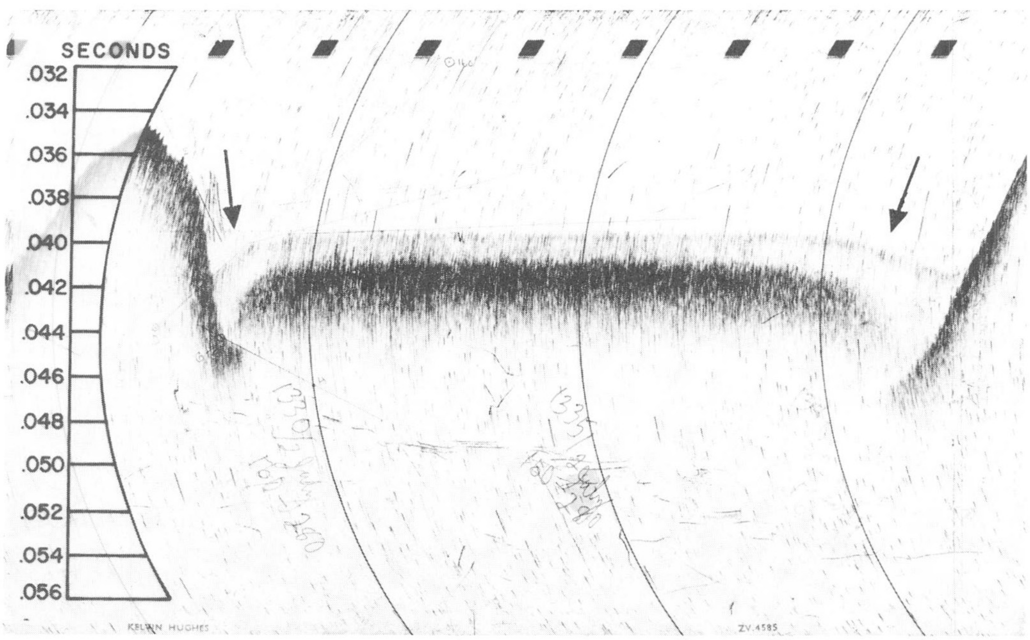


Figure 15. MS26B record showing "two metre" reflector (between arrows).

transported elsewhere, no reflector should be seen; (d) If part of the gas is generated at depths exceeding 8 m, then the down-dipping of the reflector at the margins of the central basin, near sub-bottom highs, and in the thin sequences of the small basins in the northern part of the bay is due to less gas production in these areas. Variations in basement morphology that are more than 10-15 m below the sea floor appear to have no effect on the depth of the "two-metre" reflector, suggesting there is no significant contribution of gas from very deep sediments.

GEOMORPHOLOGIC EVOLUTION

Several distinct stages in the geomorphic evolution of St. Margaret's Bay can be recognized. The bedrock basin may in part represent an exhumed sub-Carboniferous surface, as is the case for Mahone Bay (Barnes, 1976). The over-deepened central basin of the bay, with a bedrock sill to the south (Fig. 3), is presumably the result of glacial erosion; a similar feature is present in the Bedford Basin — Halifax Harbour area. The steep north and gentle south face of the sill resembles the steep north side and gentler south side of the Halifax peninsula. Drumlin deposition in and around the bay has produced characteristic landforms, but no other prominent glacial depositional landforms have been recognized in the bay.

Following retreat of the ice, a lake would have been ponded behind the 55-m-deep sill. The morphology of the former lake floor is generally much smoother

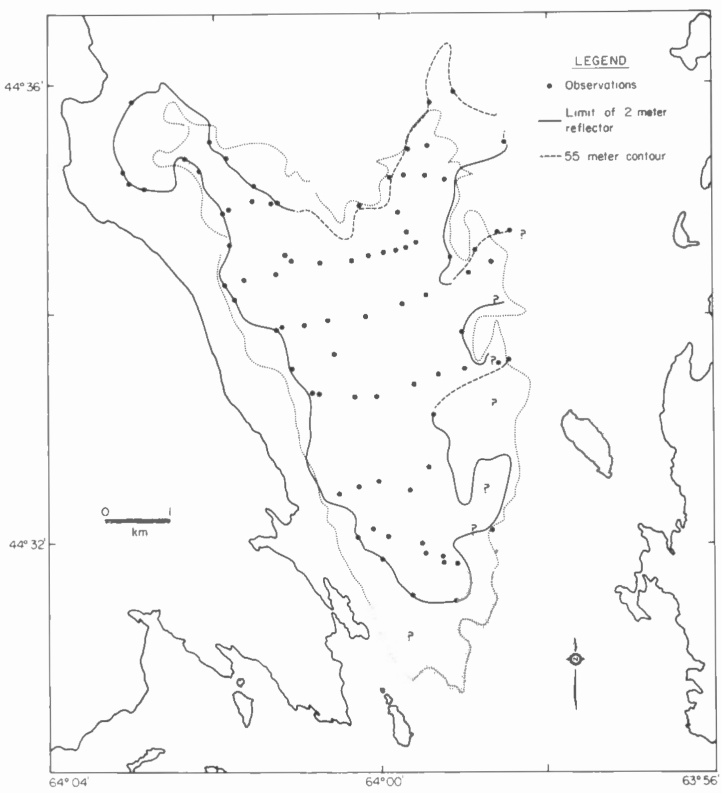


Figure 16. Distribution of the "two metre" reflector in the Central basin of St. Margaret's Bay.

than that in shallower areas (Fig. 4), in which river erosion would have taken place. Smaller lakes may have been ponded in shallow basins in the northern part of the bay. (?) Emerald Silt was deposited in these lakes, modifying the glacial morphology. The terrace at 53-59 m and the steep slopes at 44 to 55 m probably developed as shore features at this time.

The channels draining south from the sill presumably follow the trend of preglacial rivers. They were perhaps modified by subglacial drainage during ice retreat, and would have existed as river valleys flowing out of the St. Margaret's Lake shortly after deglaciation.

If we use Grant's (1970a, b) estimates of postglacial sea levels, the sea would have first entered St. Margaret's Bay about 11 500 B.P. By 9000 B.P., the sea would have been 35 m below its present level, with only two narrow channels a couple of hundred metres wide joining the bay to the open sea. By 7000 B.P., with sea level at -20 m, the entrance to the bay would have been half its present width.

As sea level rose, a barrier beach may have been established at the entrance to the bay. As water depth increased faster than sediment supply could build up the beach, it would have been breached permanently. Much of the sand was probably redistributed onto the sand sheet southwest of Shut-In Island.

In the northern and eastern part of the bay, erosion of drumlins has taken place at the shoreline as sea level rose. Cliff recession has probably been at the rate of around 0.2 m/yr., by comparison with rates of till cliff retreat elsewhere in Nova Scotia (Bowen, 1976, p. 30). The possible terrace at around 33 to 36 m may represent a period when sea level rise slowed or was static, as a result of interaction of eustatic sea level rise and isostatic rebound of the land.

CONCLUSIONS

1. St. Margaret's Bay is underlain by a bedrock depression in granite. Bedrock morphology was probably modified by glacial erosion, to produce a silled basin. Both till deposition and the present gross morphology of the bay were controlled by its bedrock form. Meguma Group rocks are found south of the bay.
2. Two types of till are visible in seismic reflection profiles — till sheets and drumlins. Surficial sediment samples permit the distinction of till sheets of local petrology from red till drumlins containing abundant exotic clasts.
3. Sediment acoustically similar to the Emerald Silt locally overlies till, especially in the central basin of the bay.
4. Sediment acoustically similar to the LaHave Clay fills basins, with thicknesses rarely exceeding 10 m.
5. The surficial sediment distribution appears to reflect present energy conditions, rather than being relict. Reworking of till, especially along the coast, contributes the greatest amount of sediment to the bay at present. Sands are common in the higher energy areas near the sill, and offshore

south of the sill. Muds fill basins in the central bay and sandy muds fill depressions in the northern part of the bay. Sandy gravels and sandy gravelly muds dominate the shallower waters of the northern and eastern parts of the bay.

6. In the central basin, sediment is accumulating at about 0.15 cm/yr., most of this is resedimented from shallower water during storms. The sediment is very rich in organic matter, which decomposes to methane. The methane forms a prominent sub-bottom acoustic reflector.
7. The geomorphology of the bay suggests a lake filled the bay after deglaciation when sea level was more than 55 m below its present level. The gradual Holocene rise in sea level has been important in the evolution of the geomorphology and sediments of the bay.
8. The combination of detailed Hydrographic Service Field sheets, MS26B sounder records, and grab samples provide a comprehensive method of mapping sediment distribution in an area like St. Margaret's Bay. Small seismic reflection profiling systems can, under some circumstances, provide good information on the type and distribution of till bodies, when combined with data on land and grab samples. Drilled cores are a successful means of identifying different tills. Slates can be reliably distinguished from other bedrock types with a magnetometer: the distinction of granite from quartzite is less easy.

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