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DARTMOUTH, N. S.

ON THE SEDIMENTS AND STRATIGRAPHY OF THE SCOTIAN SHELF

by

Lewis H. King
(Geological Survey of Canada)

REPORT B.I.O. 67-2

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ABSTRACT

Sediments on the Scotian Shelf can be grouped into five facies that appear to be the products of a relict glacial-marine environment. Pleistocene glacial debris covered the shelf and it was reworked and redeposited in littoral and sublittoral environments that resulted from a contemporary low stand of sea level; as indicated by a submarine terrace at 110 to 115 metres. The glacial-marine environment gave rise to sand, silt, and clay facies. Topographic highs, which represented islands during the low sea-level stand, served as source areas for these deposits. Transgression of the Holocene sea onto the high areas caused further modification in zones of wave action, thus giving rise to beach sands and gravels, as well as coarse lag deposits; collectively designated the sand and gravel facies. The unmodified portion of the glacial debris is designated glacial till. These five sedimentary facies have been mapped in detail utilizing echograms and textural analyses of bottom samples.

The stratigraphic interpretations are based on echograms, continuous seismic-reflection profiles, radiogenic ages and interpretation of the surficial geology. The unconsolidated sediments rest on an erosional unconformity developed across beds of possible Tertiary or Cretaceous age. In general these older beds are overlain by the Pleistocene deposits of glacial origin. The sand, silt, and clay facies appear at least in part to be contemporaneous with the glacial deposits; however, deposition of the clay facies was more prolonged and overlaps the silt facies. The sand and gravel facies is a transgressive basal deposit underlain by glacial debris.

The relation of the erosional unconformity to the bottom topography suggests Pleistocene and later deposition upon either a glacially eroded terrain and/or a dissected coastal plain.

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INTRODUCTION

In a recent paper (King, 1965) the writer discussed the surficial geology of the Scotian Shelf and emphasized the use of echograms as a mapping tool in delineating the sedimentary facies.

This paper is an extension of the previous work and covers a complete section across the Scotian Shelf, 85 kilometres wide and 190 kilometres long (Fig. 1). Data from echograms, continuous seismic reflection profiles, radiogenic ages and sediment distribution patterns provide the basis for an assessment of the stratigraphy of the unconsolidated sediments and uppermost bedrock of the shelf. The survey was carried out on the CSS KAPUSKASING in April of 1964-65.

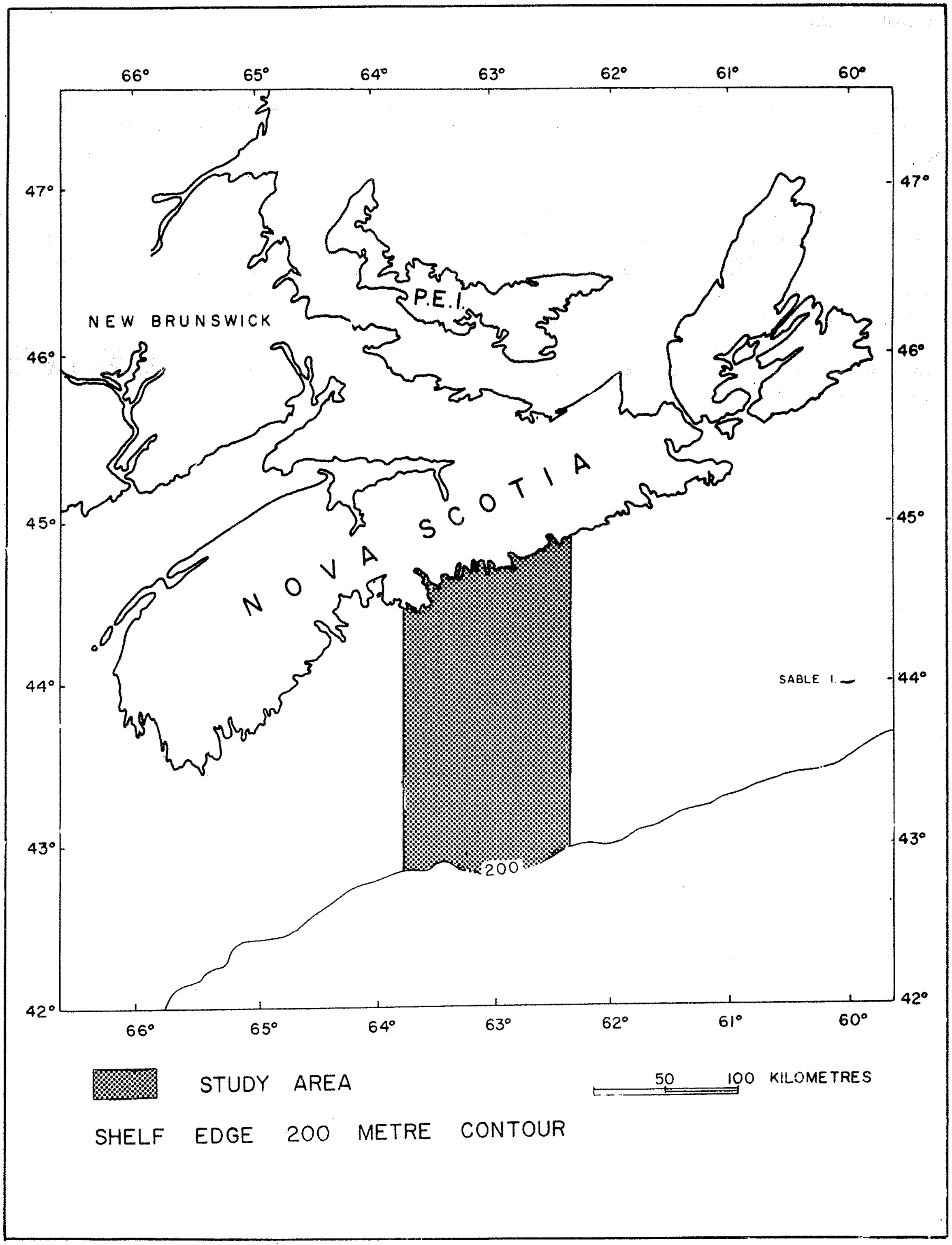

Figure 1 Index map of study area.

BATHYMETRY

For convenience in presentation the section has been divided into a northern and southern area with the division at latitude 43°45′N. The bathymetry of the section is shown in Figures 2 and 3. The area is contoured in 20-metre intervals and grouped into 100-metre intervals as indicated by the shaded areas. The shelf is typical of formerly glaciated shelves which have an irregular surface with many troughs and basins. These depressions on the Scotian Shelf have been previously noted by Shepard (1934, 1963) who attributed their origin to glacial scouring.

The present study area only covers about one-quarter of the shelf but examples of many of the features which seem to be typical of the shelf as a whole are present. The major morphological features fall into categories similar to those described by Holtedahl, (1958) for continental shelves off Norway, Labrador and Alaska. On the basis of the Holtedahl classification the major divisions are: (1) an inner shelf bordering mainland Nova Scotia, (2) an area of longitudinal and transverse depressions within the shelf and (3) an outer shelf or outer banks region.

The inner shelf has an average width of 25 kilometres and terminates at approximately the 100 metre contour. Continuous seismic profiles indicate that its rough surface is underlain by resistant bedrock, probably a continuation of the Ordovician strata from mainland Nova Scotia. Bottom sampling indicates a thin layer of winnowed glacial debris.

The longitudinal trough is immediately seaward from the inner shelf and runs parallel to it. The trough is 40-50 kilometres in width, and extends more or less continously along the entire length of the shelf even though its relief is only of the order of 120-140 metres. It is most poorly developed within the study area as its seaward margin is partially eroded by the development of two transverse depressions which branch out from the trough. Its southern margin within the study area is defined by the northern slope of Sambro Bank and The Patch. The Patch is a small bank at latitude 44°15′N shown at the eastern boundary of the study area (Fig. 2). The inner margin of the trough is underlain by presumed Ordovician bedrock while the central portion and outer margin are underlain by younger stratified rock of possible Tertiary or Cretaceous age. These bedrock surfaces are overlain by 20-100 metres of unconsolidated sediment.

The two transverse depressions: Emerald and LaHave Basins, extend outward from the longitudinal trough. They are elongated in shape and attain respective depths of 280 and 250 metres. They extend seaward for 80-100 kilometres and terminate against the outer banks. The rims of the basins have gentle undulating surfaces accented by a number of isolated banks. These banks were exposed as islands during the Pleistocene when sea level stood at the 110-115 metre level. A saddle on the outer banks between

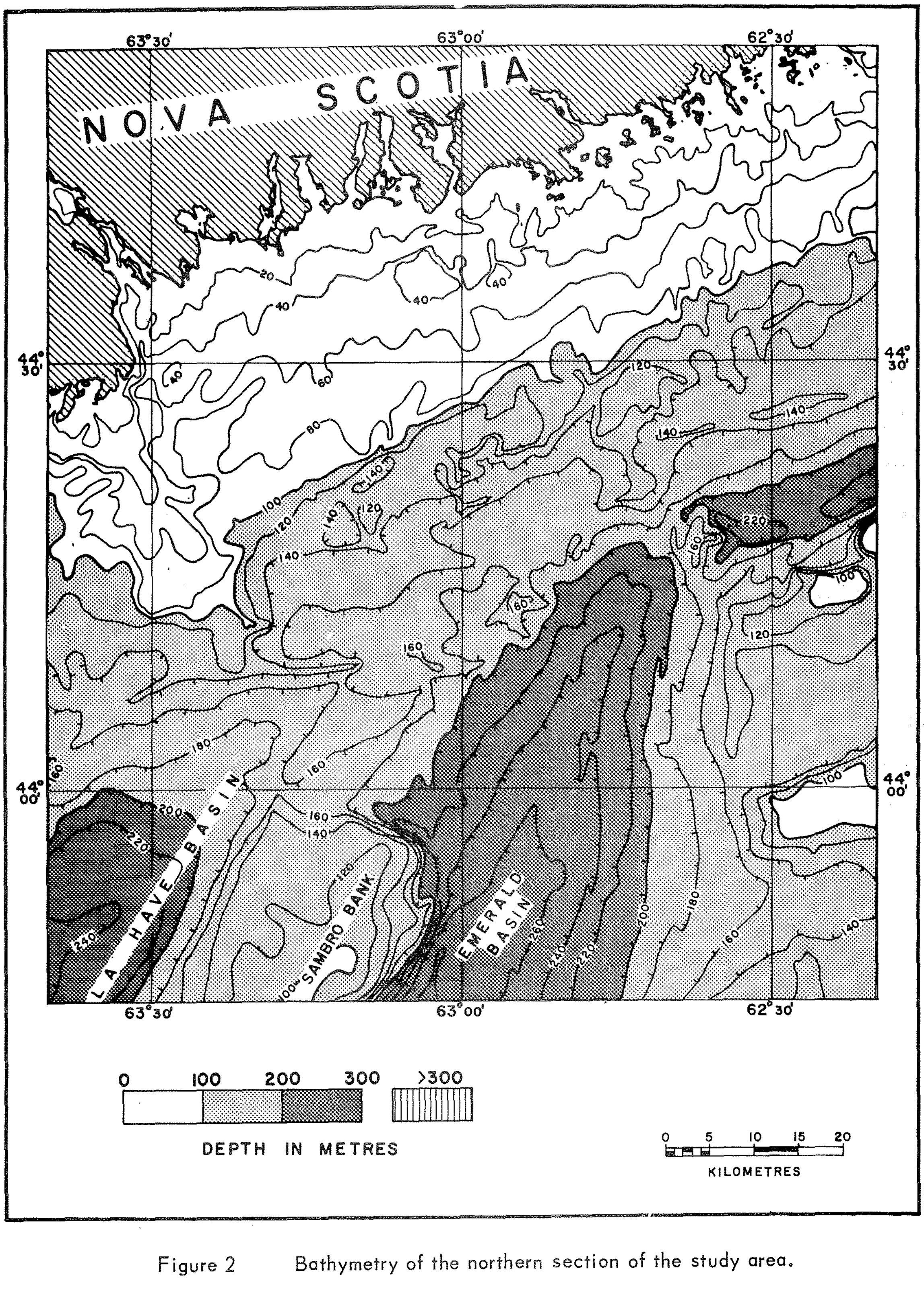

Figure 2 Bathymetry of the northern section of the study area.

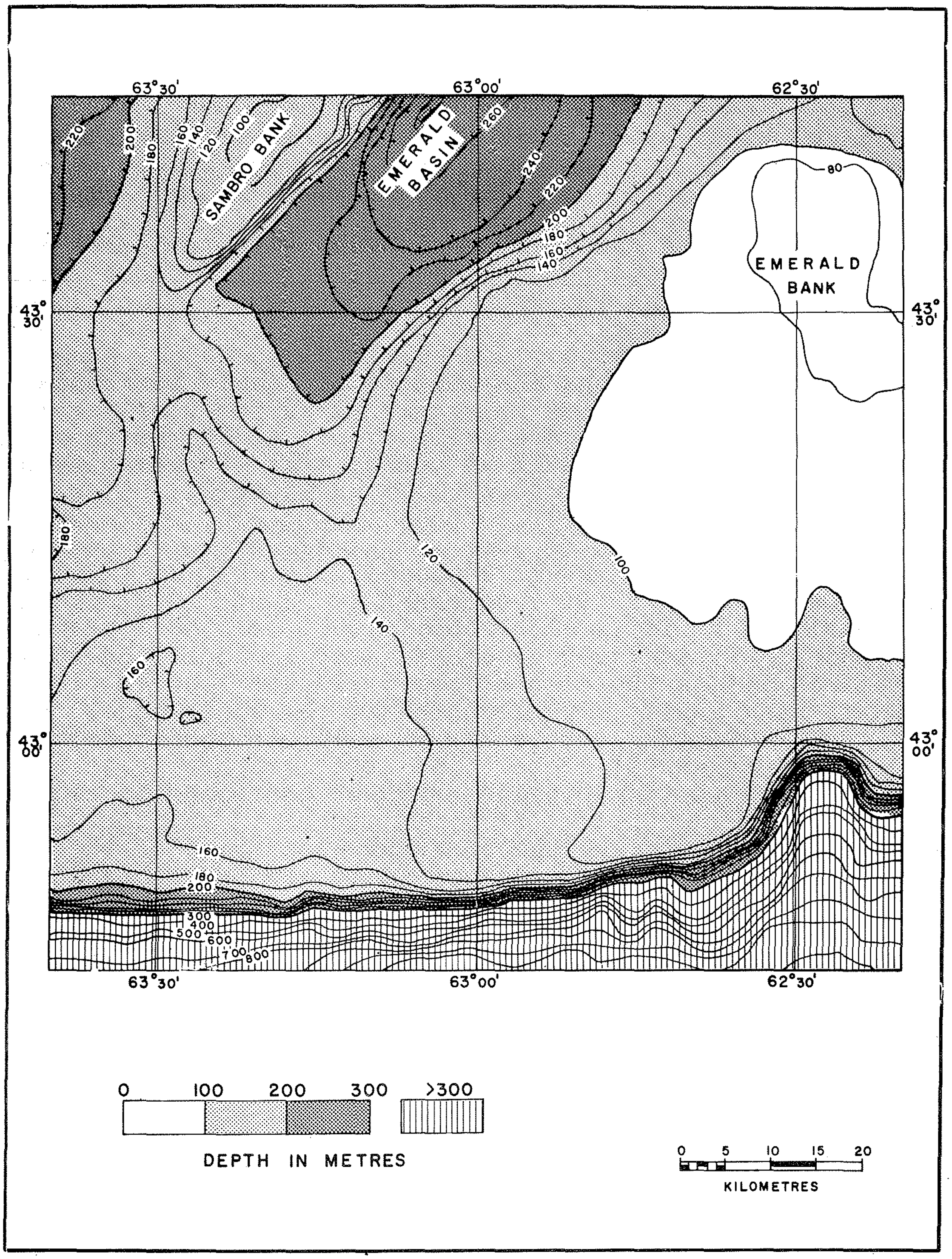

Figure 3 Bathymetry of the southern section of the study area.

Emerald Bank and LaHave Bank, which is immediately west of the map area, forms a 135-metre sill for the basin complex. This sill was significant during the low stand of sea level when it served as the threshold over which the main exchange of waters between the basins and the open sea occurred.

Within the study area the region of the outer banks varies from 50-80 kilometres in width and the shelf edge occurs at about 200 metres depth.

Across the central and outer shelf sub-bottom profiles indicate an erosional surface developed on well stratified bedrock which dips gently seaward. Although the bedrock is covered by glacial debris and recent marine sediment, the present topography is to a very large extent influenced by this old erosional surface. Many of the isolated banks have flat tops and consist of nearly horizontal beds which are bounded on all sides by erosional surfaces of varying slope. Some of these slopes are steep erosional scarps in which case the features can be classed as mesas. The truncated beds are mostly covered by a layer of unconsolidated material.

The outer banks region is also to a large extent a bedrock feature and appears to represent a cuesta; probably an extension of the Georges Bank cuesta first recognized by Johnson (1925) and recently confirmed by Emery and Uchupi (1965), and Malloy and Harbison (1966). Truncated beds are clearly indicated on sub-bottom profiles across the cuesta face while the seaward side or back slope forms a gentle dip slope toward the shelf edge. At the shelf edge the reflecting layers increase in dip and conform to the surface of the continental slope. The stratigraphic relations of the beds on the sub-bottom profiles suggest a prograding sequence. Evidence of prograding shelves from continuous reflection profiles have been reported along the shelf of the east coast of the United States by Moore and Curray (1963) and Emery and Uchupi (1965).

The origin of the erosional unconformity at the surface of the bedrock is discussed later under bedrock geology.

METHOD OF MAPPING

While mapping the surficial geology of the shelf extensive use has been made of echograms as an aid in interpreting the sediment type. Echograms obtained on the geological cruises, as well as echograms previously obtained by the Canadian Hydrographic Service for charting purposes, have been used. During the initial work a close correlation was noted between the bottom samples and the character of the echograms obtained between stations. As this work progressed and the relations between the textural analyses and the acoustical data became better understood, it became apparent that the hydrographic data could be utilized in advance of the geological sampling. Preliminary geological maps are now prepared in advance of sampling and the sampling program is laid out in accordance with the sediment distribution established on the basis of the acoustical data. Experience has shown that the preliminary maps are remarkably reliable but the samples are required for confirmation and minor adjustments to gradational boundaries, as well as for other laboratory studies. Use of the combined techniques conserves ship time and enables one to map to a high degree of detail, far beyond limits considered realistic if mapping was based on sample control alone. Echograms provide a fairly exact picture of contact relations with regard to the nature and sharpness of sediment boundaries, as well as their location in space. Under some conditions the stratigraphic relations are also evident on the records.

Figures 4 and 5 show the degree of sampling control for the northern and southern sheets. Samples were taken at each station with a modified van-Veen grab sampler and echograms were obtained between stations. The north-south lines are tracks for the echograms obtained from the Hydrographic Service.

The echogram classification (King, 1965) is based on the shape of the surface of the bottom, as well as the relative degree of compaction of the sediment. The degree of compaction is to a large extent a function of the clay content. Most of the records were obtained with a Kelvin Hughes, 26B, conventional echo-sounder which is particularly well suited for this purpose because of its relatively high frequency and short pulse length.

Although the mapping technique has been discussed in the earlier paper in some detail, subsequent work under more demanding circumstances has necessitated certain modifications in the interpretation of some of the more difficult boundary relations. Therefore, a further discussion on the interpretation of the echograms is indicated in this report. The classification is shown in Figure 6.

<u>Type I</u> represents the clay facies:- a soft, uncompacted bottom with a smooth surface which is penetrated readily by sound. For optimum results the echo-sounder should be operated at a relatively low gain to produce a result whereby the echograms show a thin dark line at the sediment-water interface while the area of the record

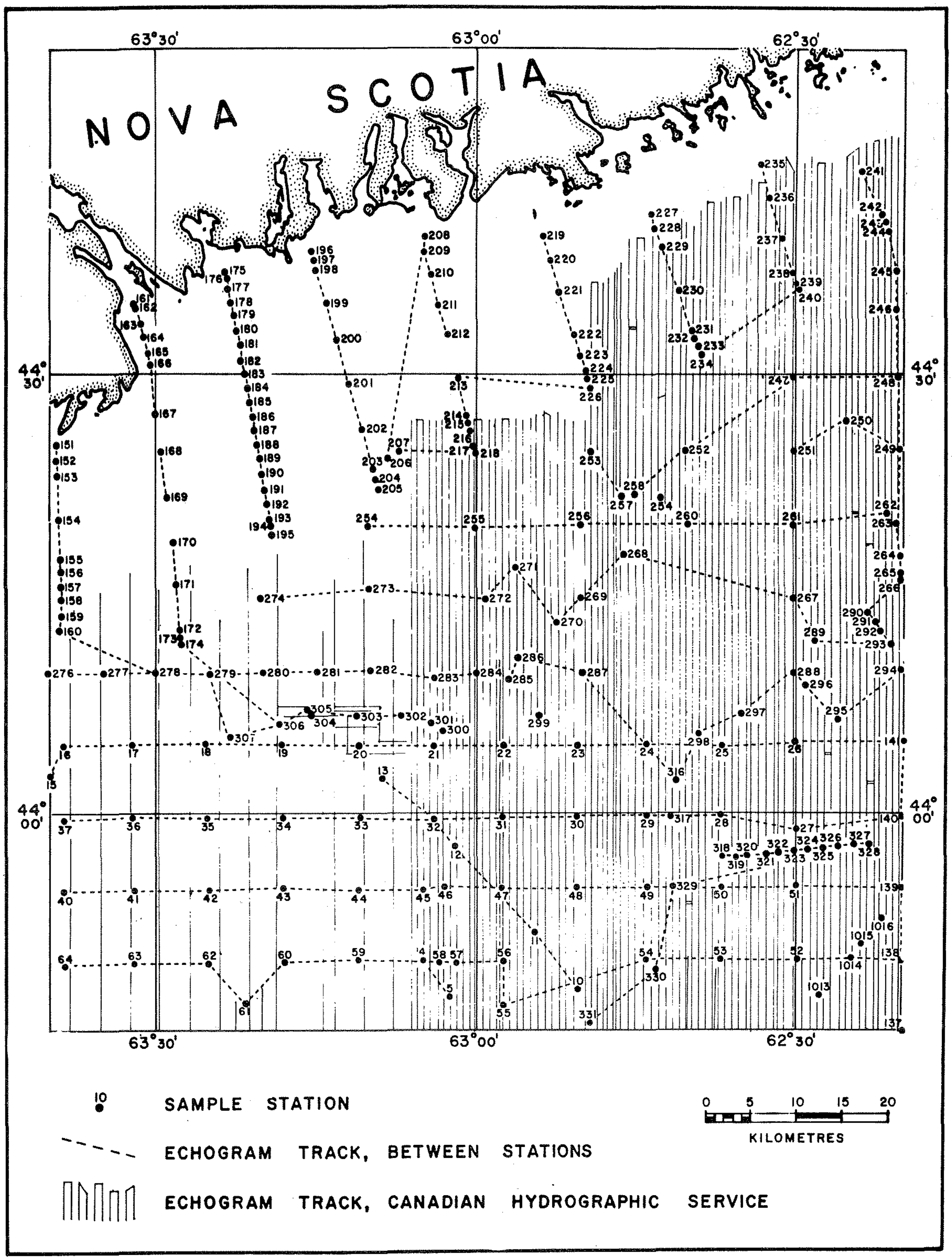

Figure 4 Acoustical and bottom sampling control for the northern section.

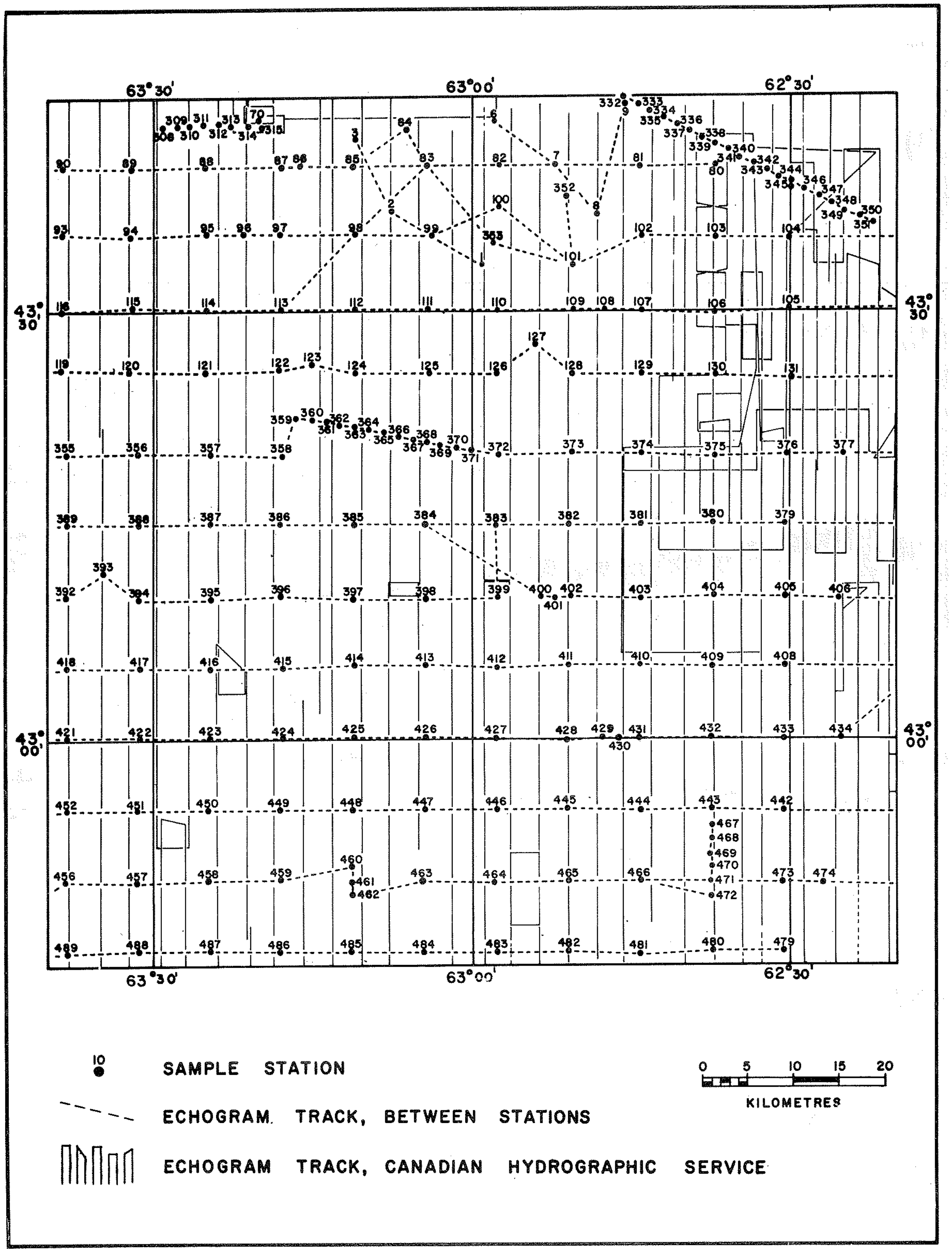

Figure 5 Acoustical and bottom sampling control for the southern section.

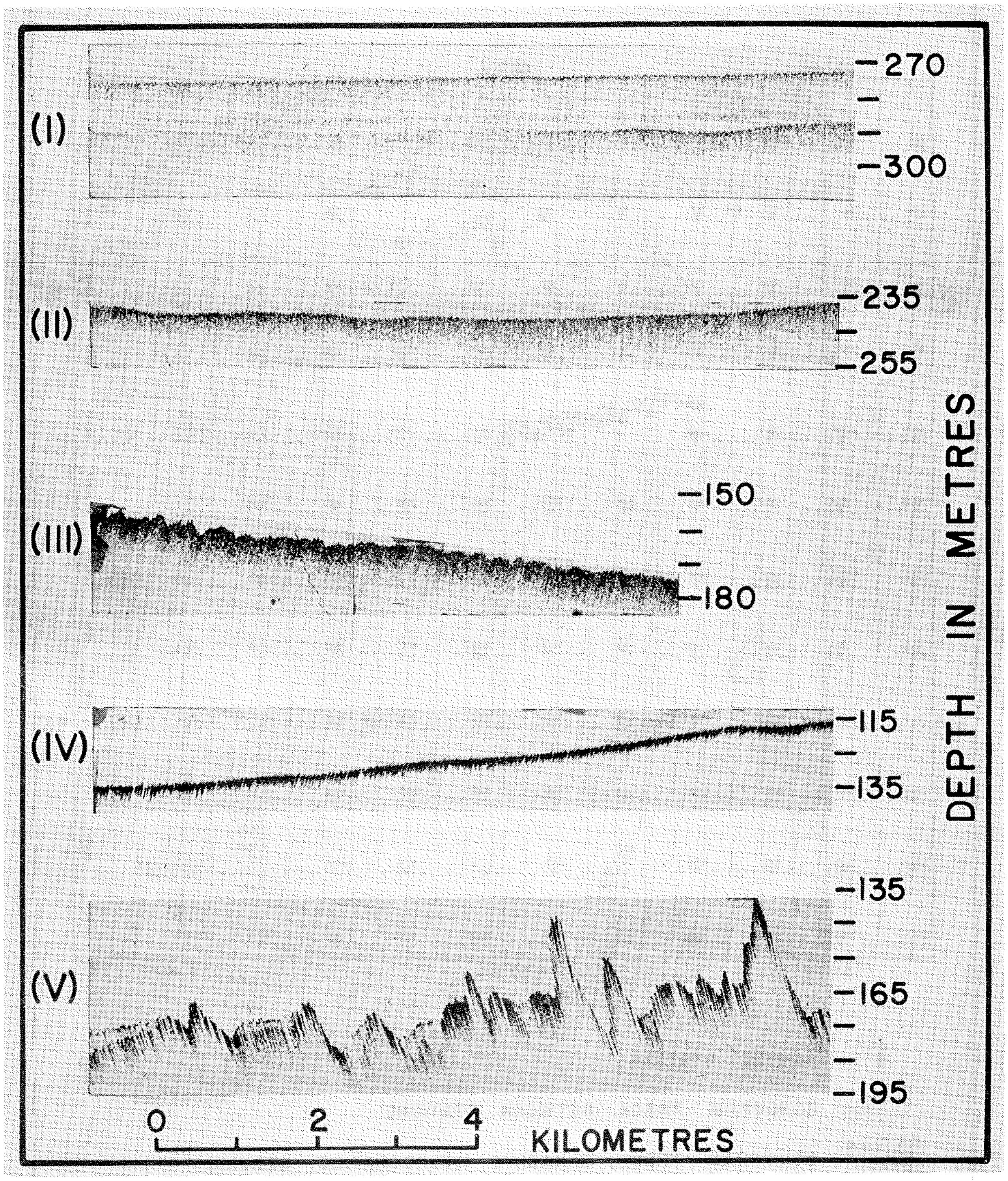

Figure 6 Classification of echograms (after King, 1965).

below this surface is relatively clear, or acoustically transparent, except where structure or an impermeable sub-bottom is encountered.

Type II represents the silt facies:- a semi-compacted bottom with a smooth surface. Sound does not penetrate the bottom as readily as in Type I and a grey sub-bottom record is produced under the optimum gain conditions specified under Type I. The sediment-water interface is not clearly defined by a thin dark line; instead this area of the record blends uniformly with the grey sub-bottom record.

Type III represents glacial drift:- a semi-compacted to compacted bottom with an undulating surface. The undulating surface is the most characteristic feature.

Type IV represents both the sand facies and the sand and gravel facies:- a hard, generally smooth bottom. The record is thin and black at a low gain setting on the echo-sounder. These facies are divided by a submarine terrace at 110-115 metres; sand dominates below the terrace while sand and gravel patches dominate above the terrace.

Type V represents an intimate distribution of glacial drift on the peaks and clay in the low areas between the peaks. This type was previously mapped as an undifferentiated bottom but in areas where control is good a pattern can be resolved.

The clay and silt facies present no major difficulties in mapping except in a few instances where the silt grades from a poorly sorted to a well sorted material. The boundary between the well sorted silt and the sand facies is difficult to delineate exactly as the sound does not penetrate the well sorted silt. In such instances one must rely solely on contrast in the thin line at the sediment-water interface. This line is black over sand and grey over silt and, unless the records are of optimum quality, it is difficult to locate the boundary precisely. In any event the acoustical data indicates the problem and samples can be chosen to improve the resolution.

Two difficulties have arisen in mapping the glacial drift and both pertain to the boundary between it and the sand facies in the depth range of 130-140 metres. Normally, the contrast between the undulating bottom for the till and the hard smooth bottom for the sand is well defined and this generally occurs close to 130 metres depth which is about 20 metres below the level of the submarine terrace. In areas where the slopes are steep the boundary is poorly defined and in the preparation of the preliminary maps it is assumed to occur at 130 metres and subsequent sampling is required to resolve the boundary. Even with the textural data from the samples the boundary is sometimes indistinct due to the difficulty of distinguishing a relatively undisturbed till from a modified till. If the slopes are steep, however, the horizontal error in positioning the boundary is small.

Modified tills have been included with the sand facies as their dominant textural grade is sand. Bottoms on which they occur have an erosional rather than depositional aspect and the shape of the bottom remains undulating like that of a true till (till-controlled bottom). Where undulating surfaces occur between 130 metres and the terrace level the boundary relations are gradational, and sampling must be used as an aid in delineating the boundary between the sand facies and the till.

As mentioned previously the boundary between the sand facies and the sand and gravel facies is distinguished by depth on the echograms and this conforms to a fairly sharp textural division. Samples show that above the terrace the textural variations are erratic, varying from well defined sand and gravel occurrences to areas where mixing of these textural grades is dominant. Below the terrace sand is the dominate type, however, gravel sometimes occurs especially in the areas of modified till. The most diagnostic textural characteristic is the occurrence of some silt and clay and they impart a well defined tail to the frequency distribution curves. On the average the respective silt and clay contents are 10 and 5 per cent. Clay and silt are rarely found above the terrace. The bottom across the sand and gravel facies is generally smooth, but in areas where this layer is thin the underlying till imparts some irregularities to the surface. Continuous seismic profiles across such areas confirm the presence of till in the immediate subbottom.

GEOLOGY OF THE UNCONSOLIDATED SEDIMENTS

The distribution of the unconsolidated sediments is shown in Figures 7 and 8. The units are named tentatively according to their dominant textural aspect. As mapping progresses over a greater area of the shelf and relations between these sedimentary units become better known, it will be possible to develop a more satisfactory system of nomenclature.

In order to understand the present distribution of sediments on the shelf it is important to recognize the main parameters of the sedimentary framework in effect from the late Pleistocene to the present. It was earlier recognized that many of the sediments of the shelf are relict and that some developed under shore and shallow-water conditions associated with lower eustatic sea levels resulting from the Pleistocene glaciation. The local expression of this low stand of sea level is seen in a well developed submarine terrace which has been mapped throughout this portion of the Scotian Shelf. Because it occurs at 110-115 metres, the bank areas were well above sea level as the glaciers were withdrawing from the shelf. As the geological history is developed in this report it will become apparent that the glaciers extended across the entire shelf and as they receded they left a variety of glacial deposits which were modified by marine processes under a variety of energy conditions. Fine sediments were winnowed from the banks, and deposited with a definite relationship to water depth, prevailing currents and the bottom topography. In the deeper areas the glacial deposits were modified to a lesser extent because they were not subjected to high energy conditions.

Glacial Drift:

Figures 7 and 8 show that large areas of glacial drift occur on the shelf. These deposits have undoubtedly undergone some modification by bottom currents; nevertheless, they are still recognizable as till. The surface distribution of the glacial drift is limited to intermediate depths from 130-140 metres at the upper boundary to 200-210 metres at the lower boundary. The glacial deposits completely flank Sambro Bank, extend northerly across a saddle between Emerald and LaHave Basins, thence northeast and southwest across the heads of the basins and immediately seaward of the inner shelf. On the east side of the area they more or less surround the two small banks north of Emerald Bank.

The irregular pattern is caused partly by ponding of clays between the low east-west trending till ridges along the northern portion of the basin complex, partly by burial under clay and silt in the main basins and partly by erosion and reworking processes beyond the old shoreline which is delineated by the boundary for the sand and gravel facies.

In addition to the surficial occurrences, till has been recognized as a sub-bottom deposit over the greater part of the

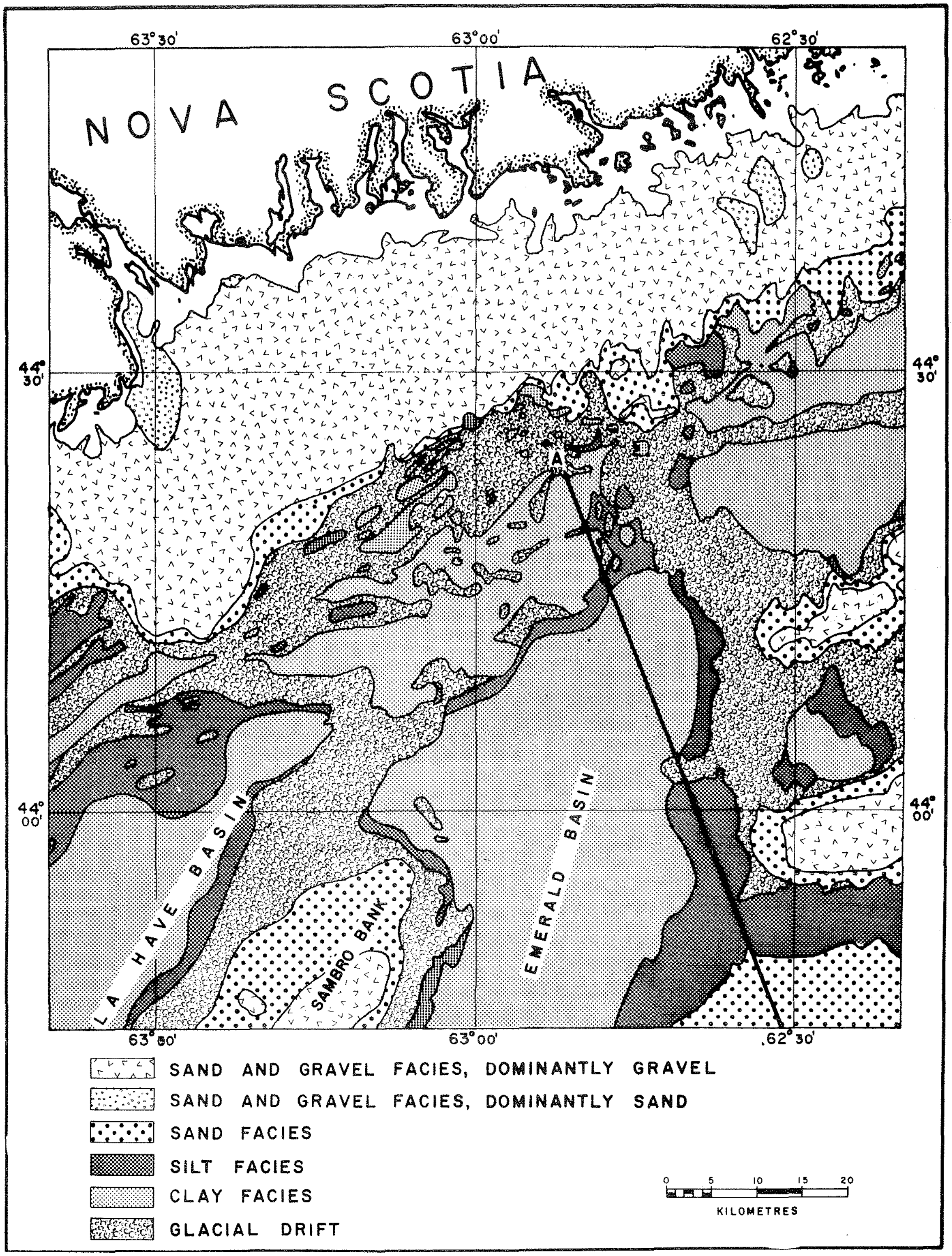

Figure 7 Distribution map of the inconsolidated sediments across the northern section.

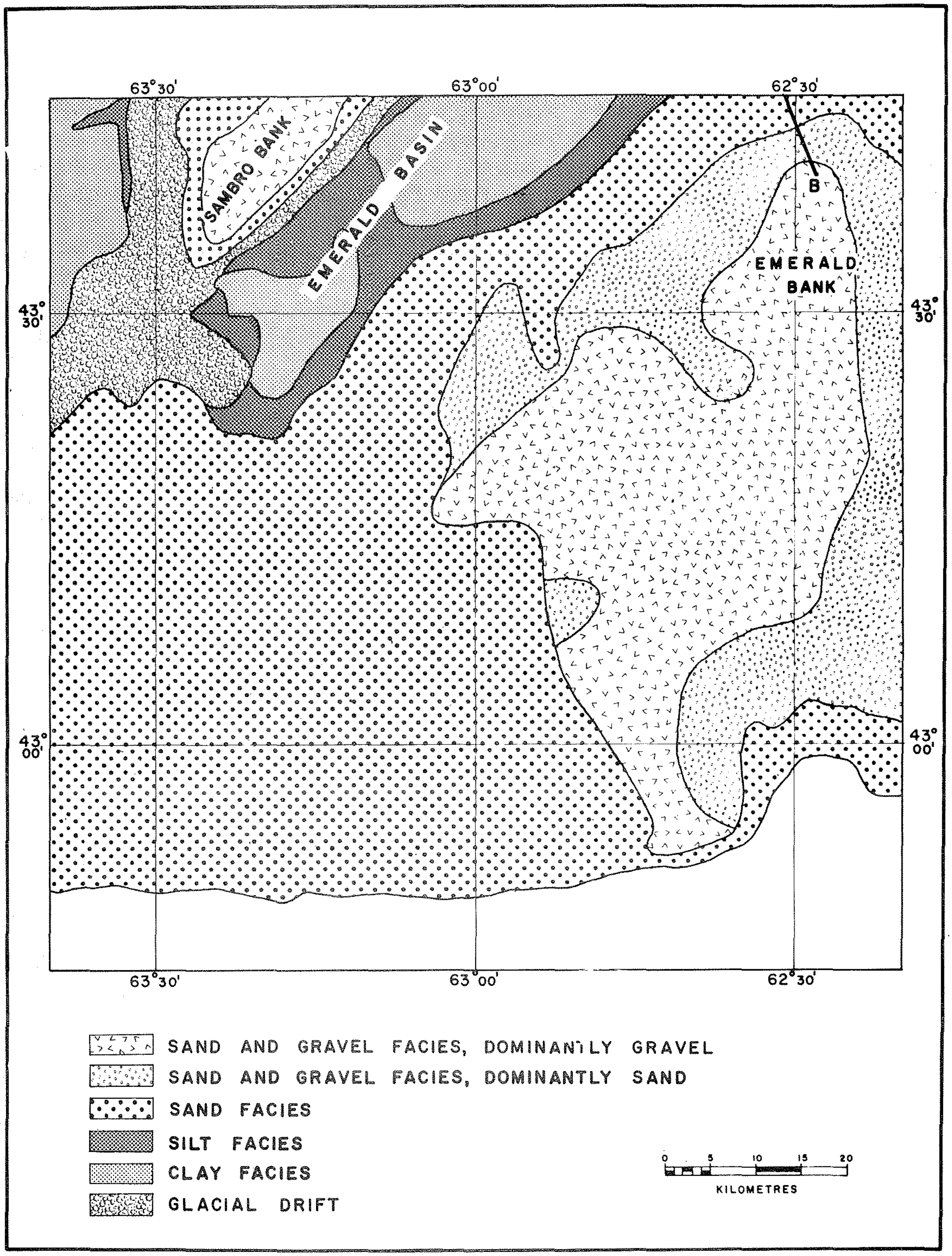

Figure 8 Distribution map of the inconsolidated sediments across the southern section.

study area. This is evident from echograms and continuous seismic profiles. Figure 9 is a geological section along the line AB and is based on a record from a continuous reflection-seismic profiler (EG & G International unit with sparkarray) operated at a 2,500 joule output and fired once every three seconds. The very shallow portion of the section within the bubble pulse on the seismic record was resolved on a 26B Kelvin Hughes echo-sounder and the sediment type at the surface was confirmed by means of bottom samples. The till occurs as a continuous blanket with an undulating surface and is only slightly stratified in a few locations. It attains thicknesses up to 100 metres where it fills irregularities on the underlying bedrock or forms local hummocks. For the most part if appears to be a normal ground moraine type of deposit. Of special interest are two large hummocks in section A-a and a-b which have respective heights of 50 and 90 metres, as well as a number of minor peaks at the beginning of the section. On the map (Fig. 7) these features appear as ridges and others are present in addition to those shown in the section. Some are overlain by a thin layer of silt. Within the study area some extend for distances up to 40-50 kilometres in a direction subparallel to the coastline and one extends well beyond the limit of the map. These ridges are thought to be part of an end-moraine complex. Some of the minor ridges are also part of this complex as indicated in the section, but some are merely an expression of underlying bedrock ridges with a thin till cover.

The texture of the glacial debris varies widely, ranging from 0.05-1 millimetres in median diameter and from 0.8-4 quartile deviation (QD_ϕ) or sorting. The dominant textural grade is sand but angular rock fragments in the gravel range are generally present. As mentioned previously the till and sand facies boundary is sometimes gradational and this is reflected in the lower sorting values.

The coarse fraction of the till is made up of fragments of quartzite, slate, granite and some basalt which appear to have been derived from the mainland of Nova Scotia. The finer fractions contain from 50-60 per cent quartz and intermediate amounts of feldspar, mica, sericite, kaolinite, illite and chlorite. Calcite is generally in the 1-2 per cent range while organic matter is generally in the 0.75-1.5 per cent range.

Sand Facies:

The sand facies was deposited in and adjacent to the littoral zone, and its distribution as shown in Figures 7 and 8 is generally restricted to a narrow band of a few kilometres width along the submarine terrace. In a few areas where the bottom gradient is low this band widens accordingly to widths as great as 10 kilometres. In the outer bank area the sand facies is very extensive and occupies the entire saddle between Emerald Bank and LaHave Bank just to the west of the study area. As mentioned earlier this area was a sill for the LaHave-Emerald Basin complex. Tidal currents were undoubtedly strong across this sill as water depths were only of the order of 15-25 metres in the shallower

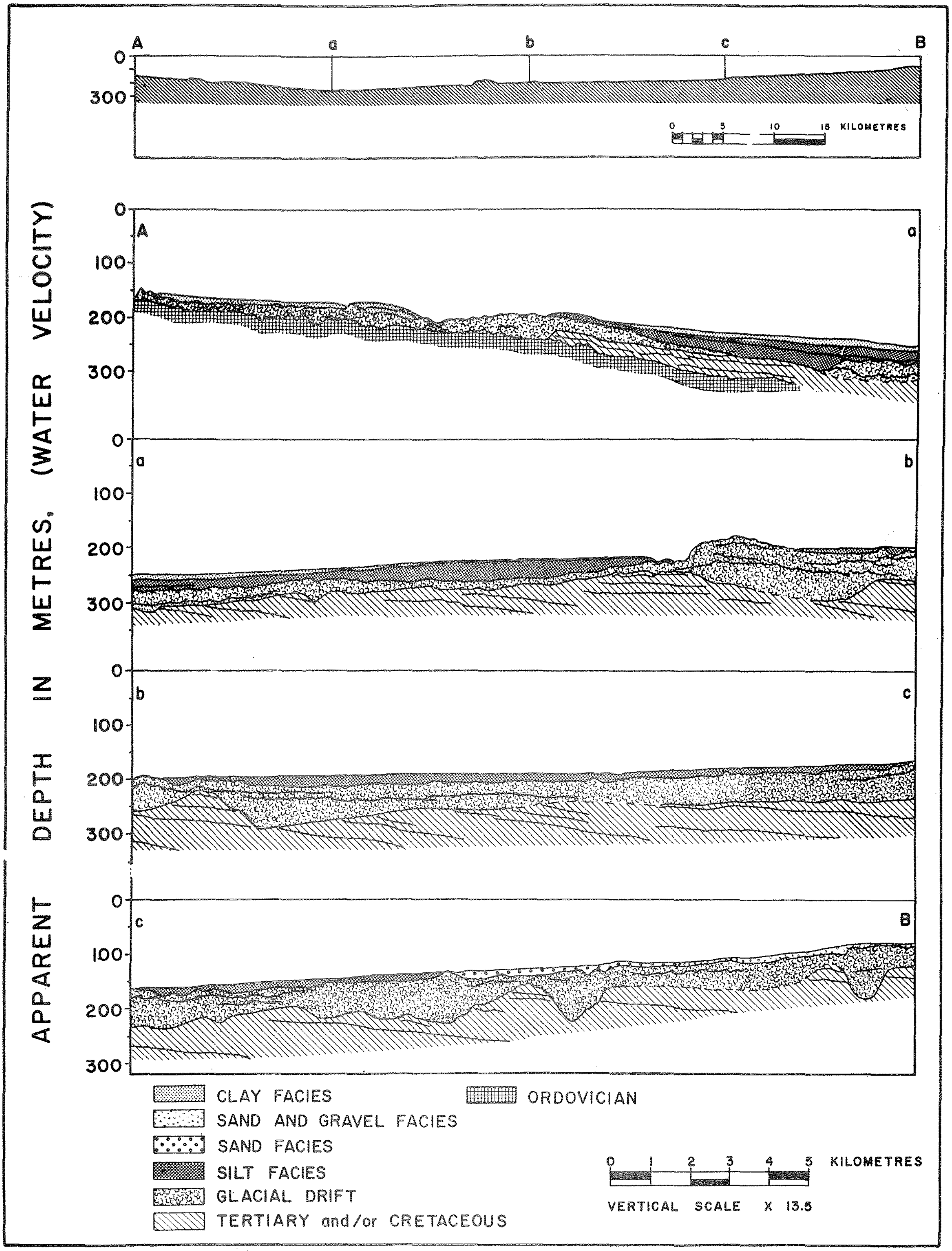

Figure 9 Geological section along the line AB. Based on bottom samples, an echogram and a continuous – reflection seismic profile.

parts. Sub-bottom profiles indicate that sediment transport was extensive. Sand pockets up to 80 metres in thickness accumulated in some areas across the sill. In other areas the sand facies forms only a thin veneer across the underlying glacial drift. In the geologic section (Fig. 9) the sand facies is very thin and its true thickness could not be resolved on the sub-bottom records.

The median diameter of the sand facies varies from 0.6-0.06 millimetres with an average of 0.2 millimetres. The sorting (QD_ϕ) varies from 0.1-1.5 and averages 0.7. Although the sands attain a high degree of sorting close to the old shoreline according to the quartile deviation index, they, nevertheless, contain on the average about 10 per cent silt and 5 per cent clay thus imparting a pronounced tail to the frequency distribution curves. Further away from the terrace the sands are more poorly sorted and where they border the till the relations are commonly gradational. This relation appears to arise from a modification of the till. The modified till probably occurs as a very thin veneer because the bottom across such areas is undulating and indicative of till control.

The quartz content of the sand facies generally falls in the range between 65-75 per cent. The grains are generally well rounded but angular grains are not uncommon. Feldspar and mica occur in the 5-10 per cent range while the remaining layered silicates fall below 5 per cent. Calcite is highly erratic, ranging from 0.2 per cent to as much as 50 per cent in some local shell beds. Organic matter generally varies from 0.2-1 per cent. Glauconite becomes significant in the samples across the outer banks.

Silt Facies:

The main surficial occurrence of the silt facies is generally confined as a narrow band to the peripheral areas of the basins. Along the western side of Emerald Bank the silt occurs adjacent to the sand facies but in most other areas glacial debris separates the silt and sand facies. Boundaries between the silt and glacial drift are sharp and easy to define, and this is also generally true for the silt-sand boundaries. In one instance, however, the silt extends into shallower water along a channel between Emerald Bank and the small unnamed bank immediately to the north. Here the silt becomes well sorted and forms a gradational contact with the sand. The high degree of local sorting in the silt (values as low as 0.5 QD_ϕ) probably arises from strong current action during deposition. Strong tidal currents must have prevailed at the low stand of sea level when the channel was only 40-50 metres deep. These boundary relations suggest that the silt and sand facies are contemporaneous.

For the most part the silt facies is very poorly sorted and the quartile deviation ranges from 1.5-3. The median diameter of the suite of silt samples varies between 0.01-0.05 millimetres. The poorly sorted condition of the silt suggests a short distance of transport, rapid burial and little subsequent reworking.

The petrographic composition of the silt is very similar to that of the glacial till. On the average it contains 55-65 per cent quartz, 10-15 per cent feldspar, 5-10 per cent mica and 10-15 per cent of other layered silicates including illite, chlorite and kaolinite. Calcite and organic matter are somewhat higher varying from 2-5 per cent and 1-2.5 per cent respectively.

Data from sub-bottom profiles show that the silt facies is extensive, underlying all the basin areas. This is evident in the typical geological section (Fig. 9). Thicknesses up to 40 metres are shown on this section and some records indicate even greater thicknesses. All records show that the deposit is well stratified. Sub-bottom records in the deeper areas of the basins showing the relations of this facies to the end-moraine deposits strongly suggest that it is a proglacial deposit.

A radiogenic age determination on organic carbon from a core taken at station 332 shows the age of the silt to be 18,800 years B.P. The sample was taken along a 35 centimetre interval of the core, 10 centimetres below the top. This age suggests that the glaciers were withdrawing from at least this portion of the shelf during maximum world-wide glaciation at approximately 19,000 years. Because the silt and sand facies are considered to be contemporaneous, the 18,800 year age must represent the age of the submarine terrace at 110-115 metres. This is in good agreement with the 19,000 year age for the minimum eustatic sea level reported by Curray (1960) and Shepard (1963), and so it would appear that the terrace represents the minimum stand of sea level in this area for the last glacial advance. The relations also imply that little or no crustal movement on this area of the Scotian Shelf has taken place since glaciation.

Clay Facies:

The boundaries of the major portion of the clay facies conform closely to the elongated shape of the basins. Other portions of the clay facies are ponded in an irregular pattern adjacent to the morainic ridges north of the basins. As shown in the section in Fig. 9, it overlies the silt and occurs in thicknesses of 15-20 metres. These thicknesses are determined from the echograms which were obtained in conjunction with the seismic profiles and are usually not evident on the latter records as the events occur within the bubble pulse.

It seems probable that the clay facies was deposited contemporaneously with the silt and sand facies at a deeper and more distant point from the source, and that subsequent and more prolonged deposition of the clay resulted in an overlap of the clay across the silt. Radiocarbon determinations on the organic carbon from the top and bottom sections of a 3-metre core taken in the clay facies gives ages of 4,640 B.P. for the top and 10,020 B.P. for the bottom. The top interval of core was taken 10 centimetres below the present surface. The core was taken at station 331, only 4.5 kilometres from the silt core which gave an

18,800 age. Longer cores will be taken in the clay to provide sedimentation rates in the basin and determine the age of the base of the clay.

The texture of this unit is relatively homogeneous as a whole and falls in the category of silty clay with an average median diameter of 0.003 millimetres and a sorting coefficient of 1.97 QD_{ϕ}. However, grain-size variations do occur at the south end of Emerald Basin and across the northern portion of the basin complex. In these areas the samples sometimes fall in the clayey silt category.

The silty clays are composed dominantly of layered silicates with values in the range of 50-60 per cent. Quartz ranges from 20-30 per cent and feldspar from 10-15 per cent. The quartz content in the clayey silts increases to 35-50 per cent. The calcium carbonate and organic matter contents range from 2-6 per cent and 2.5-5 per cent respectively.

Sand and Gravel Facies:

As mentioned previously the sand and gravel facies is found above the submarine terrace and consists of erratically dispersed occurrences of sand, gravel and mixtures of these textural grades. On the basis of bottom samples the facies is divided into two major groups with the division at 50 per cent gravel.

During the low stand of sea level areas represented by this facies were exposed to subaerial weathering and erosion and subsequently during the Holocene transgression the material was reworked in the zone of wave action, winnowing essentially all the silt and clay fractions. The coastline along the larger banks was relatively straight and conducive to strong longshore currents. These currents depleted the sand budget in the areas where gravel now dominates and formed extensive sand deposits in other areas. In the study area the high gravel unit is dominant, but further east across the eastern portion of Emerald Bank, as well as the greater portion of Sable Island Bank, sand is dominant. The high gravel or lag deposits occupy almost the entire inner shelf, the tops of all the small isolated banks and the greater part of Emerald Bank to within a few kilometres of the shelf break.

Sub-bottom profiles suggest an average thickness of 10-20 metres for the sand and gravel unit across an underlying blanket of glacial debris. It appears to represent a transgressive basal deposit.

Although the mineralogical composition of the sand and gravel is similar to that of the other units the percentage distribution is different. Well rounded quartz dominates in the sands and shows values of 80-90 per cent. Calcite ranges from 0.1-0.5 per cent except for local accumulations of shells. Organic matter is also low, between 0.2-0.3 per cent. Glauconite is evident on the outer banks and was possibly derived from the underlying sediment through glacial erosion.

The coarse fraction is similar to that of glacial till in composition, and contains the entire gravel-size spectrum of particles including large boulders. This fraction differs from that of the till in that particles of the former are well rounded. This suite appears to have originated from the mainland of Nova Scotia and provides fairly conclusive evidence that glaciers occupied the entire shelf. The presence of this coarse mainland suite cannot be explained by means of ice-rafting following transgression; otherwise, the silt and clay facies would contain similar fractions.

Although the ice cover extended across the shelf it apparently experienced considerable thinning because there appears to be no evidence for postglacial crustal rebound. Similarly, Goldthwait (1924) was unable to ascertain any evidence for glacial rebound along the southern coastline of Nova Scotia but found extensive evidence in the form of raised beaches in the Bay of Fundy region as far south as Brier Island. This study corroborates Goldthwait's conclusions regarding a zero isobase along the central axis of Nova Scotia.

BEDROCK GEOLOGY

Across the inner portion of the shelf the unconsolidated sediment is underlain by basement rocks, presumably the Meguma Series which is Ordovician in age (Fig. 9). Further south it is underlain by a younger sequence which wedges out against the Ordovician basement. These younger beds show as strong events on the seismic profiles and dip gently to the south at an angle of less than 1°. In the up-dip direction the beds are truncated at an irregular erosional surface. This surface is also fairly pronounced on many of the records, but where it cannot be seen directly it is not difficult to infer on the basis of the truncated beds. These beds terminate against the basement along a line roughly parallel to, and approximately 45 kilometres from, the present coastline.

Bedrock samples have not been dredged from the bottom within the study area so its age can only be inferred from the nearest known sections. A Tertiary cap on Georges Bank was first studied in detail by Stetson (1936, 1949) from sections in the submarine canyons along the face of the bank and Emery and Uchupi (1965) have identified these beds on their seismic profiles. These authors report a section consisting of 270 metres of Tertiary strata conformably overlying Cretaceous beds across the top of the bank. Marlowe (1965) reported a Tertiary section in the Gully east of Sable Island, and on the basis of more recent and extensive sampling in the same area Marlowe and Bartlett (1967) described a Miocene section that may be as thick as 800 metres. A Tertiary age for the section within the study area is, therefore, not unlikely. On the other hand, the possibility of a Cretaceous age cannot be overlooked especially for the sub-crops nearest shore and deepest in the section. Cretaceous beds occur at the northern slope of Georges Bank and are well known at the wedge end of the emerged coastal plain south of New Jersey. Cretaceous sediments are also known on the mainland of Nova Scotia at Shubenacadie and Middle Musquodoboit north of Halifax, (Stevenson, 1959).

Bedrock and its relation to the submarine topography has already been briefly discussed under bathymetry. Conclusions are difficult to draw until sufficient data permits discussion of the topography of the shelf as a whole in relation to the underlying bedrock surface. For the area under consideration it is difficult to explain the erosional surface across the underlying bedrock in terms of glacial erosion alone. The present evidence leaves little doubt that the glacier occupied the entire study area and the enclosed nature of the basins is strongly suggestive of a glacial origin. However, this is somewhat apparent as the underlying bedrock surface does not always conform to this pattern completely. For example, the sill across the outer banks is underlain by a thicker sequence of unconsolidated sediment than is normal for the outer banks region and the depth to bedrock under a large portion of the sill is similar to that found in Emerald Basin. This indicates breaching across the outer bank cuesta, possibly by stream erosion.

The profiles across the basins are not U-shaped, as in the case of the profile across the Laurentian trough. In the latter area, as well as in the greater part of the Gulf of St. Lawrence, the evidence for major glacial erosion is considerably more convincing (Shepard, 1931), (Nota and Loring, 1964) and (Shepard and Dill, 1966).

The orientation of LaHave and Emerald Basins is northeast-southwest, whereas the direction of ice movement across the southern coast of Nova Scotia is dominantly southeast as indicated by glacial striae and the orientation of drumlins. In addition, the orientation of the moraine system parallel to the coastline lends support to a southeast movement of ice across the shelf.

Continuous seismic profiles across Sambro Bank clearly indicate a stoss and a lee side, developed with respect to a southeasterly direction of ice movement. The lee side is much steeper and was possibly quarried by the glacier. The accumulation of a much thicker section of drift on the lee side suggests a crag and tail development with respect to a southeasterly movement of ice.

The isolated mesa-like banks within the shelf, the prominent cuesta ridge which has been breached to the continental slope, and the many small V-shaped irregularities across the surface of the bedrock appear to be more easily explained in terms of a preglacial period of subaerial erosion. As the present study develops it will probably be possible to draw more definite conclusions regarding the origin of the erosional surface, but on the basis of the present evidence it would appear that the causes are interacting. The evidence for intense glacial erosion across the inner shelf is strong, as the topographic expression of its surface appears almost identical to that of the land area. Across the central and outer portion of the shelf the picture becomes more indefinite. Certain erosional features seem to be of definite glacial origin while the major topographic expression reflects that of a partially dissected coastal plain which has possibly been modified considerably by glacial erosion. There is no clear evidence that the direction of movement of the glaciers across the middle and outer shelf was other than southeast; the glacier apparently cut across the axial trend of the basins.

Shepard (1963, p. 260) describes formerly glaciated shelves as "the most distinctive and clear-cut shelf types" and it seems logical to attribute their peculiar characteristics to glacial erosion and deposition. However, in the study area the evidence for extensive glacial erosion is not distinct much beyond the outer limits of the inner shelf. No evidence exists for a tectonic origin for the topographical anomalies.

In the region of the Gulf of Maine and Georges Bank glacial erosion appears to have been more extensive. Emery and Uchupi (1965) conclude that the irregular topography within the Gulf of Maine, in Massachusetts on the west, and off Nova Scotia on the northeast clearly indicates that glacial ice was the chief erosional and depositional agent. They further state that no clear topographic evidence exists of the former presence of a glacier atop the bank. They also conclude that earlier stream erosion possibly occurred. Malloy and Harbison (1966) conclude from a detailed study of the Gulf of Maine that its geologic history can best be understood when it is realized that its formation follows the classic erosional development of a coastal plain complicated by ice-sculpturing. They find considerable evidence for a preglacial erosional landscape, but suggest that much of the detail of the earlier erosional pattern was removed by the advent of the Pleistocene glacier.

CONCLUSIONS

The general conclusions regarding the sedimentology and near-surface stratigraphy of a section across the Scotian Shelf south of Halifax, Nova Scotia are summarized below.

(1) Echograms are an effective tool in the detailed mapping of unconsolidated sediments but sample control is also required.

(2) The morphology of the Scotian Shelf fits the Holtedahl classification of formerly glaciated shelves. The major divisions are: (a) an inner shelf bordering mainland Nova Scotia, (b) an area of longitudinal and transverse depressions within the shelf and (c) an outer shelf or outer banks region.

(3) Sub-bottom profiles across the shelf indicate an erosional surface developed on well stratified bedrock. Although the bedrock is covered by unconsolidated sediment, the present topography is to a very large extent controlled by this old erosional surface.

(4) The outer banks region represents a cuesta with truncated beds at the cuesta face and gently dipping beds on the back slope which extend to the continental margin and then assume the dip of the continental slope. The cuesta was breached, possibly by streams, at the southern end of Emerald Basin and subsequently filled with unconsolidated sediment forming a sill for the basin complex.

(5) A well developed submarine terrace was formed within the study area and is an expression of the coastline 18,800 years B.P.

(6) As the glaciers were withdrawing from the shelf, the glacial-marine environment gave rise to the sand, silt and clay facies. On the higher bank areas fines were winnowed from the glacial debris and deposited in relation to water depth, prevailing currents and the bottom topography. The sand facies was laid down along the old shoreline.

Below the zone of strong wave action, ground moraine and a system of end moraines were deposited without extensive modification. The stratigraphic relations of the silt facies to the end moraines as seen from continuous seismic-reflection profiles, suggest that the silt is proglacial. At intermediate depths the sand and silt facies show a gradational relationship suggesting that they are contemporaneous.

It seems probable that the bottom of the clay is either contemporaneous or penicontemporaneous with the sand and silt facies; however, sedimentation of the clay was more prolonged and resulted in the transgression of this unit across the silt.

(7) The age and depth of the submarine terrace agree with the minimum eustatic sea level reported by Curray (1960) and Shepard (1963) and the relations suggest little or no crustal movement in the area since glaciation. This suggests a thin cover of ice

across the shelf during glaciation.

(8) The sand and gravel facies developed above the terrace is a transgressive basal deposit.

(9) The inner shelf is underlain by basement rock presumably of Ordovician age, while the central and outer part is underlain by younger bedrock of possible Tertiary and/or Cretaceous age. The contact extends parallel to the coastline at approximately 45 kilometres from the shore.

(10) The origin of the erosional surface across the bedrock and thus the configuration of the present topography, is complex and possibly resulted from two interacting agents. Certain erosional features seem to be of definite glacial origin while the major topographic expression reflects that of a partially dissected coastal plain which has possibly been modified considerably by glacial erosion.

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