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PAPER 65-38

THE GEOLOGY OF PART OF THE CONTINENTAL SLOPE NEAR SABLE ISLAND, NOVA SCOTIA

(Report and 4 figures)

J. I. Marlowe

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ABSTRACT

Core and dredge samples and echo-sounding records from part of the continental slope east of Sable Island provide data on the bottom sediment, geomorphology, and geologic structure of the area. A large canyon (The Gully) adjacent to Sable Island is of special interest.

Topographic benches occur on the continental slope and in The Gully. A comparison of topographic profiles from this area with profiles from elsewhere along the east coast of North America suggests that the topographic benches reflect the presence of outcropping bedrock formations.

Unconsolidated sediment on the continental shelf consists mainly of sand and gravel, while sediment on the continental slope is predominantly mud. Thin layers of sand occur in some cores from the continental slope and suggest that sand from the shelf is periodically transported downslope into deeper water.

Resistant, compact siltstone and sandstone occur at some localities in The Gully. Foraminifera indicate that some of the siltstone may be as old as Miocene. Other compact sediments are lithologically similar to formations that occur in Georges Bank.

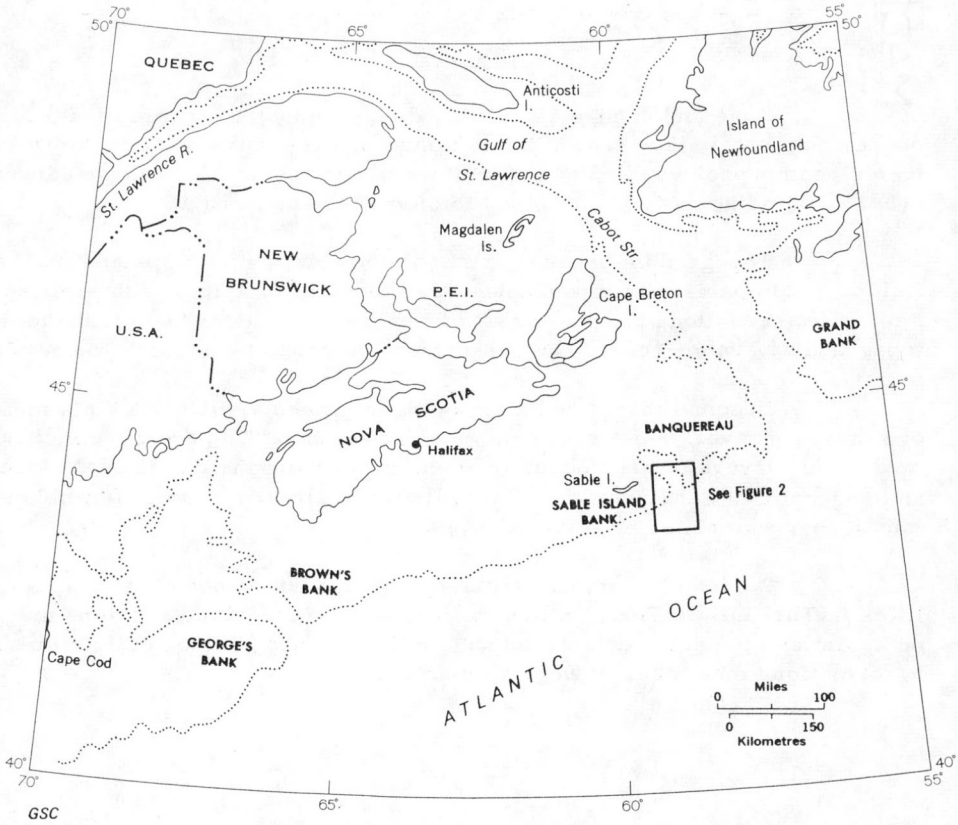

Figure 1. Index map showing area of study near Sable Island. Dotted line indicates approximate boundary of continental shelf

THE GEOLOGY OF PART OF THE CONTINENTAL SLOPE NEAR SABLE ISLAND, NOVA SCOTIA

INTRODUCTION

During April and May, 1964, the initial stage of a geological investigation of the continental slope off Nova Scotia was carried out by Geological Survey personnel stationed at the Bedford Institute of Oceanography, Dartmouth, Nova Scotia. The purpose of this investigation was twofold: (1) to study the sediment of the continental slope in order to obtain data pertaining to the environmental history of that physiographic province, which data will be applicable to the interpretation of ancient sediments; and (2) to determine the extent and nature of any pre-Pleistocene rocks that may crop out along the edge of the continent. The first cruise of this project was intended to be a reconnaissance of a sample part of the study area. Delays in obtaining deep-coring equipment made this intent a necessity and, although only short bottom cores were obtained, it is felt that the primary objective of the cruise was attained.

The part of the continental slope selected for study lies 190 miles east by south of Halifax, Nova Scotia, and is located east and southeast of Sable Island (Fig. 1). It is bounded approximately by latitudes 43°23' and 44°17' N. and by longitudes 58°34' and 59°22' W. The northern part of the study area lies between the East Bar of Sable Island and Banquereau. It includes a large submarine canyon, shown on navigational charts as The Gully (Canadian Hydrographic Service Chart 4490) and covers a section of the continental slope from the edge of the Scotian Shelf to depths exceeding 2,700 metres.

The operation was carried out in CSS Kapuskasing, attached to the Bedford Institute of Oceanography. A total of eleven working days was spent at sea, during which period 58 cores, snapper samples, and dredge samples were collected. Water depths were obtained by standard navigational echo sounders, which were effective to approximately 3,000 metres. The ship was positioned by Loran and, where feasible, piloted to more precise positions by sounding over distinctive bottom features. Field sheets of the Canadian Hydrographic Service (Goodwill, 1961)[1] were used as base charts.

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[1]Names and/or dates in parentheses refer to publications listed in the References.

The writer is grateful to Captain W. Thorne and the officers and crew of CSS Kapuskasing for their excellent cooperation during the cruise. He also wishes to thank his colleagues L.H. King and J. Dugas, both of the Bedford Institude of Oceanography, for assisting in the operation. G.A. Bartlett, also of the Bedford Institute, very kindly examined and identified foraminifera from some of the samples. The services of numerous other institute personnel who aided in the preparation for the cruise are greatly appreciated.

Working Methods

The sampling program was planned using field sheets of the Canadian Hydrographic Service as a base chart. Contours drawn at 100-fathom intervals on these sheets revealed the presence of numerous small canyons tributary to The Gully and suggested the occurrence of more or less continuous ledges along the walls of the main canyon. In order to detect variations in depositional environments within the study area, sample stations were selected on the basis of topography. Where significant differences in bottom sediment type appeared between stations, the interval between was sampled. The sampling pattern was designed to provide information from the continental slope proper and from The Gully area (Fig. 2).

Soundings on the field sheets of the Canadian Hydrographic Service were taken in parallel, north-south trending lines spaced 2 miles apart. Echo-sounder records made during sampling operations in the area indicated that some bottom features escaped delineation on the field sheet sounding lines; these features are included in the contoured bathymetric chart of this report (Fig. 2). In the upper reaches of The Gully, depths were shallow enough that the record from the echo sounder indicated differences in bottom type. Soft sediment was penetrated to a greater depth than was hard bottom, and it was possible in shallow depths to relate bottom sediment type to topography. Resolution of bottom hardness was not possible in depths greater than 200 metres. However, a number of sounding runs were made in the upper, shallower, part of The Gully in order to observe the details of bottom topography in that area.

Difficulty with electronic positioning was experienced in the initial stages of the cruise. It was considered, for the purposes of this investigation, that the position of the ship relative to the bottom was more significant than its geographical position. It was found that Loran positions corresponded most closely with bottom topography. When precise positioning over distinctive bottom terrain was desired, the ship was positioned approximately with Loran and then piloted onto its exact station by echo-sounder. Some stations in non-distinctive topography were located by dead

reckoning from known positions on the bottom. Stations described in this report are located relative to each other and to the configuration of the bottom. Geographical coordinates for the stations (Appendix) are considered to be of second-order accuracy.

Bottom core samples were obtained with a 125-lb. piston corer to which a snapper sampler was attached as a trigger weight. Cores were preserved in the plastic core-barrel liners in which they were collected, and only superficial analyses were made of them at sea.

A light dredge sampler, built on a pattern of the U.S. Coast & Geodetic Survey (Stewart, 1962), was trawled from the stern of the ship in an attempt to sample resistant rock or compact sediment layers, which could not be sampled by corer or snapper. Samples were obtained with the dredge to a depth of about 1,000 metres. Trawls were made upslope in all cases and sample areas were selected, when possible, so that the drift of the ship could be utilized to move the dredge along the bottom. Where this was not possible, the ship was manoeuvred at dead slow speed with the trawl wire paid out directly astern.

Cores and other samples are described in this report according to the results of examination by binocular microscope. Sand-grain sizes were measured with a micrometer eyepiece and size-class distributions were estimated where this was practical. Compositional percentages, where given (Appendix), are also estimated. The author does not find, as did Ericson, et al. (1961), that reliable estimates can be made of size classes in the (-) 62 micron range. Sediment textures in this report are accordingly described as estimated percentages of gravel, sand, and mud. The term "mud" (Twenhofel, 1937) is used for all particles of less than 62 microns diameter, except where silt-size particles are coarse and abundant enough to be readily distinguishable. The modifier "silty" is applied to the term "mud" in such cases. Cores were allowed to dry to a putty-like consistency before they were halved longitudinally for examination. Sample descriptions in this report are preliminary and will be supplanted by more exact analyses in a later paper.

Physical Environment

The area of this report extends from the edge of the continental shelf at approximately 200 metres to depths of over 2,700 metres. It is influenced by both shallow-water and deep-water processes of the Atlantic Ocean, and it covers part of the geological zone of transition from continental rocks to rocks of the deep ocean basins. The most striking physical feature of the area is the configuration of the bottom, which slopes steadily away from the continental shelf edge to the abyssal sea floor.

Shallow-water processes are effective in the northern part of the study area and are strongly influenced by wave and current motion. The effects of currents and waves in the vicinity of Sable Island (Fig. 1) are the subject of several authors (MacDonald, 1883, 1884, 1886; Patterson, 1894; Erskine, 1953) and are as yet imperfectly known. The shoals around the island, and the island itself, undergo rapid changes of form during periods of storms. According to the above authors, Sable Island appears to have been reduced in size and to have migrated eastward along Sable Island Bank during historical time.

Water circulation in the study area is affected by the interaction of the Gulf Stream and the Labrador Current, which come together in the southwestern area of the Grand Banks of Newfoundland (Hachey, 1961). Large-scale mixing of these waters produces "slope water", a water mass with temperatures intermediate between those of the parent masses, which flows over the Scotian Shelf with a predominantly southwesterly set. The Gulf Stream proper at times flows close to the edge of the continental shelf off Nova Scotia. Its path meanders and is not fully understood. Strong surface currents occur around East Bar of Sable Island and in The Gully. MacDonald (1883) described currents that sweep around the island and speculated (1886) on the possibility of these currents being caused by eddy action between the two major drifts of the region, the Gulf Stream and the Labrador Current. The cyclical current around Sable Island is discussed further by Trites (1956). The Nova Scotia Pilot (Anonymous, 1960) states that a southward-setting ebb tidal stream in the area may attain a velocity of 2 knots. On two occasions during the present Kapuskasing cruise, southerly drifts of 5 knots were established in The Gully by Loran positions while lying dead in the water in flat calms.

Previous Geological Work

MacDonald (1883, 1884, 1886), in a general study of Sable Island, discussed the dynamic nature of the island and its associated banks and gave accounts of the rapidity with which the shoal areas at the west side of The Gully were shifted by wave action. Patterson (1894) described the island as shoaling rapidly from "as much as one hundred and seventy (fathoms) off its eastern extremity", and speculated on the subsurface nature of the banks. A geological appraisal of the Sable Island area was made by Goldthwait (1924). Johnson (1925) described the offshore banks of northeastern North America, based on poor sounding information, and noted that similar features occurred in most of the banks. A brief description of the present study area was also given. Pertinent to this study is the work initiated by Shepard (1934) on Georges Bank, which was based on detailed soundings and which described a number of submarine canyons. This work was continued by Stetson (1936, 1949), who described the stratigraphy and palaeontology of

rocks cropping out on Georges Bank. Stephenson (1936) discussed a rock of Upper Cretaceous age from Banquereau, which was brought up in a fishing trawl. Erskine (1953), in an ecological study of Sable Island, commented on the origin of the island and concluded that it was a sand bar in near-equilibrium with wave and current forces.

Officer and Ewing (1954) concluded, on the basis of seismic data, that Coastal Plain sediments occurred on the continental shelf and continental slope south of Halifax. They also found that a thick accumulation of probable Triassic sediment existed on the continental shelf off Halifax.

Heezen, et al. (1959) summarized the work on the geology of the continental margin of eastern North America and discussed the general physiographic nature of the continental slope off Nova Scotia. In a series of stratigraphic diagrams, they demonstrated that formational contacts can be projected from known stratigraphic positions ashore to coincide with prominent ledges on the continental slope, and concluded that the ledges may be structural benches. Ericson, et al. (1961) discussed two cores taken from The Gully and related the sedimentary record contained in them to climatic and depositional conditions. One of the cores (Lamont Core No. A-173-9, Appendix) extended to a depth of 3.74 metres and was composed entirely of post-glacial sediment.

BOTTOM MORPHOLOGY

The sea bottom in the area of study is underlain by the continental slope and, to a lesser extent, the continental shelf. The slope in this vicinity is incised by a large submarine canyon ("The Gully"), which heads on the continental shelf between Banquereau and Sable Island Bank. On either side of this canyon, the slope is corrugated with numerous furrows and ridges, which trend downslope and are generally parallel.

Sable Island Bank lies on the edge of the continental shelf at the northwestern corner of the area under study. Sable Island is the dry summit of this bank which, at its eastern end, is composed of shifting shoals (Anonymous, 1960). East Bar of Sable Island (Fig. 2) extends about 14 miles east-northeastward of the east point of the island. Depths over most of East Bar range from 3 to 55 metres and the sea breaks heavily in this area. Depth contours on East Bar reflect the shape of the shoreline of the island and indicate that the bar has a very gently sloping, nearly flat surface. The eastern end of the bar borders The Gully, where depths increase sharply.

The west end of Banquereau lies on the east side of The Gully (Fig. 2) and on the edge of the continental shelf. Depths over the bank in this area are not less than 55 metres. Banquereau is remarkably flat-topped

at its western end; soundings show variations in depth of no more than 4 metres over distances exceeding 10 miles (Goodwill, 1961, Sheet W31). The southern and western edges of Banquereau are convex in profile to approximately the 200-metre contour; below this depth, gradients steepen onto the continental slope or into the canyon.

The shelf area between Sable Island Bank and Banquereau is a hill-and-valley terrain with depths ranging between 120 and 240 metres. This area forms a saddle between the two banks, which curves slightly to the northwest around East Bar of Sable Island. The topography in this trough is distinctive enough to serve as an aid to navigation in the upper reaches of The Gully. Detailed contouring of bottom soundings in this area and farther landward across the shelf has led A. Cok (Dalhousie University, personal communication) to the conclusion that the valleys form a dendritic pattern which leads southward to the main canyon.

At approximately the 190-metre depth contour, the gradient of the bottom increases abruptly. That part of the bottom below 190 metres in Figure 2 is discussed here as the continental slope, that part above 190 metres, as the continental shelf. Along the seaward face of the continental margin, gradients range from 1:10 to 1:5. Heezen, et al. (1959) defined the true continental slope as having a minimum gradient of 1:40. They described briefly the continental margin off the Scotian Shelf and state that gradients measured along profiles located 40 to 180 miles southwest of Sable Island range from 1:25 to 1:70. Profiles of the slope on either side of the mouth of The Gully to a depth of 1,800 metres (E, F, G, H, Fig. 3) show gradients ranging from 1:18 to 1:5. An examination of these profiles and the contoured bathymetric chart of the area (Fig. 2) shows that the gradient down the continental slope is not constant but undergoes abrupt changes. Some of these changes in slope appear on the profiles as topographic benches, which can be traced on the chart for considerable distances. In Figure 3, bottom profiles down the slope are superimposed to show that breaks in slope occur at comparable depths on several profiles. There is a decrease of gradient at approximately 950 metres on Profiles F, G, and H; Profile E does not show this break in slope. Topographic benches can be seen in all the profiles at approximately 1,300 metres. A minor, but possibly significant, break in slope occurs in Profiles F and G at 1,700 metres. Heezen, et al. (1959) discussed at length the relation of similar topographic benches on Georges Bank to dredged rock samples of Tertiary and Cretaceous age, and showed that the stratigraphic sequence established by Stetson (1949) was clearly reflected in the topography of the submarine canyons of that area. They further pointed out that resistant stratigraphic units can be projected from known positions in drill holes on shore to coincide with prominent topographic benches on the continental slope, and suggested that the benches have a structural significance. The possibility that the topographic benches near The Gully may be structural benches will be investigated further in this paper.

Detailed soundings indicate that the continental slope on either side of the mouth of The Gully is furrowed with canyons, which trend directly downslope. Between Stations 36 and 13 (Fig. 2) the slope appears to be dissected by a parallel system of canyons of varying sizes. In the area between Stations 15 and 41, depth contours are more irregular and suggest the existence of isolated high topographic forms, rather than elongate ridges. The topographic benches previously discussed form definite nickpoints in some of the canyons to the west of The Gully. A wide bench between the 1,300-and 1,400-metre contour lines in that area is incised by canyons, which in some cases are continuous across the bench. Two narrow canyons near Stations 30 and 31 appear to head on the bench.

Lobate contour patterns on this bench from Station 13 southwestward and east of Station 15 suggest that the bench may be dissected into isolated high areas. Such forms appear in profiles from Georges Bank (Heezen, et al., 1959). Other benches can be seen between the 400- and 600-metre and the 700- and 1,000-metre contours on the west side of The Gully.

The Gully, as shown on navigational charts (British Admiralty, Chart 2670, 1961), is the low area that separates Sable Island Bank and Banquereau. Due east of Sable Island, this low area becomes a submarine canyon, which extends a distance of 35 miles to a depth of at least 2,800 metres (Fig. 2). The width of the canyon, as defined by the 400-metre contour, increases from 1 mile near its head to more than 8 miles at the seaward edge of the continental shelf. The walls of the canyon are steep, attaining a gradient as high as 1:2 below the 400-metre contour. In profile, the canyon is V-shaped (Fig. 4). Its course is slightly sinuous and it trends generally southward, with a deflection to the southeast at about the 2,200-metre contour. Its longitudinal gradient varies between 1:18 and 1:9. Side canyons occur along the west wall.

Transverse profiles of the canyon (Fig. 4) show its steep-sided, V-shaped form. The floor of the canyon appears to be very narrow on all sounding runs across The Gully. Breaks in slope at 400 metres on the profiles can be traced along both walls of the canyon to join those on the continental slope. The heads of side canyons in the west wall are located in this topographic bench. The headward extents of contour lines on the floor of the main canyon are highly interpretive, and no attempt is made here to show a longitudinal profile of The Gully.

Sounding runs along the west wall of the canyon reveal the existence of a large number of narrow, steep-sided canyons. Many of these features are less than 400 metres wide at the line of crossing and are not shown on the bathymetric chart (Fig. 2). The walls of these small canyons, as shown on echo-sounder records, are extremely steep. Careful manoeuvring

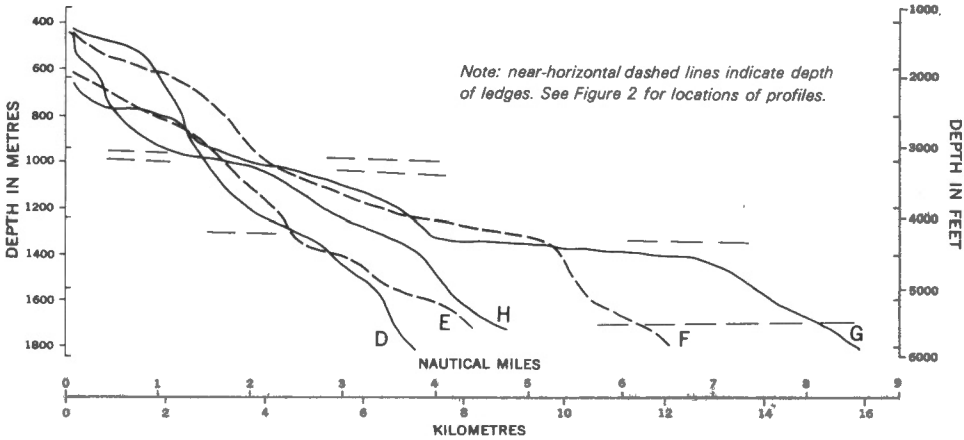

Figure 3. Topographic profiles down the continental slope

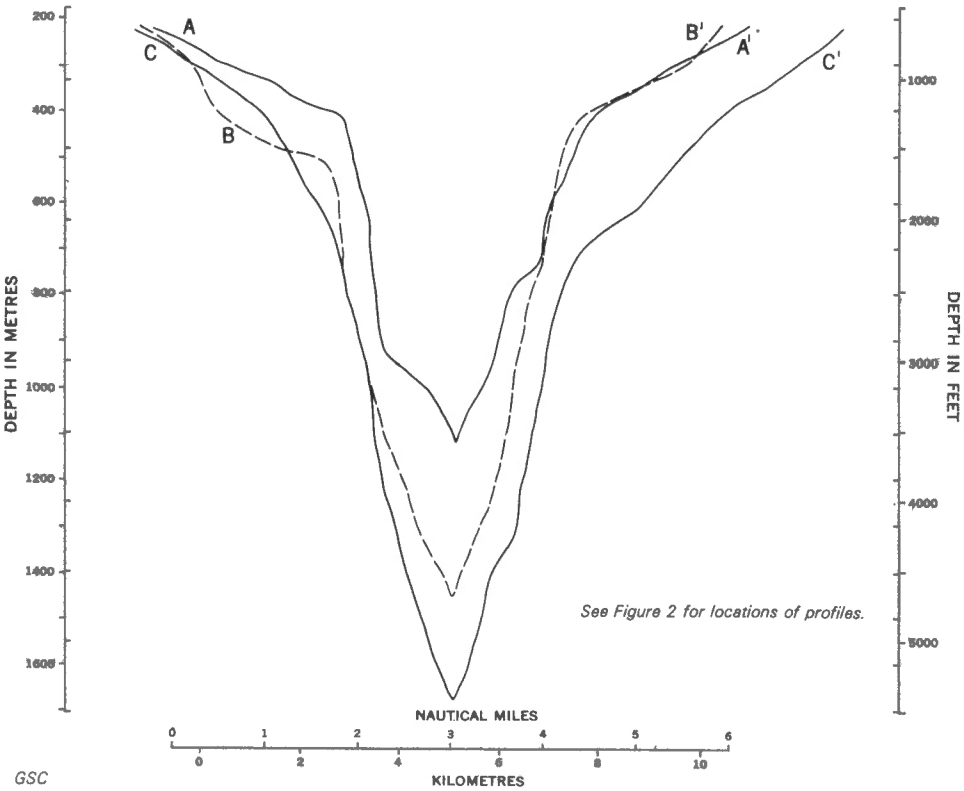

Figure 4. Transverse topographic profiles across The Gully

of the ship during the operation allowed the recovery of a short core from near the bottom of one of these canyons (Station 12). A depositional face with a slope of 45° formed the top of the core sample. This sample and others taken in the inner part of The Gully (Samples 6, 8, 11, and 21) are composed of compact, silty mud. The Gully is typical of submarine canyons as described by Keunen (1950) and Shepard (1963) and, like other canyons of the eastern margin of North America, appears to be cut into resistant materials.

UNCONSOLIDATED SEDIMENTS

Unconsolidated bottom sediment in the study area consists of sand and mud with minor amounts of gravel- and cobble-size particles. There is a general decrease in grain size toward deeper water, the greater part of the gravel and sand being found on the banks and other parts of the continental shelf and the mud occurring in deeper water. In the following discussion, core numbers refer to Figure 2 and the Appendix.

Eleven samples were collected from the edge of the continental shelf to provide information on that physiographic province as a source of sediment to the continental slope. Bottom sediment on the southern flanks of Sable Island Bank and Banquereau consists of sand and muddy sand with minor amounts of gravel. The mud-size sediment in these areas is greenish grey. This mud increases in abundance with water depth and there is a corresponding decrease of median sand grain size. Pebbles occur erratically over the banks in the study area. In the low saddle between Banquereau and Sable Island Bank at the head of The Gully, numerous pockets of soft sediment, probably predominantly mud size, occur between the ridges. These deposits were observed on echo-sounder records, but were not sampled.

Sand on the continental shelf within the study area is composed predominantly of quartz with a small and varying amount of organic carbonates. Sand- and pebble-size pelecypod and echinoderm debris is abundant. Igneous and metamorphic pebbles and cobbles are common on the banks and are similar to rocks found on the Nova Scotian coast. It is considered that these fragments have been transported by glacial action. Greenish grey quartzite is especially abundant as gravel on Sable Island Bank.

Sediment on the continental slope was cored to a maximum depth of 2.9 metres below the bottom. In general, greater penetration of the bottom by the corer was achieved at those stations that were located farthest down the slope. Core samples from the slope consist of mud with varying amounts of sand. Gravel comprising 30 and 100 per cent respectively of the total sediment was observed in samples 4 and 40.

Sand in amounts of 5 per cent or more occurs in cores from the continental slope and makes up a major portion of the stratigraphic column at some stations. In Core 20, from the east wall of The Gully, muddy quartz sand occurs as a massive deposit with no observable bedding. Core 39, from the axis of The Gully in 2,860 metres of water, contains sand in layers, which decrease in thickness and abundance with depth below the surface. An 11-cm thick layer of well sorted quartz sand at the surface is underlain by a 50-cm thick unit of interbedded layers of clean sand and sandy mud. Cores 13 and 36, from the slope west of The Gully, contain similar sand sequences. Sand is distributed irregularly in small proportion through all the cores from the slope west of The Gully. Core A-173-8 of the Lamont Geological Observatory, taken 2 miles south of Core 39 of this report, contains abundant quartz sand in layers of varying thickness; their Core A-173-9, from 16 miles southeast of the study area, also contains abundant sand beds.

The presence of sand layers in deep-sea and continental slope sediments is discussed by Keunen (1950) and Shepard (1963) and is generally attributed to deposition by turbidity currents flowing downslope. These currents are believed by various authors to be responsible for the erosion of submarine canyons (Daly, 1936; Keunen, 1937, 1938; Ericson, et al., 1961). Sand layers are commonly associated with submarine canyons, and it is generally agreed that the sand was transported away from the continents by processes resulting from submarine slides or slumps in steep topography along the continental slope.

Thin layers of clean moderately well sorted sand occur in several cores (e.g., Cores 3, 10, and 14), and in some cores graded bedding was observed (Cores 13, 36). The most obvious source for this sand is the sediment of the continental shelf, where relatively well sorted sand is common. It is almost certain, in view of the locally strong wave and current action, that sand is intermittently carried over the edge of the canyon from East Bar of Sable Island. This sand would move downslope, possibly as a sand flow (Shepard, 1963), and would perhaps initiate movement in unstable sediments already at the base of the canyon. Sand transported off the continental shelf by currents would be channelled toward the deep sea floor by the numerous canyons along the face of the slope. None of the sand layers observed in the present study contained structures that could not have been formed by the action of normal bottom currents.

Grey quartzite pebbles occur in many of the cores from the slope and are considered to have been transported from the continental shelf, where such a lithology is common. Sample 4, taken in the upper part of The Gully, is composed of quartzitic and gneissic gravel typical of probable glacial deposits on the banks above the station. Core 44, which was obtained

from the eastern edge of the study area, contains 51 cm of sandy mud interbedded very irregularly with lumps of fine gravelly, grey clay. On the basis of its structure, this unit appears to be a slump or slide deposit and may be derived from glacial till on the shelf.

Mud on the continental slope is reddish brown or various shades of grey. Layers of sand and traces of gravel are found in both these colour types and textural indications are that they were deposited by the same process. Where greyish mud and reddish brown mud are present in the same core, the former overlies the latter. Exceptions to this arrangement are Cores 14 and 17, where the reverse is true. Contacts between the two types are gradational in some cores (for example, Core 30) and sharp in others (for example, Core 31). Core 2, from the east wall of the main canyon near its head, and Core 43, from the flank of a smaller canyon on the continental slope, contain interbedded reddish brown and grey mud layers. There is no apparent variation in texture between layers in Core 2, but the grey layers in Core 43 are slightly coarser than the reddish brown layers and contain scattered granules of quartz, red sandstone, and aggregates of pyrite. Contacts between layers in these two cores are variably sharp or gradational.

Several cores from the upper slope contain greenish grey mud (e.g., Cores 42 and 25), which corresponds in colour with mud on Sable Island Bank and Banquereau. Muddy sand of this colour in Core 19 gave off a very strong odour of hydrogen sulphide when brought aboard. Such an odour is commonly associated with decaying organic matter in sediment that receives little or no oxygen from overlying waters. Finely divided pyrite is abundant in Core 19 and there is a gradation to darker shades of greenish grey with depth in the core. Pyrite specks and aggregates were noted frequently in grey-coloured mud layers in many cores.

The reddish brown mud layers contain sand grains in varying amounts. In Cores 34 and 43, reddish rock fragments make up a large proportion of the sand. Grains of red sandstone and shale are found in trace or minor amounts in most of the reddish brown units. These muds therefore appear to be derived from reddish sediments that were probably deposited under oxidizing or subaerial weathering conditions.

An interesting lithologic association in sand-size grains contained in the reddish brown mud is the common occurrence of basalt grains with sandstone and shale grains. Such an association is characteristic of Triassic fault basins found in the Bay of Fundy and southward along the margin of the Atlantic Coastal Plain. While there is no lack of sources for basalt fragments in the Nova Scotia area, the angular and fissile nature of associated red shale grains indicates that the distance of transport may not be great. Seismic evidence points to the possible existence of a Triassic trough off Halifax (Officer and Ewing, 1954). If such a trough does lie to landward of the study area, it is possible that it has contributed material to the sediment of the continental slope.

An abundant foraminiferal fauna is found throughout the cores. It is expected that faunal analyses will assist in the interpretation of the sediment record. Evidence of burrowing is common in mud layers, especially in those having no bedding structure. In the latter, bedding structures have probably been destroyed through redistribution of the sediment by organisms. Burrows filled with sand were observed but, more commonly, a mottled colour pattern is the only evidence of mud-feeder activity. Open, undistorted burrows are found at a few centimetres depth in some cores.

COMPACT SEDIMENT

Hard, compacted sediment was sampled or otherwise detected at several stations along the inner part of The Gully. These stations were located along the west wall and on the floor of the main canyon (Fig. 2). Topography in this area is steep and local relief is high.

At Station 2, on the west wall, the corer imbedded itself firmly in the bottom and it was necessary to place heavy and sustained strains on the wire to retrieve the equipment. When brought aboard, the steel cutting bit of the corer was found to be broken off along a brazed joint. There was no indication that the core barrel had penetrated the bottom; therefore, penetration by the core bit to a depth of less than 10 cm was sufficient to hold the corer securely in the bottom. A few small fragments of dark, well-compacted silt were found in the snapper sampler and adhering to the broken bit. At Station 4, in the axis of the canyon, the corer did not penetrate and a few small pebbles were brought up in the snapper.

Cores 6, 8, 11, and 12, all taken from between 700 and 800 metres depth on the west wall, contained hard, compact, dark grey-brown silt. Cores 6 and 12 were short plugs in the cutting bits, less than 10 cm in length, and were composed entirely of hard sediment. Core 8 contained 7 cm of grey-green, muddy sand, which overlay a 2-cm-thick layer of stiff sandy mud with iron oxide staining; below this was 8 cm of hard, dry, compact silt. Core 11 stopped in 3 cm of hard, dark grey, clayey mud, which was overlain by 12 cm of the same material in a less compact condition. Three cores were taken on Station 21, in the axis of The Gully at more than 1,400 metres of water. Two of these cores contained clayey mud; the third consisted of 6 cm of hard, brown silt. The compact material in all these cores contained well defined, laminated bedding and abundant muscovite flakes along the bedding planes. At Station 48, over the axis of a steep and narrow side canyon, the corer did not penetrate the bottom and no sample was retrieved by the snapper.

Dredge trawls were made across the 800 to 200 metre depth zone along the west wall of the canyon in an effort to obtain larger samples of the compact sediments brought up in cores (Appendix). Trawl D-1, up the north side of the steep side canyon in which Station 48 was located, recovered lumps of hard, dark brown, clayey mud with no apparent bedding structure. Trawl D-3, up the west wall of The Gully between 800 and 400 metres, brought up large fragments of stiff, grey, weakly fissile clay. Neither of these samples appeared to be the compact material cored from the canyon wall. During Trawl D-2, up the west wall of The Gully from 400 to 200 metres, the equipment became fast on the bottom and it was necessary to manoeuvre the ship to free the dredge. A load of stiff grey clay lumps and tabular fragments of weakly cemented sandstone was brought to the surface on a second attempt, after the dredge again became fast on the bottom. The sandstone fragments were thoroughly penetrated by burrowing organisms and most of the fragments were stained, as by weathering, on one face. As great resistance to the dredge was encountered over the course of this trawl, it is considered that the sandstone was broken from an outcropping rock ledge.

Similar lithologies were reported by Stetson (1949) in his stratigraphic study of the Georges Bank canyons. He described a formation of Navarro age from which samples of partly indurated, dark-coloured, silty clay containing a large amount of mica were recovered. The samples contained a diagnostic Upper Cretaceous fauna and the formation from which they were taken was correlated with the Kemp clay of the Gulf coast. Of all the Georges Bank formations described by Stetson, the compact sediment samples from The Gully are most similar lithologically to this unit. Stetson described several sandstone units, ranging in age from Navarro to Miocene.

Also similar lithologically to rocks from Georges Bank described by Stetson is part of a cobble of coarse glauconite sandstone, which was recovered at the top of Core 47. This rock is easily friable and appears to have undergone weathering, as its silty matrix is stained with iron oxide. It was brought up from the floor of The Gully and, as it overlies a soft mud layer, appears to represent a talus deposit from higher up the canyon wall. Stetson described a similar friable greensand from rocks of Pliocene age on Georges Bank.

Compact sediments from Cores 6, 8, and 12 contained foraminifera, which have been identified by G.A. Bartlett of the Geological Survey and Bedford Institute of Oceanography (Appendix B). Core 6 contained the greatest variety of foraminifera, as well as the most abundant individuals. Bartlett (personal communication) stated that the fauna listed resembles most closely the late Tertiary fauna described by Cushman (1936) from the

Georges Bank samples of Stetson (1936). Siphonina pulchra, generally found in rocks of Miocene age is present in moderate abundance. As there is no evidence of reworking of the compact sediment samples, it is concluded that the sediment may be as old as Miocene.

Many of the species identified by Bartlett exist today in warm ocean waters. The faunal assemblage in general resembles Gulf Coast faunal assemblages. Cushman found a similar relationship between faunas from Georges Bank and the Atlantic and Gulf Coastal Plain (Stetson, 1949). The foraminifera from Cores 6, 8, and 12 commonly show secondary replacement by calcite and etched surfaces, and have the aspect of a fossil fauna.

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APPENDIX A

Summary Logs of Samples *

(See Figure 2 for locations)

Sta. No.	Depth (Metres)	Latitude N.	Longitude W.		Description (top to bottom)
1	330	44°00'	59°04'		Sand, grey-green, fine to medium, quartz. Snapper sample.
2	649	44°02'	59°02'		Silty mud, dark brown, dry, compact. Few fragments on core bit.
3	406	44°03'	59°01'	0-21 cm	Mud, light grey, slightly very fine sandy; 5 mm-thick layers of very fine quartz sand at top and 8 cm; slump structure at 12-18 cm; light and dark grey colour banding in mud, with no apparent textural variation.
				21-26 cm	Mud, light brown, massive, stiff.
4	1060	44°01'	59°01'		Gravel; 2 fragments gneissoid rock, 6 fragments quartzose sandstone. Snapper sample.
5	293	44°01'	58°58'		Sand, light brown; approx. 5% mud; very fine. Snapper sample
6	892	43°58'	59°01'	0-8 cm	Mud, dark brown, silty; firm, slightly fissile.

* Samples are cores unless otherwise stated

Sta. No.	Depth (Metres)	Latitude N.	Longitude W.		Description (top to bottom)
7	511	43°56'	59°02'	0-16 cm	Sand grey-green, very fine; approx. 10% mud; occasional broken shell fragments.
				16-72 cm	Sandy mud, grey; 30% sand, very fine; sand content grades to 5% at base of core; occasional corroded shell fragments.
8	823	43°55'	59°01'	0-7 cm	Muddy sand, grey-green; 30% mud; massive.
				7-9 cm	Sandy mud, orange-brown; 30% sand; sand 10% rock fragments, 90% quartz; massive, firm.
				9-17 cm	Mud, dark grey-brown; 20% quartz sand; 1-5 mm laminae; hard, dry.
9	1580	43°54'	58°59'	0-10 cm	Muddy sand, dark grey-green; 40% mud; quartzose; 1/2-1 cm bedding.
10	1090	43°52'	58°55'	0-84 cm	Mud and sandy mud, light brown; 15% very fine quartz sand in scattered pods throughout; 2 mm-thick sand layers at 54 and 57 cm.
11	825	43°54'	59°00'	0-12 cm	Mud, clayey, medium brown.
				12-15 cm	Mud, clayey, dark grey, slightly fissile; abundant muscovite flakes on bedding planes.
12	777	43°52'	58°59'	0-6 cm	Mud grey-brown; 5% very fine quartz sand; 1-5 mm laminae; compact, fissile.

Sta. No.	Depth (Metres)	Latitude N.	Longitude W.		Description (top to bottom)
13	1280	43°40'	58°55'	0-86 cm	Sandy, mud, brown in upper half grading to grey-brown in lower half; 40% very fine quartz sand below 40 cm; many 1 cm-thick sand layers with occasional corroded and broken shell fragments in lower 30 cm.
14	2285	43°45'	58°52'	0-31 cm	Sand and sandy mud, grey-brown; alternating layers of massive, sandy mud and 1/2-1 cm-thick sand beds; 1 cm-thick layer of clean, well-sorted fine sand at base.
				31-104 cm	Mud, grey; 10% sand; burrow mottling throughout; 1 cm-thick beds of clean quartz sand at 47 and 80 cm.
15	1426	43°49'	58°48'	0-89 cm	Mud, reddish brown; massive; rare, very fine to medium, grains of quartz and rock fragments throughout.
16	823	43°51'	58°45'		Sample lost.
17	402	43°54'	58°55'	0-41 cm	Mud, reddish brown; massive; very slightly sandy in lower 5 cm.
				41-57 cm	Muddy sand, grey-green; iron oxide stain in bedding plane at 44 cm; occasional grey quartzite granules; moderately well sorted at 51-57 cm.

Sta. No.	Depth (Metres)	Latitude N.	Longitude W.		Description (top to bottom)
18	220	43°57'	58°55'	0-51 cm	Sandy mud, brown; 5% grey-green quartzite granules and fine pebbles; massive; clay coatings on quartz grains.
19	439	43°56'	58°57'	0-79 cm	Muddy sand, grey-green; quartz; mud-size pyrite aggregates below 20 cm; very strong odour of H_2S on retrieval.
20	880	43°56'	58°59'	0-9 cm	Mud, grey-green; 1/2-1 cm-thick bedding; abundant broken shell fragments; base sharp.
				9-29 cm	Muddy sand, dark brown; very fine quartz; massive; base sharp.
				29-33 cm	Muddy sand, grey-green; quartz; massive; base sharp.
				33-38 cm	Muddy sand, dark brown; quartz; massive.
21	1420	43°56'	59°00'	0-6 cm	Mud, silty, brown; 5% very fine quartz sand; 1 mm-thick laminae; abundant muscovite on bedding planes; hard, compact.
22	275	43°56'	59°03'		Muddy sand, slightly gravelly, grey-green; quartz, 10% shell debris; grey-green quartzite pebbles. Snapper sample.

Sta. No.	Depth (Metres)	Latitude N.	Longitude W.		Description (top to bottom)
23	1573	Position indefinite; between 22 & 24		0-18 cm	Sand, grey-green; fine to very fine quartz; massive; base sharp.
				18-38 cm	Mud, dark grey; massive with 1 mm-thick laminae of light brown mud in lower 5 cm.
24	990	43°49'	58°59'		Sample lost.
25	850	43°46'	58°59'	0-90 cm	Mud, grey-green; massive; has homogeneous, reworked, aspect; occasional pyrite blebs; occasional corroded and broken shell fragments.
26	357	43°46'	59°02'		Sand, very light brown; very fine quartz; 15% mud. Snapper sample.
27	420	43°43'	59°02'	0-10 cm	Mud, brown; 5% fine gravel, 5% coarse quartz sand; gravel is sandstone and igneous rock fragments; massive.
28	366	43°45'	59°02'	0-47 cm	Muddy sand, dark yellow-brown; 5% rock fragments; poorly sorted, very fine to very coarse; massive.
29	820	43°41'	59°03'	0-126 cm	Silty mud, grey-brown; 10% very fine sand; massive.

Sta. No.	Depth (Metres)	Latitude N.	Longitude W.		Description (top to bottom)
30	1591	43°35'	59°04'	0-307 cm	Mud, grey in upper half, light brown in lower half; trace fine to coarse sand; 2 cm-thick layer of fine to coarse quartz sand and rock granules at 208 cm; no apparent structure or vertical variation in mud.
31	1591	43°35'	59°05'	0-156 cm	Mud, grey-brown; 10% quartz and rock sand and granules; very poorly sorted; frequent blebs of finely divided pyrite; broken, calcareous foraminifera common; 1 cm-thick layers of well-sorted, medium quartz sand at 75 and 94 cm; base transitional.
				156-235 cm	Sandy mud, reddish brown; 15% sand; 5% fine gravel; sand and gravel 75% quartz, 25% rock fragments; rock fragments predominantly basaltic; 161-191 cm grey-brown mud with little sand; 1 cm-thick layer of well-sorted, coarse, quartz sand at 161 cm; mud generally massive.
32	1840	43°32'	59°05'	0-85 cm	Mud, grey; massive; burrow mottling throughout; 1 cm-diameter, open burrows in upper 40 cm; base transitional.
				85-190 cm	Mud, reddish grey; 10% very fine to medium sand, 50% quartz, 50% rock fragments; unit is colour transition from unit above; base transitional.

Sta. No.	Depth (Metres)	Latitude N.	Longitude W.		Description (top to bottom)
32 (cont'd)	1840	43°32'	59°05'	190-228 cm	Mud, reddish grey; 10% sand; 5% fine gravel; sand and gravel 50% quartz, 50% metamorphic, granitic, basaltic, and red shale fragments; 212-217 cm brick-red, contains abundant basalt and red shale fragments.
33	2060	43°30'	59°05'	0-290 cm	Mud, grey-green, changes gradually to grey-brown in lower half; 10% sand; very faint colour banding in 1/2-1 cm-thick layers.
34	1518	43°30'	59°16'	0-110 cm	Sandy mud, grey; 15% sand, very fine to medium; 25% rock fragments; grades from very slightly sandy mud to top to 20% sand at 50 cm, from very slightly sandy mud at 60 cm to 20% sand at base; rare granules of quartz and grey-green quartzite throughout; base transitional.
				110-145 cm	Sandy mud, grey; 15% sand, trace fine gravel; red mud with sharp basal contact in top 4 cm; basaltic granules frequent throughout unit; base transitional.
				145-290 cm	Sandy mud, reddish brown; 20% sand, medium to very coarse, 50% quartz, 50% red sandstone and shale and basaltic fragments; massive; sand becomes finer and less abundant with depth in unit.

Sta. No.	Depth (Metres)	Latitude N.	Longitude W.		Description (top to bottom)
35	2286	43°24'	59°16'	0-147 cm	Mud, grey; massive; open burrows in upper 30 cm; base sharp.
				147-190 cm	Mud, reddish brown; trace of red sandstone fragments; 1/2 mm-thick, grey mud laminae spaced 3-4 cm apart throughout unit; laminae inclined at 5° to core and to upper contact.
36	1150	43°34'	59°17'	0-50 cm	Mud and muddy sand, light grey; predominantly mud; sandy mud in 5 mm-thick laminae at 43-47 cm; some layers graded, some reverse graded, some have sharp contacts; base transitional.
				50-75 cm	Mud and muddy sand, grey; sandy layers interbedded with mud as in above unit; brick-red in top 4 cm; becomes massive, slightly sandy mud at 69-75 cm; base transitional.
				75-108 cm	Sand and sandy mud, reddish brown; lithologies interbedded in 1/2-1 cm-thick layers; muddy sand in lenses and pods; abundant red sandstone and shale fragments; occasional black shale fragments; frequent burrows, filled with quartz and Globigerina sand; base transitional.

Sta. No.	Depth (Metres)	Latitude N.	Longitude W.		Description (top to bottom)
36 (cont'd)	1150	43°34'	59°17'	108-283 cm	Mud, reddish brown; massive; frequent pyrite blebs; occasional red sandstone and shale granules throughout; red shale pebble at 113 cm.
37	823	43°37'	59°16'	0-249 cm	Mud, grey-brown; 20% fine quartz sand at 0-10 cm; 5 mm-thick sand layers at 30 and 38 cm; shell debris at 38 cm; 38-48 cm, 5 mm-thick sand layers spaced 1 cm apart; 5% sand throughout mud layers.
38	357	43°39'	59°16'		Sand, grey-green; quartz; very fine; well sorted; 5% mud. Snapper sample.
39	2880	43°42'	58°46'	0-11 cm	Sand, grey-green; quartz; 1% glauconite; fine to very fine; massive; base sharp.
				11-61 cm	Sandy mud, grey-brown; 20% quartz sand; 1 cm-thick layers of clean sand at 16, 24, 26, 28 and 38 cm; base transitional.
				61-80 cm	Mud, grey-brown; massive; 1 cm-thick, graded sandy layer at 79 cm; base transitional.
				80-120 cm	Mud, brown; 2% fine to medium sand; massive.

Sta. No.	Depth (Metres)	Latitude N.	Longitude W.		Description (top to bottom)
40	1840	43°50'	58°40'	0-10 cm	Sandy mud, grey-brown; 20% very fine quartz sand; massive; base sharp.
				10-30 cm	Muddy, sandy gravel, grey-green; pebbles as large as medium, sand and mud in approximately equal proportions; gravel and sand are imbedded in a clayey mud matrix; gravel and sand composed of red sandstone and siltstone, grey sandstone and siltstone, and quartz.
41	1609	43°54'	58°36'	0-264 cm	Mud, grey-brown; 1% quartz sand at 234-264 cm; massive.
42	1061	43°56'	58°37'	0-174 cm	Mud, grey-green; red sandstone, fine, pebble at 87 cm; abundant dark irregular mottling; massive; base transitional.
				174-232 cm	Sandy mud, grey-brown; 174-204 cm contains abundant quartz sand in layers 1 cm thick; 15% sand in other parts of unit.
43	732	43°57'	58°37'	0-8 cm	Sand, brown; 15% mud; quartz; massive; base sharp.
				8-90 cm	Mud, reddish brown and grey; interbedded in 1/2-1 cm thick layers; frequent granules of quartz, pyrite, and red sandstone in grey layers; contacts between layers non-uniformly sharp or gradational; base transitional.

Sta. No.	Depth (Metres)	Latitude N.	Longitude W.		Description (top to bottom)
43 (cont'd)	732	43°57'	58°37'	90-217 cm	Mud, grey-brown; occasional granules of pyrite, red sandstone, and grey sandstone; 2% sand-size clay aggregates at 187-217 cm.
44	585	43°58'	58°35'	0-97 cm	Sand and muddy sand, grey-green; gradational sequence of fine quartz sand to muddy sand at 0-40 cm; reverse gradation at 40-60 cm; muddy sand at 60-97 cm; coarse pebble black schist at 85 cm; base transitional.
				97-148 cm	Mud and sandy mud, brown; sandy mud interbedded very irregularly in 3-4 cm lumps; fine pebbles in mud.
45	384	43°59'	58°35'		Sand, grey-green; 5% mud; quartz; very fine to fine. Snapper sample.
46	182	44°00'	58°39'		Sand, grey-green; 5% mud; quartz; very fine to fine. Snapper sample.
47	1024	44°01'	59°01'	0-5 cm	Sand, orange-brown; glauconite; fine to medium; in rusty mud matrix; friable; 25% matrix; appears to be part of a cobble; base sharp.
				5-18 cm	Mud, black; 5% fine to medium quartz sand; massive.
48	393	44°04'	59°10'		Sand, grey-green; 20% mud; quartz. Snapper sample.

Sta. No.	Depth (Metres)	Latitude N.	Longitude W.		Description (top to bottom)
49	348	44°08'	59°12'		No sample. Corer did not penetrate, snapper did not trip.
50	165	44°11'	59°15'		Sand, light brown; quartz; medium to coarse; 15% fine gravel-size, grey-green quartzite fragments; snapper sample.
51	201	44°15'	59°05'	0-12 cm	Muddy sand, brown; 30% mud.
52	165	44°16'	59°12'		Sand, light brown; quartz and shell debris; coarse. Snapper sample.
53	147	44°15'	59°16'		Sand and gravel, brown; grey-green quartzite, igneous and metamorphic rock fragments; sand coarse; gravel very fine to medium. Snapper sample.
54		44°16'	59°21'		Sand, brown; quartz; medium to coarse. Snapper sample.
55	219	44°14'	59°17'		Sand, brown; quartz; medium. Snapper sample.
D-1	300 to 200	44°04'	59°10'		Dredge trawl up north slope of side canyon in vicinity of Station 48. Dredge half-filled with dark brown, clayey mud with no apparent bedding structure. Strain on wire moderate.

Sta. No.	Depth (Metres)	Latitude N.	Longitude W.	Description (top to bottom)
D-2	500 to 300	43°57'	59°03'	Dredge trawl to northwest up west wall of The Gully in vicinity of Station 7. Very heavy strain on wire; parted weak link on first attempt; on second attempt, manoeuvred ship to break dredge free of bottom. Recovered load of stiff, grey clayey mud and tabular fragments of very fine, friable sandstone. Sandstone thoroughly burrowed; iron oxide-stained on some flat surfaces.
D-3	800 to 400	43°51'	58°59'	Dredge trawl up west wall of The Gully. Recovered load of stiff grey clay with weak fissility.

Cores from The Gully area described by Ericson, et al., 1961

Sta. No.	Depth (Metres)	Latitude N.	Longitude W.		Description (top to bottom)
A-173-8	2725	43°40'	58°46'	1025 cm	Long; mud with graded sand layers at intervals; thickness and abundance of sand layers increase with depth.
A-173-9	3245	43°27'	58°34'	374 cm	Long; mud with thin graded sandy layers in first metre and at approximately 2.5 metres.

APPENDIX B

FORAMINIFERA IDENTIFIED BY G.A. BARTLETT FROM CORES 6, 8 AND 12

Anomalina sp.

Bolivina sp.

Bulimina sp.

Cassidulina sp.

Ceratobulimina cf. crassa d'Orbigny

Dentalina cf. adolphina d'Orbigny

Dentalina sp.

Eponides cf. umbonata (Reuss)

Frondicularia sp.

Glandulina sp.

Globigerina sp.

Globigerina sp.

(?) Gumbelina sp.

Guttulina sp.

Nodogenerina georgiana Cushman

Nodosaria spp.

Nonion cf. pompiliodes (Fichtel and Moll)

Plectofrondicularia sp.

Pullenia quinqueloba (Reuss)

Siphonina pulchra Cushman

Siphonina spp.

Uvigerina cf. flintii Cushman

Vaginulina cf. atlantisae Cushman

Virgulina sp.