SMITHSONIAN CONTRIBUTIONS TO THE
EARTH SCIENCES

NUMBER 8

*Daniel J. Stanley,
Donald J. P. Swift,
Norman Silverberg,
Noel P. James,
and Robert G. Sutton*

# Late Quaternary Progradation and Sand *Spillover* on the Outer Continental Margin Off Nova Scotia, Southeast Canada



SMITHSONIAN INSTITUTION PRESS
CITY OF WASHINGTON
1972

# ABSTRACT

Stanley, Daniel J., Donald J. P. Swift, Norman Silverberg, Noel P. James, and Robert G. Sutton. Late Quaternary Progradation and Sand *Spillover* on the Outer Continental Margin Off Nova Scotia, Southeast Canada. *Smithsonian Contributions to the Earth Sciences,* number 8, 88 pages, 1972.—Three distinct sediment types have prograded seaward from the outer shelf to the slope and rise in the vicinity of Sable Island Bank southeast of Nova Scotia during late Quaternary time. On the slope, the oldest facies recovered in cores is a brown to brick red, irregularly stratified, pebbly-sandy-clayey silt. Locally it is covered by an olive gray, clayey silt with a low sand and pebble content. This more homogenous gray facies displays abundant biogenic structures. A third facies, a thin layer of very fine, gray sand and muddy sand, locally covers brown and olive gray sediments on the slope and upper rise. All three facies contain similar light, heavy, and clay mineral suites.

The regional distribution of these facies has been determined by core traverses normal to the shelf edge, including one passing down the axis of The Gully (largest submarine canyon in the area), and another extending down the dissected slope off Sable Island Bank. The brown, late Pleistocene unit is exposed on the floor of The Gully and on its dissected deep-sea fan; postglacial bottom processes have kept younger sediments from accumulating in these areas. The brown beds also are exposed on the lower slope and rise off Sable Island in areas of slumping or non-deposition. The olive gray facies, late Pleistocene-Holocene in age, occurs primarily on the slope; it is thicker on flanks of slope valleys and thinner or absent on the divides. It is absent on part of the lower slope and upper rise. On the lower rise, tan mud with a coarse fraction rich in Foraminifera and shell debris may be the equivalent of the olive gray slope facies.

These sediments reflect changes in the sedimentary regimen during the post-Wisconsinan transgression. The observed sequence starts with the Wisconsin low stand of the sea when glacial drift, including reddish-brown, fluvioglacial sediments, were deposited over the Nova Scotian Shelf as far as Sable Island Bank. Periglacial outwash spread across the bank and flowed seaward around it. Deposition of the slope and rise brown facies is associated with this period; textural inhomogeneity suggests downslope transport by mass movement. Pebbly lenses resulted, in part, from ice-rafting prevalent during this phase. The contact between brown and the overlying olive gray, clayey silt facies is often abrupt, commonly occurring within several centimeters; this change is correlated with the rise of the late Quaternary sea above the margin of Sable Island Bank.

As the sea transgressed across Sable Island Bank in late glacial time, fines winnowed from fluvioglacial sediment were moved north of the Bank (into the Gully Trough) and seaward onto the slope. Coarse materials no longer reached the slope with former frequency, and the fines were supplied at a markedly lower rate. This decrease in sedimentation rate on the slope coincides with an increase in the organic fraction and bioturbation. Suspended fines were reduced to a gray hue as they passed through the sediment-water interface whose rate of upward growth was now an order of magnitude smaller. The Pleistocene-Holocene boundary of approximately 10,000 years B.P. occurs within the olive gray facies. As sea level attained its near-present position, and the present configuration of bottom currents was established, the lag (modified relict or *palimpsest*) sands on the Nova Scotian Shelf began a pattern of radial dispersal that may now be observed on Sable Island and associated banks. This bottom current activity has resulted in the development of *spillover sands* on the upper slope and deposition of thin discontinuous layers (including some turbidites) on the slope and rise and in The Gully Canyon.



*Official publication date is handstamped in a limited number of initial copies and is recorded in the Institution's annual report,* Smithsonian Year.

UNITED STATES GOVERNMENT PRINTING OFFICE
WASHINGTON : 1972

**For sale by the Superintendent of Documents, U.S. Government Printing Office Washington, D.C. 20402 - Price $1.25 (paper cover)**

## Contents

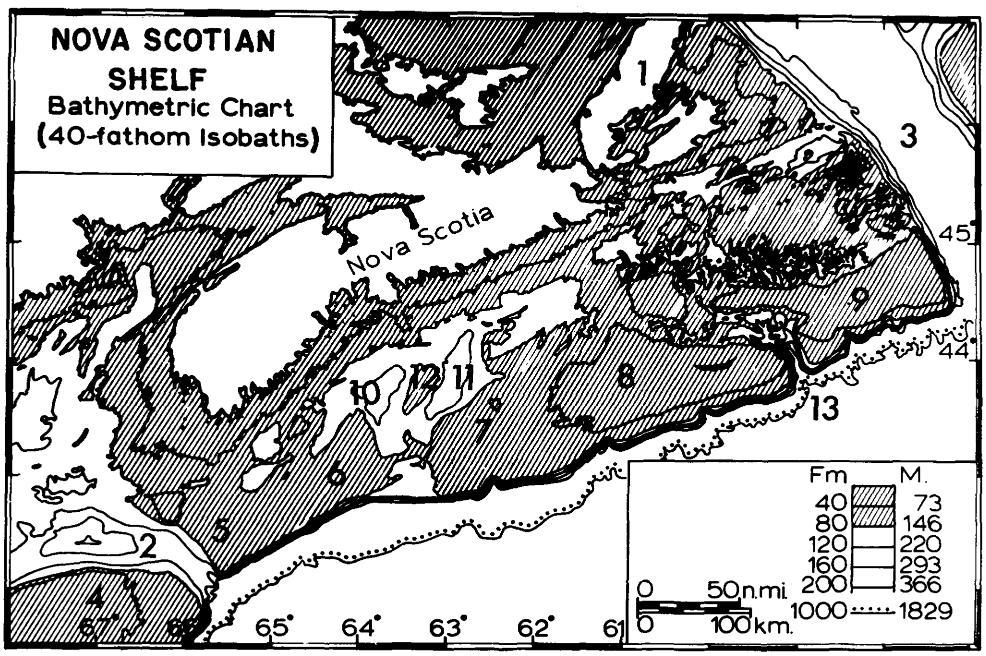



FIGURE 1.—Bathymetric chart of the Nova Scotian Shelf showing localities discussed in text. 1, Cape Breton Island; 2, Northeast Channel; 3, Laurentian Channel; 4, Georges Bank; 5, Browns Bank; 6, La Have Bank; 7, Emerald Bank; 8, Sable Island Bank; 9, Banquereau Bank; 10, La Have Basin; 11, Emerald Basin; 12, Sambro Bank; 13, The Gully submarine canyon. Shaded area on shelf (<146 m deep) was subaerially exposed (partially covered by ice) during the maximum Pleistocene low stand of sea level (Stanley et al. 1968).

*Daniel J. Stanley,*
*Donald J. P. Swift,*
*Norman Silverberg,*
*Noel P. James,*
*and Robert G. Sutton*

# Late Quaternary Progradation and Sand *Spillover* on the Outer Continental Margin Off Nova Scotia, Southeast Canada

## Introduction

The surface of the wide, presently submerged, continental margin bordering the peninsula of Nova Scotia and Cape Breton Island, southeast Canada, has been modified in recent geological time by marked glacial erosion and deposition and by the effect of sea-level fluctuations. These two phenomena were to a large degree responsible for modifications of topography and sediment distribution on the Nova Scotian Shelf as reviewed in a number of earlier studies, including those of Upham (1894), Goldthwait (1924), Johnson (1925), Shepard (1931), and Shepard et al. (1934). More recent marine geological investigations bearing in one way or another on the effects of ice and eustatic changes on the Nova Scotian margin have been reported by Shepard (1963), Heezen and Drake (1964), Hubert (1964), Nota and Loring (1964), Cok et al. (1965), Marlowe (1965, 1969), Rvachev (1965), Silverberg (1965), Clarke et al. (1967), Conolly et al. (1967), Hubert and Neal (1967), James and Stanley (1967, 1968), King (1967a and b, 1969), Medioli et al. (1967), Stanley (1968), Stanley and Cok (1968), Stanley et al. (1968), Prest and Grant (1969), Stanley and Silverberg (1969).

To date, however, little attempt has been made to synthesize Quaternary sedimentation on the outer Nova Scotian margin. The present study is an attempt to detail petrologic characteristics and stratigraphy of the uppermost sedimentary sections on the outermost shelf, slope, and rise off Nova Scotia, particularly in the area southeast of Sable Island Bank. This report summarizes and synthesizes the following petrologic and topographic data collected by the authors: core samples from the Nova Scotian Slope and Rise and Sohm Abyssal Plain (collected by the Lamont-Doherty Geological Observatory) south of the Nova Scotian Shelf (Sutton 1964); core samples along a traverse south of Sable Island Bank collected by Stanley and Swift on the CSS *Hudson* in December 1964; cores samples and topographic data collected off Sable Island Bank (Silverberg 1965); cores, bottom sediment grab samples, photographs, and topographic data gathered from the northern and eastern margins of Sable Island Bank (James 1966). Synthesis of this material makes it possible to demonstrate how late Pleistocene to Holocene glacioeustatic events affecting the Nova Scotian Shelf and mainland left a marked imprint on the sedimentary cover beyond the shelf-break. In addition to an interpretation of

*Daniel J. Stanley, Division of Sedimentology, Department of Paleobiology, National Museum of Natural History, Smithsonian Institution, Washington, D.C. 20560. Donald J. P. Swift, Institute of Oceanography, Old Dominion University, Norfolk, Virginia 23508. Norman Silverberg, Department of Oceanography, University of Washington, Seattle, Washington 98105. Noel P. James, Department of Geological Sciences, McGill University, Montréal, Québec, Canada. Robert G. Sutton, Department of Geological Sciences, University of Rochester, Rochester, N. Y. 14627.*

late Quaternary progradation, particular attention is paid to postglacial and modern sediment-dispersal processes that have resulted in the spillover of reworked relict (*palimpsest* after Swift et al. 1971) sands from the shelf to the slope and rise environments beyond.

## Geography and Topography of the Study Area

### *General Setting*

The continental shelf off the Atlantic coast of Nova Scotia,[1] an area of about 120,000 km,[2] is over 700 km in length and extends from the Northeast Channel northeastward to the Laurentian Channel (Figure 1). It is a broad northeast-southwest-trending platform, about 100 km wide off the southwest coast of Nova Scotia and about 250 km wide off Cape Breton Island. The shelf is narrowest off the northeast coast of Cape Breton in the area of St. Paul's Island. The shelf displays the typical dissected topography of glaciated margins with deep basins and linear troughs (Shepard et al. 1934, Holtedahl 1955, Stanley, et al. 1968). The shelf depth is extremely variable and locally deeper than 375 m. One point on Sable Island Bank is actually emergent: Sable Island, nearly 200 km from the mainland. The continental shelf differs from the nonglaciated shelf south of the Gulf of Maine in several respects: it is considerably wider, displays a much higher degree of relief and dissection, and becomes shallower, not deeper, along much of its seaward margin. The Northeast Channel, a linear, U-shaped depression, separates the Nova Scotian Shelf from the Gulf of Maine. The northeastern margin of the Nova Scotian Shelf is delineated by another broad, northwest-southeast-trending trough, the Laurentian Channel. The shelf is widest in the region adjacent to the Laurentian Channel, and extends for a distance of about 250 km from the southeast coast of Cape Breton to the seaward edge of Banquereau Bank.

The Nova Scotian Shelf is distinguished by its pronounced relief and extremely complex topography, particularly on the eastern half of the shelf (Figure 1). Morphologic cross-shelf gradients do not approach the exponential curvature associated with mature construction, "equilibrium" neritic platforms. Phys-

[1] The three main continental margin provinces are called *Nova Scotian Shelf, Nova Scotian Slope,* and *Nova Scotian Rise.* Use of the abbreviated name Scotian Shelf and Scotian Slope is discouraged to minimize possible confusion with another glaciated region, the Scotian Sea in higher latitudes of the South Atlantic.

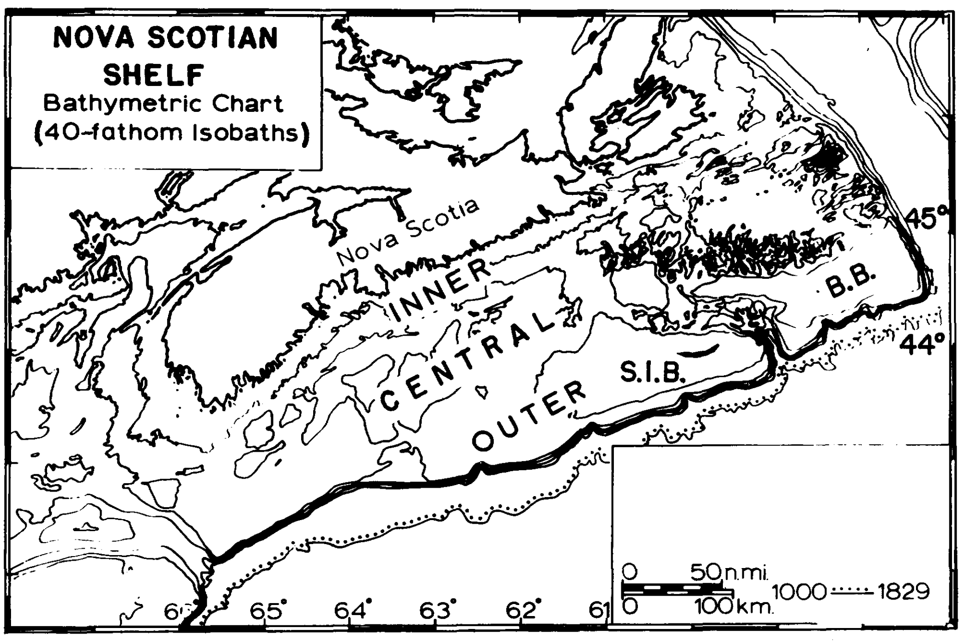



FIGURE 2.—Inner, central, and outer physiographic provinces of the Nova Scotian Shelf as defined in Stanley and Cok (1968). S.I.B. = Sable Island Bank. B.B. = Banquereau Bank.

iographic provinces of the shelf are well displayed on Canadian Hydrographic Service Fisheries Charts 4040, 4041, and 4350. The shelf may be divided into three major physiographic zones that are oriented roughly parallel to the Nova Scotian mainland (Stanley and Cok 1968); these are referred to as the *inner, central,* and *outer* shelf provinces and delineated on Figure 2.

### *Morphology of the Outer Margin Near Sable Island Bank*

The outer Nova Scotian Shelf region emphasized in this study is generally broad and flat, and is shallower to the east where two large banks—Banquereau Bank and Sable Island Bank—are less than 90 m deep. On the western section of the shelf, Browns Bank, La Have Bank, and Emerald Bank are somewhat deeper and their upper surfaces average about 100 m. This series of generally flat banks along the outer continental shelf between Georges Bank, south of the Gulf of Maine, and the Great Bank off Newfoundland falls physiographically and geologically within the Submerged Atlantic Coastal Plain Province. The bottom relief is slight over most broad shelf bank tops (slope of 1 to 1000): smooth undulations are due to the presence of migrating subaqueous sand dunes (James and Stanley 1968). The shelf actually emerges on Sable Island Bank as Sable Island, the only such island on the outer shelf off northeast North America.

Sable Island Bank, a sand-covered platform approximately 250 km in length, has a maximum width of about 115 km when using the 90 m (50 fm) isobath as the bank margin (Figure 3). This Bank, the longest such feature on the outer Nova Scotian Shelf, lies between Banquereau Bank (to the east-northeast) and Emerald Bank (to the west-southwest) and covers an area of approximately 17,000 $km^2$. Sable Island, at approximately 60°W longitude, 43°50′N latitude, is located on the eastern margin of the Bank, about 185 km southeast of Cape Canso and 334 km southeast of Halifax on the Nova Scotian mainland. The Island, a low (1-20 m), east-west trending, arcuate bar of sand flats and dunes about 39 km long and 1.5 km wide, has been recently described (James and Stanley 1967). Extremely gentle gradients east and south of Sable Island are 1:880 and 1:330 respectively, and 1:280 north of the island (Figure 4). More than one-half of the Bank lies at depths of less than 55 meters. The western part of Sable Island Bank, known as Western Bank, is separated from Emerald Bank by a shallow depression, the Western Gully; Western Bank lies at depths of about 55 to 90 m.

The morphology and sediments of Sable Island Bank have been discussed in earlier studies by Upham (1894), Johnson (1925), Shepard et al. (1934) and more recently by Marlowe (1965, 1967), Rvachev (1965), James and Stanley (1967, 1968), Stanley and Cok (1968), Stanley and Silverberg (1969).

A region of irregular submarine topography, The Gully Trough, separates Sable Island Bank, Middle Bank, and Banquereau Bank (Figure 3). The dominant feature of this dissected area is a broad valley oriented east-west with a tributary-like branch entering from the north between Middle Bank and Banquereau Bank. The Gully Trough includes isolated topographic highs rising up to a depth of 110 m and basins deepening to 200 m. The central portion deepens slowly from west to east and, on swinging south off the east bar of Sable Island, deepens abruptly to form The Gully submarine canyon. This feature is part of a broad relict dendritic pattern leading southward toward the main canyon. The fluvioglacial origin of this depression (see Figure 11) is discussed in a later section.

### *The Gully Submarine Canyon*

The seaward margin of the Nova Scotian Shelf is dissected at several localities, but nowhere as much as in the headward region of The Gully, the large impressive submarine canyon between Sable Island Bank and Banquereau Bank. The morphology of The Gully Canyon, extending well onto the Nova Scotian Shelf and bordering the eastern margin of the Sable Island Bank (Figure 3), has been detailed elsewhere (Marlowe 1967, 1969, Stanley 1967). This depression is a sinuous, steep-walled, V-shaped submarine valley, that displays most of the criteria of "type" submarine canyons (Shepard and Dill 1966).

Marlowe (1964, page 17) in his preliminary study of this area describes the physiography as follows:

> The width of the canyon, as defined by the 400 meter contour, increases from one mile near its head to more than eight 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 meter contour. In profile, the canyon is V-shaped. Its course is slightly sinuous and it trends generally southward, with a deflection to the southeast at about

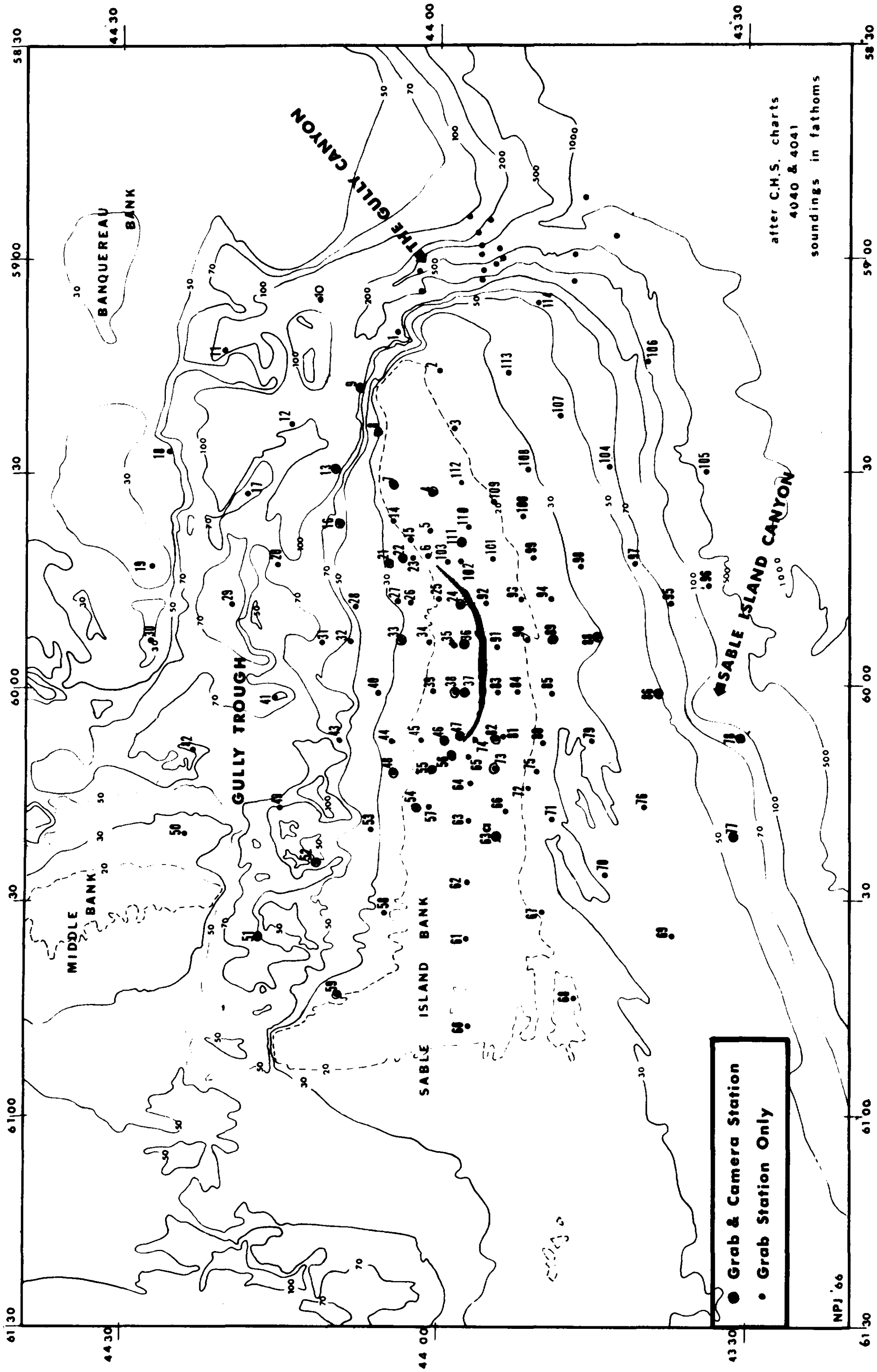



FIGURE 3.—Chart showing Sable Island Bank and adjacent area including Banquereau Bank, Middle Bank, The Gully Canyon, Gully Trough, and continental slope and upper rise. Samples collected at Stations 1 to 114 are detailed in James (1966). Cores collected in The Gully Canyon are also shown in Figure 16. Depths in fathoms.

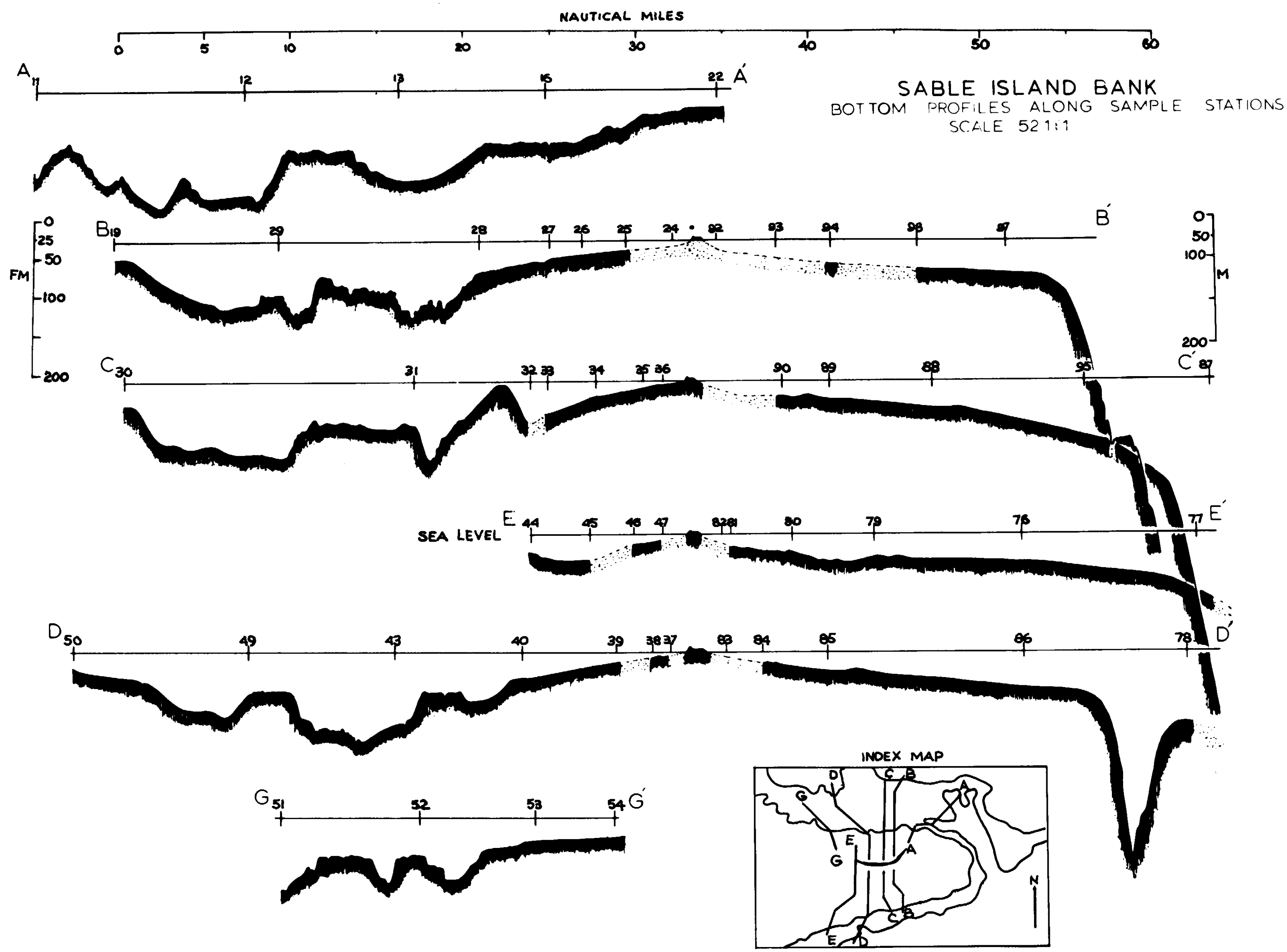



FIGURE 4.—Bottom profiles (from PDR traces) across Sable Island Bank and The Gully Trough north of the bank (see inset).

the 2200 meter contour. Its longitudinal gradient varies between 1:18 and 1:9. Side canyons occur along the west wall.

The Gully divides Sable Island Bank from Banquereau Bank, and its shelfward continuation, the Gully Trough, bifurcates and forms north- and northwest-trending troughs in the area of Middle Bank (Figure 3).

*Slope and Upper Rise Off Sable Island Bank*

The southeastern margin of Sable Island Bank forms the east northeast-west southwest trending shelf-break and slope. The transition from shelf to continental slope (gradient > 1:40) occurs within a distance of 2 to 4 km (Figures 4, 5). The slope bordering the seaward edge of the Bank is approximately 240 km in length and extends from the southwest margin of the Bank (at about 62°00′W longitude, 43°00′N latitude) to the Gully Canyon at about 59°07′W longitude, 43°45′N latitude). A detailed chart of the slope and uppermost rise south and southeast of Sable Island Bank (Silverberg 1965, his figure 2) was contoured at a 50-fm (91 m) interval using soundings of Canadian Hydrographic Service boat sheets as a base (a simplified version of this chart contoured at 100-fm interval is shown on Figure 6). This data was collected to depths of about 2000 m on the CSS *Kapuskasing* in 1960 and 1961. DECCA navigation (± 1 nautical mile accuracy) was used to control the position of traverses spaced 2.4 to 3.2 km apart across the maximum slope inclination. The chart, prepared by Silverberg at a scale of one inch to approximately five nautical miles, covers the area 59°00′ to 62°00′W longitude and 42°30′ to 44°00′N latitude (see inset, Figure 6). The same soundings have been

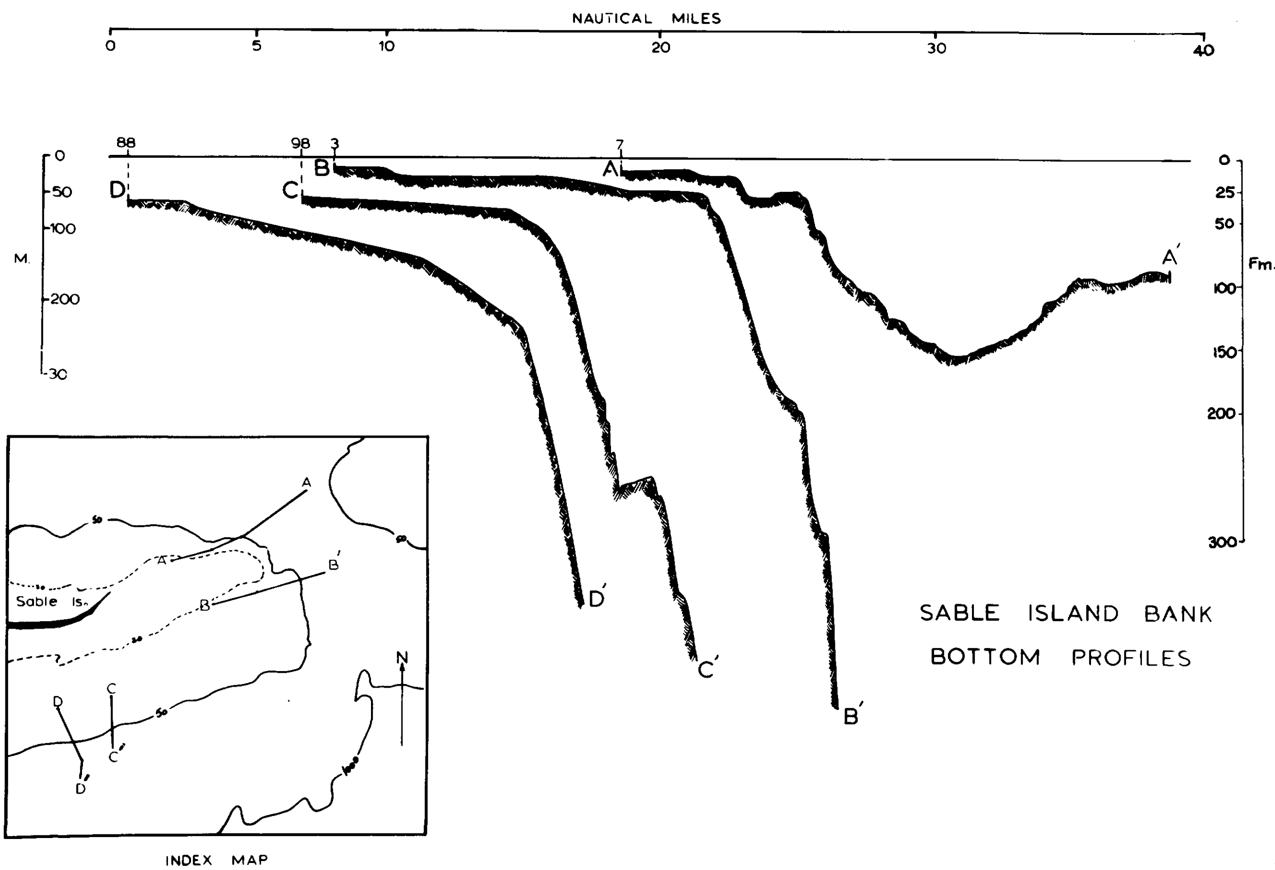



FIGURE 5.—Bottom profiles (from PDR traces) across the southern and eastern margins of Sable Island Bank (see inset).

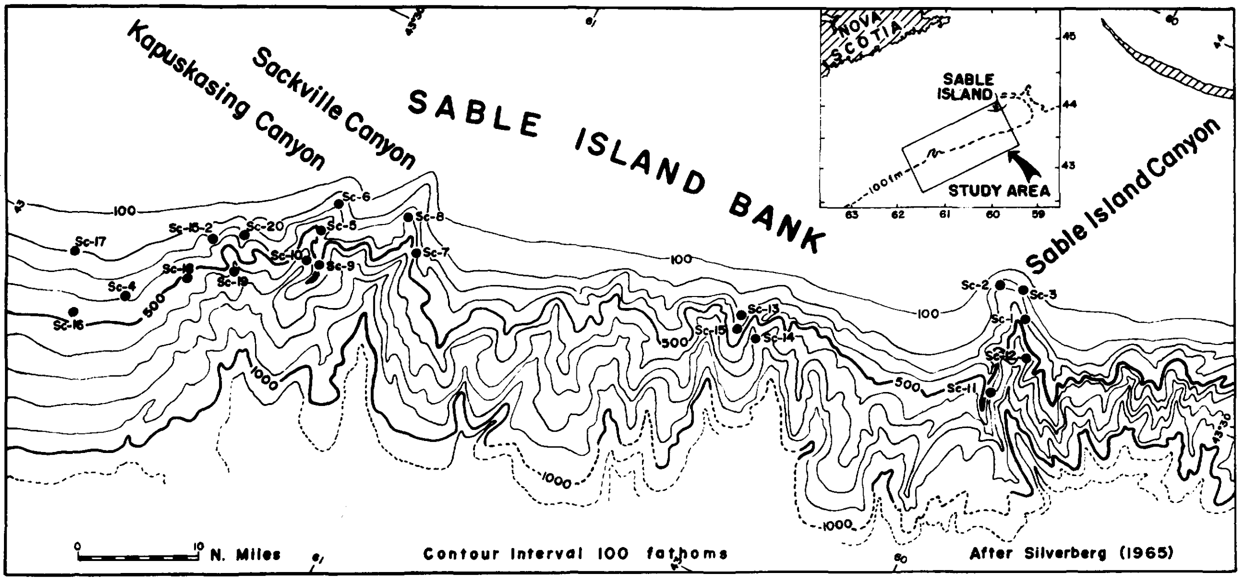



FIGURE 6.—Dissected Nova Scotian Continental Slope southwest of Sable Island (modified after chart by Silverberg, 1965). Note smooth, nonscalloped slope west of the Kapuskasing Canyon, in contrast with areas between Sackville Canyon and Sable Island Canyon. Cores (Sc-l to Sc-20) are detailed in Silverberg (1965). Depth in fathoms.

contoured in a somewhat more generalized fashion by the Canadian Hydrographic Service on their Fisheries Charts 4040 and 4041 (at a scale of 1:300,000). The slope and rise immediately adjacent to The Gully Canyon (Figure 16) have been charted (Marlowe 1967). Also available are several profiles of the slope (Heezen et al. 1959) and of the rise beyond (Pratt 1967).

The break between shelf and slope (gradient 1:40) occurs at depths ranging from 110 to 146 m, but most frequently between 119 to 137 m. The shelf-break occurs at similar depths along most of the outer margin between Newfoundland and area south of New England (Uchupi 1968). Gradients from 1:10 to 1:25 characterize the upper slope (Figures 4, 5). Only three large depressions were found actually to head on the outer shelf margin at depths of less than 200 m in the region west of The Gully: (a) Sable Island Canyon, about 5 km wide at approximately 60°03′W longitude, 43°35′N latitude (almost due south of Sable Island); (b) Sackville Canyon, about 4 km wide at 61°09′W longitude, 43°10′N latitude; and (c) Kapuskasing Canyon, about 3 km wide at 61°17′W longitude, 43°16′N latitude. A small narrow ridge, approximately 1.5 × 3 km, extends from the shelf edge toward the slope at 59°15′W longitude and 43°41′N latitude.

The slope becomes considerably dissected below 600 m where more than twenty large north northwest-south southeast-trending depressions 1 to 8 or more km across are noted on the charts between 59° and 61°W longitude. Cross-sectional profiles parallel to the slope indicate that most valleys tend to be **U**-shaped rather than **V**-shaped (Figure 7). Gradients along the top of intervalley ridges are approximately 1:20; that of valley axes are commonly about 1:12. Submarine valleys and gullies are straight to slightly sinuous, and most extend to the base of the slope. Some valleys appear to lack tributaries but this may be an artifact resulting from an insufficiently tight sounding net. Relief of several larger depressions exceeds 500 to 700 m on the upper continental rise, but none of the valleys appear to extend as far as the Sohm Abyssal Plain to the south (Pratt 1967). Certain valleys such as Kapuskasing Canyon, heading near the shelf-break, appear to die out near the base of the slope. It is noteworthy that most valleys head at depths greater than 400 to 700 m, and in some cases below 900 m. Large broad mounds, some of them covering an area exceed-

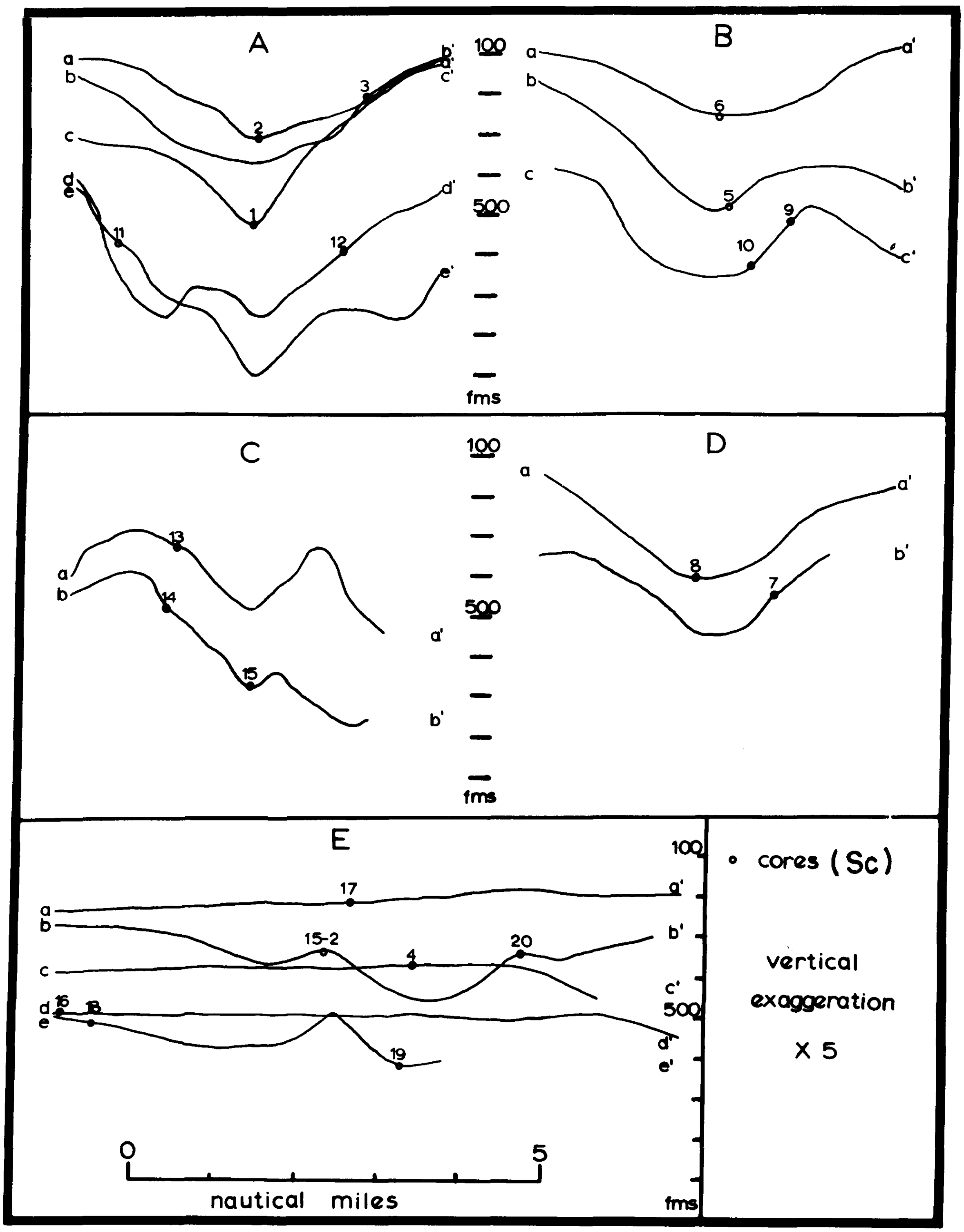



FIGURE 7.—Profiles across the upper slope showing position of cores on valley floor and margins and intervalley highs. Geographic location of cores are shown in Figure 6. Depth in fathoms.

ing 25 km,[2] occur beyond the distal termination of gullies at base-of-slope depths.

In striking contrast with this scalloped and dissected topography is the smoother more regular slope (gradient about 1:20) south of Western Bank and west of 61°30′W latitude. The shelf north of the undissected slope region (Western Bank) is generally deeper (60 to 100 m) than the bank area east of 61°30′W latitude. There are two possible explanations for the high relief on the slope south of Sable Island: (a) Sable Island Bank may have acted as a sediment barrier preventing the filling of valleys cut in Pleistocene time or earlier on the slope, or (b) conversely, Sable Island Bank provided an unusually large volume of sediment to the slope during the Pleistocene, and the high rate of sedimentation, in turn, induced overloading and, eventually, slumping. The latter hypothesis of submarine valley formation seems most probable. Analyses of seismic profiles [Uchupi 1969 (his figure 4), Emery et al. 1970] and cores (Stanley and Silverberg 1969) collected on the continental slope and rise off Sable Island Bank do, in fact, support a slumping hypothesis. Much of this slumping took place during Quaternary time, and there is further evidence to suggest that this process is still active in this general area at present. The 1929 Grand Banks slump which occurred northeast of the study area is the best documented example (Heezen and Drake 1964).

The boundary between slope and rise is difficult to establish precisely; the decrease in gradient from 2° to less than 1° is gradual. Downslope profiles show local breaks in slope near The Gully at about 950, 1300, and 1700 m (Marlowe 1967); some of these terrace-like features are probable structural benches. The rise is somewhat steeper, wider, and deeper (1000 to 1500 fm) than in some areas off the northeast United States continental margin (Heezen et al. 1959, Pratt 1967). The combined width of the slope and rise southeast of the Bank is approximately 180 nautical miles (334 km). The density of sounding notations and available profiles in water deeper than 1800 m does not, at this time, permit compilation of a detailed topographic chart of the lower rise southeast of Sable Island Bank.

## Submerged Terraces and Sea-Level Changes

A recent survey (Stanley et al. 1968) of submerged terraces has identified the position and depth of notches, benches, and other morphological features identified as terraces on the Nova Scotian Shelf. Two groups of terraces are particularly pronounced. The frequently encountered terrace at approximately 66 fm (121 m) is attributed to the maximum low stand of sea level during the last glacial stage as indicated by Curray (1965), Shepard and Curray (1967), and Milliman and Emery (1968). A lower, well-defined terrace at approximately 80 fm (146 m), cut just below the seaward edge of the outer shelf and on the steep northern margins of the outer banks, probably records one of the maximum lowerings of Pleistocene sea level. Faunal evidence at this horizon in other regions does not rule out an early Wisconsinan age (J. Ewing et al. 1960, M. Ewing et al. 1960), but there is strong indirect evidence to attribute the 80-fm terrace to an earlier glacial stage probably the Illinoian, or third major glacial episode (Donn et al. 1962).

The Nova Scotian Shelf is morphologically so irregular and highly dissected that even a small change in sea level would alter markedly the configuration of the exposed continental platform seaward of the Nova Scotian mainland (Berger et al. 1966). Even during a maximum low stand, as recorded by the terrace at approximately 146 m, several large, deeply incised areas of the shelf probably remained covered with lakes or with ice or both. These deep depressions, shown as the nonhachured sectors on the shelf on Figure 1, include basins south of Halifax, linear troughs southeast of Cape Breton, and The Gully Trough, an extension of The Gully submarine canyon. These lows, almost certainly related to fluvioglacial drainage and ice transport (Stanley and Cok 1968) have received fine-grained sediments from adjacent topographic highs since the postglacial rise in sea level.

## Sediment Distribution Patterns on the Outer Nova Scotian Shelf

### *General Textural Composition of the Shelf*

It is necessary to review the dominant petrologic trends on the Nova Scotian Shelf proper in order to properly interpret mineralogical patterns and facies changes on the continental slope and rise. The regional grain size-distribution pattern is summarized on a simplified textural facies map (Figure 8). This facies map is based on over 1000 samples collected on

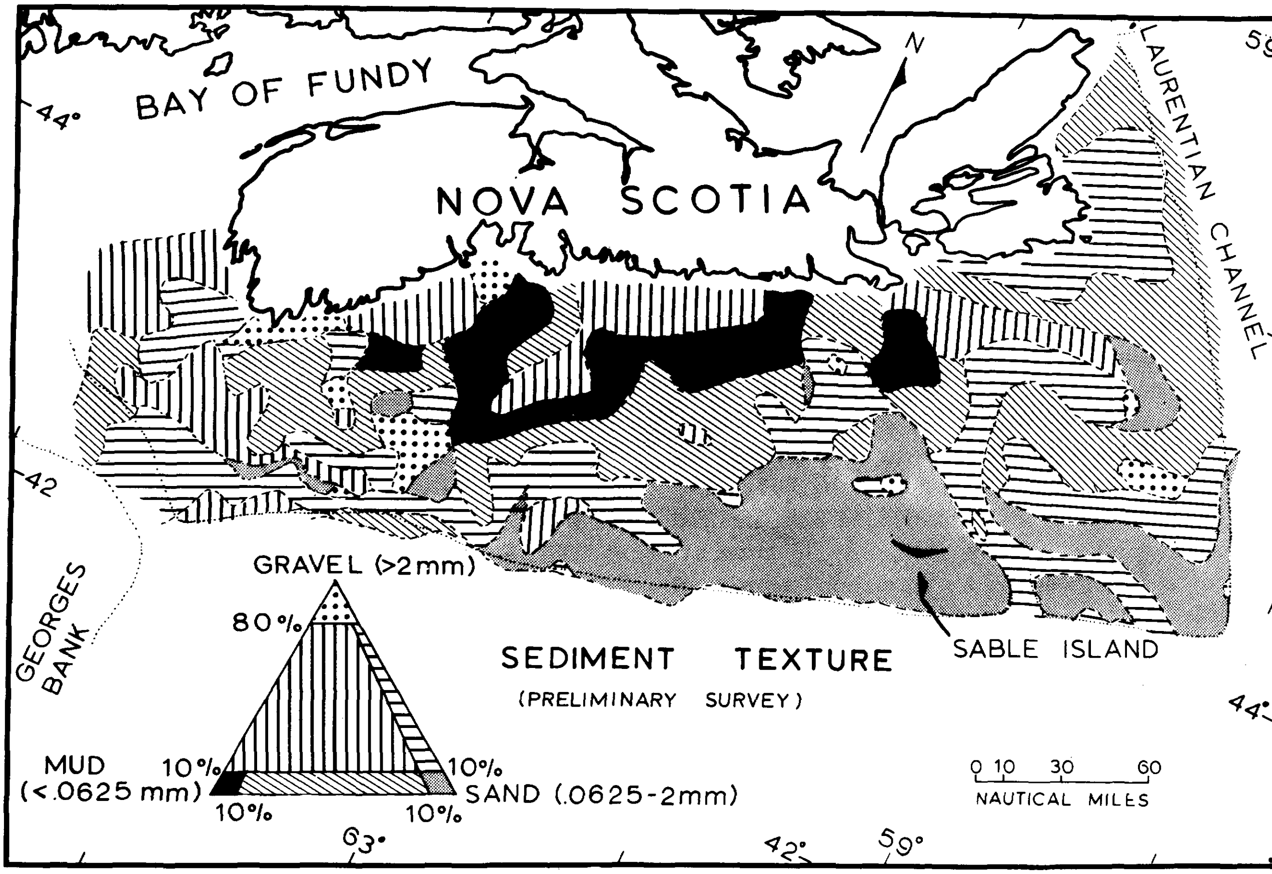



FIGURE 8.—Generalized regional size distribution of surficial sediment on the Nova Scotia Shelf (Stanley and Cok 1968).

the shelf (Stanley and Cok 1968, their figure 4). A textural classification, modified after Folk (1954), is used in which three end-members are recognized: *gravel* (fraction coarser than 2.0 mm); *sand* (fraction from 0.0625 to 2.0 mm); and *mud* (fraction finer than 0.062 mm, including both silt and clay). Intermediate textural admixtures consisting of mud and sand, of gravel and sand, and of gravel, sand, and mud are also depicted on Figure 8. The resulting distribution of textural types brings out the pattern of "outward increasing gradation," e.g., the offshore coarsening of sediment described by Shepard et al. (1934). Regional trends are neither strictly parallel, nor normal to the coast of Nova Scotia, and the overall patchiness of sediment distribution indicates that the shelf is by no means "at grade" or in equilibrium with present hydrographic conditions. The shallow outer banks are covered largely by sand or sand-gravel admixtures; deep basins and troughs on the center shelf are commonly floored with mud, and mud-sand admixtures; and much of the remainder of the inner and mid-shelf regions, particularly at intermediate depths, are covered with gravel-sand-mud admixtures that are till-like in textural composition.

The textural distribution pattern suggests that grain size bears some relation to (a) geographic position and distance from shore, and (b) depth. The correlation of grain size with depth is largely a function of recent erosional and depositional processes on the shelf. No major rivers, for instance, drain the mainland of Nova Scotia, and little sediment is provided to the shelf, with the exception of some fine-grained material that bypasses river mouths (Stanley 1968). Thus, much of the present sedimentary pattern reflects relict distribution ("remnant from a different earlier environment" according to Emery 1952, page

1105), subsequently modified by Holocene processes of reworking. The distribution of gravel-sand-mud admixtures of the upper sediment surface indicates, for instance, the widespread cover of poorly sorted diamictites transported onto the shelf by glacial ice.

The dominance of sand on much of Emerald Bank, Sable Island Bank, and Banquereau Bank is probably related to (a) the buildup of glacial outwash deposits at the frontal ice contact areas on the northern margins of these banks, and to (b) the subsequent removal by winnowing of finer grade fractions from originally more poorly sorted deposits. That much of these "fines" have probably been redeposited landward in deep areas of the center shelf region north and northwest of the banks following the last rise in sea level was suggested in an earlier study (Stanley and Cok 1968). We shall show in subsequent sections that some of the silt and clay winnowed from bank tops was also redeposited seaward on the continental slope and in canyon-subsea fan complexes during the late Pleistocene and early Holocene. This seaward dispersal of fines began prior to the time when sea level began to cover the bank areas and migrate landward across the shelf. Thus, as a result of this transgression, recently transported fine-grained sediments are concentrated over relict (Pleistocene) sediment in inner and center shelf regions and beyond the shelf-break, while coarser lag deposits remain on the outer banks, including those on the eastern half of the Nova Scotian Shelf. Details of the textural distribution on Sable Island Bank are available elsewhere (James and Stanley 1968).

The lateral variation of sorting observed on the Nova Scotian Shelf (Figure 9) substantiates these conclusions. A scale showing the relative degree of sorting is based upon the total number of phi classes that make up the size distribution of a sample at each station. Thus, the fewer the number of size classes, the

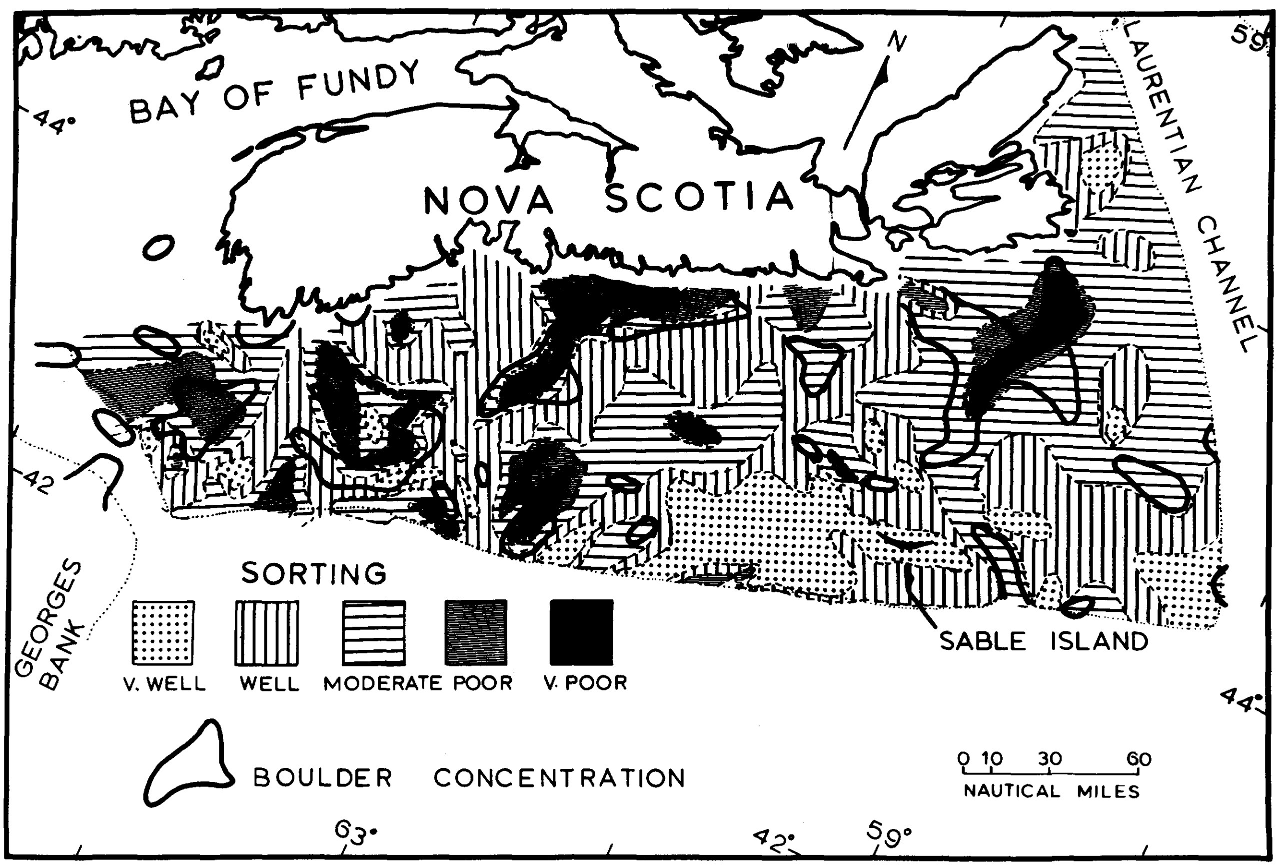



FIGURE 9.—Regional variability of sediment sorting and distribution of boulder concentrations on the Nova Scotian Shelf (Stanley and Cok 1968).

better the sorting, and vice versa. The best sorted sediments are those located on the shallow outer banks (particularly on the eastern half of the shelf), areas covered predominantly with sand. Areas displaying the poorest degree of sorting occur in elongate belts on the inner and center shelf regions; these elongate areas generally are composed of gravel-sand-mud admixtures.

Areas of boulder concentration on Figure 9 are generally closely related with the distribution of linear belts of poorly to very poorly sorted sediment. This "boulder-diamictite" association clearly defines major dispersal trends. These trends, reflecting moraines and boulder trains, extend from the present coastline toward the center shelf and outer shelf edge on the western half of the Nova Scotian Shelf. Other petrologic criteria have also resulted in the delineation of certain of these glacial moraines on the shelf (King

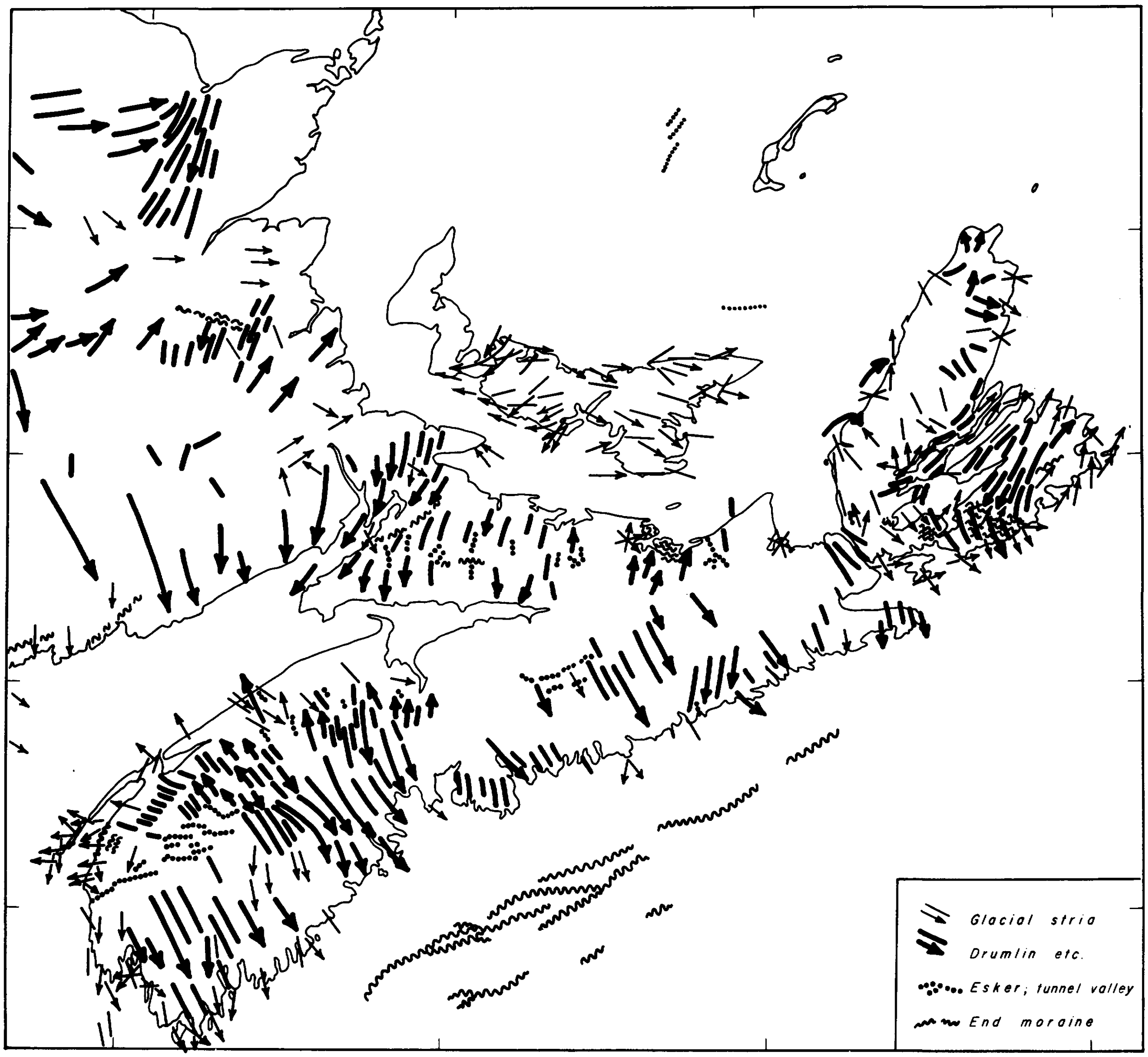



FIGURE 10.—Glacial features indicative of ice flow on Nova Scotia and adjacent areas patterns (Prest and Grant 1969, their figure 3 with the authors' permission).

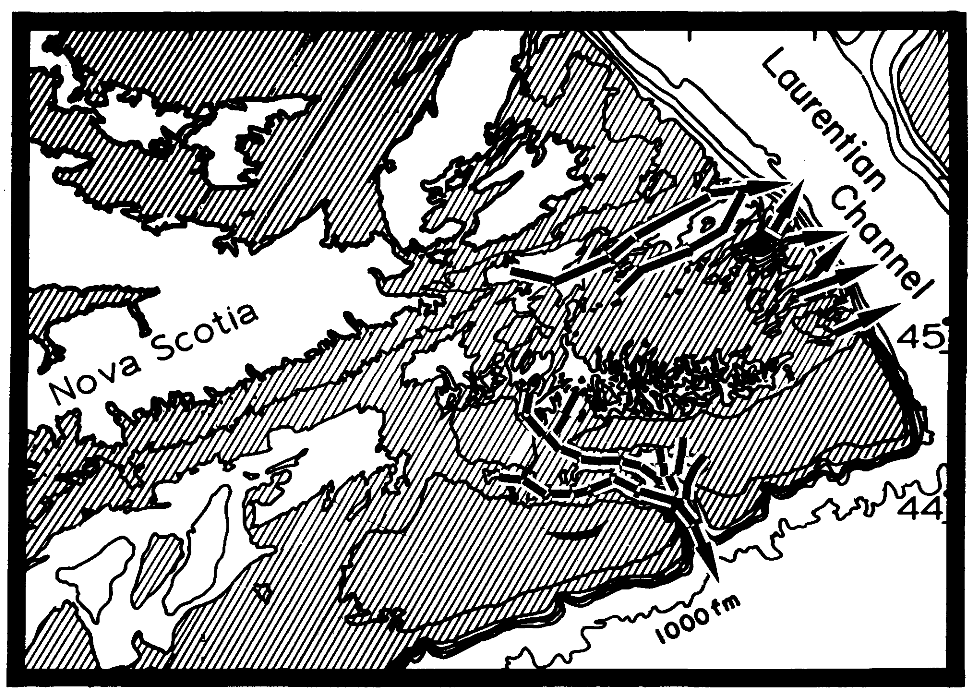
1969). Moderate to very poorly sorted sediments indicative of glacial ice transport predominates on the eastern half of the shelf north of Emerald Bank, Sable Island Bank, and Banquereau Bank.

*General Mineralogical Composition of Surficial Shelf Sediments*

The relation between mainland tills and sediment offshore has been demonstrated by plotting the distribution of lithic (rock) fragments and heavy minerals in the sand-size fractions and by examining the composition of the pebbles and boulders in the coarse fraction (James and Stanley 1968, Stanley and Cok 1968). The sum of mineralogical data, evaluated in light of the textural and morphological data, also serves to delineate the coverage of glacial deposits on the shelf.

The mineralogical composition of inner shelf sediments is similar to that of glacial drift on the mainland. Much of the coarse fraction is composed of Paleozoic material of the type cropping out on Nova Scotia. The regional distribution indicates a linear belt approximately 60 km wide that is roughly parallel to the mainland and is rich in rock (lithic) fragments (10 to over 75 percent rock fragments in the 0.6 to 1.0 mm fraction; 5 to 25 percent in the 0.4 and 0.6 mm fraction). Heavy mineral assemblages distinguished on the mainland beaches (Nolan 1963) can be correlated reasonably well with those on the inner and center shelf regions. Glacial tongues that traversed the mainland in south and southeast directions (and toward the northeast in sections of Cape Breton) according to Goldthwait (1924), Grant (1963) and Prest and Grant (1969, their figure 3) undoubtedly continued beyond the present coast. Generalized ice flow trends on the Nova Scotian mainland are depicted on Figure 10. Diagnostic heavy minerals (such as augite) or rock fragments (granite pebbles from the Cobequid Mountains) are useful for pinpointing specific source locations. Linear troughs and channels carved into the shelf (Stanley et al. 1968) indicate the general transport path of the glacial tongues (Figure 11).

Reddish brown tills, containing iron stained grains, are found on the Atlantic coast of Nova Scotia, and it is likely that they extended further onto the shelf. These mainland tills were derived from source areas (Carboniferous and Triassic) located in Bay of Fundy, Prince Edward Island, and New Brunswick regions.




FIGUGE 11.—Probable major glacial and fluvioglacial drainage patterns on northeastern sector of the Nova Scotian Shelf (Stanley and Cok 1968).

Heavily stained quartz (Stanley and Cok 1968, their figures 9, 10) and lithic grains of sand size, so abundant on the outer banks, are also valuable provenance indicators. It is almost certain that much of the glacial and fluvioglacial materials preserved on the outer banks originated in Carboniferous and Triassic terrains lying several hundreds of kilometers to the northwest. Many of the pebbles and cobbles collected on Sable Island Bank have been identified as Paleozoic in origin of the type cropping out on Nova Scotia (James and Stanley 1968).

A relatively anomalous mineralogical province occurs on the central shelf northwest of Sable Island Bank. The presence of nodules, quartzitic and glauconitic sandstone fragments, varieties of corroded garnet, and other heavy minerals of the type not found elsewhere on the shelf suggests a supply from local bedrock source areas exposed on this sector of the shelf. It is conceivable that such isolated ledges include Tertiary and Cretaceous strata (occasionally dredged by scallop fisherman) that were eroded by moving ice. Evidence of Cretaceous strata on the shelf has, in fact, been cited by Dall (1925), Stephenson (1936), King et al. (1970), and others. The seaward dipping pre-Pleistocene Coastal Plain deposits forming the submerged cuestas on the Nova Scotian shelf are evident in high-resolution subbottom seismic profiles (Uchupi 1969).

Mineralogical data provide additional support for the conclusion that Pleistocene glacial tongues at one time (although not necessarily during the Wisconsinan) extended seaward as far out as the shelf edge on the southwestern part of the shelf and as far as the Sable Island Bank-Banquereau Bank regions on the northeastern shelf. A paleogeographic reconstruction displaying the zone of ice coverage is shown in Figure 12. This schema shows that a considerable amount of ice-borne glacial marine sediment was rafted onto the slope and rise beyond by bergs breaking off the glacial front during glacial stages. Bottom photographs and dredge hauls (Cok 1970) on the slope and rise show that this did take place. In particular, photographs collected during the search for the submarine *Thresher*, whose hull bottomed at the base of the slope southeast of the Northeast Channel (Brundage et al. 1967) reveals concentrations of large boulders, some over 3 m in diameter, which were undoubtedly initially

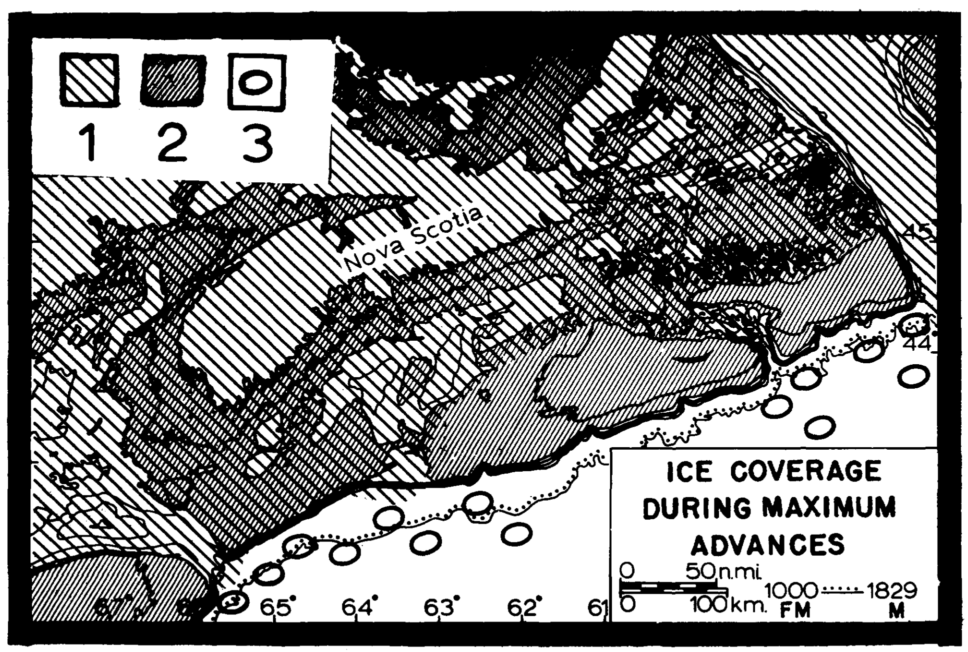
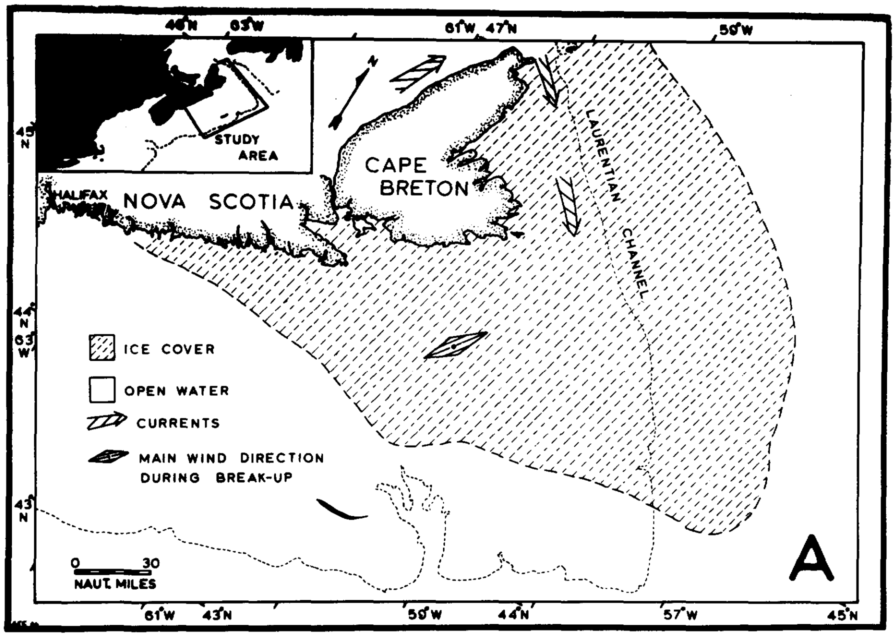



FIGURE 12.—Ice coverage on the Nova Scotian Shelf during the Pleistocene, as interpreted from sediment distribution and topography (Stanley and Cok 1968). 1, Probable extent of glacial ice during maximum advances; 2, outwash area; 3, area of berg-borne sediment.



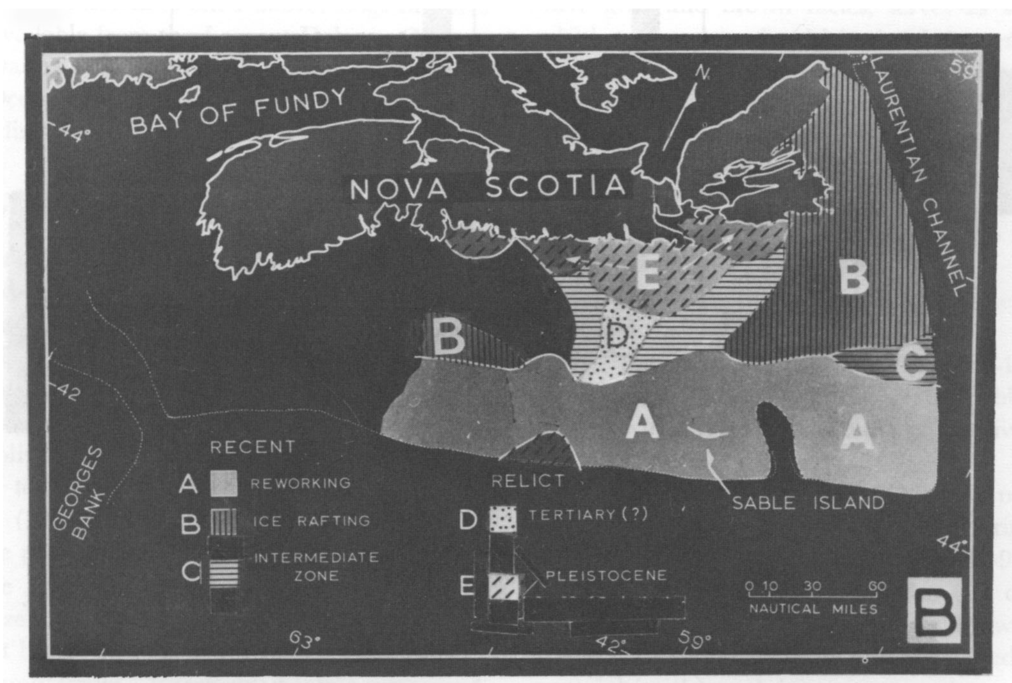




FIGURE 13.—A, Maximum ice-coverage and dominant surface current patterns on the eastern portion of Nova Scotian Shelf during ice breakup in the spring. B, Major sedimentological provinces on the northeastern Nova Scotian Shelf (explanation in text). Note that the sector of ice-rafted material (B) coincides with zone of seasonal ice-coverage shown in A. The outer banks, zones of intense erosion and textural unmixing, are blanketed by a surficial sand and gravelly sand lag.

transported into deep water by ice-rafting during glacial stages.

Attention has also been called to the importance of recent (Holocene) ice transport of sediment as a result of seasonal breakup and movement of ice from the Gulf of St. Lawrence (Stanley and Cok 1968) onto the Nova Scotian Shelf (compare the ice distribution pattern in Figure 13A with area B in Figure 13B). This addition of modern ice-rafted material on the shelf edge near Sable Island Bank and Banquereau Bank should not be overlooked. Postglacial to modern ice-rafting would probably also account for thin discontinuous patches of fine to coarse material on the slope and rise.

## General Description of Slope and Rise Sediments

### *Cores Examined*

Recognition of sedimentary facies on the continental slope and upper rise off Nova Scotia is based on a study of four sets of cores discussed in this and following sections:

(a) 20 piston cores (Figure 14) collected on the

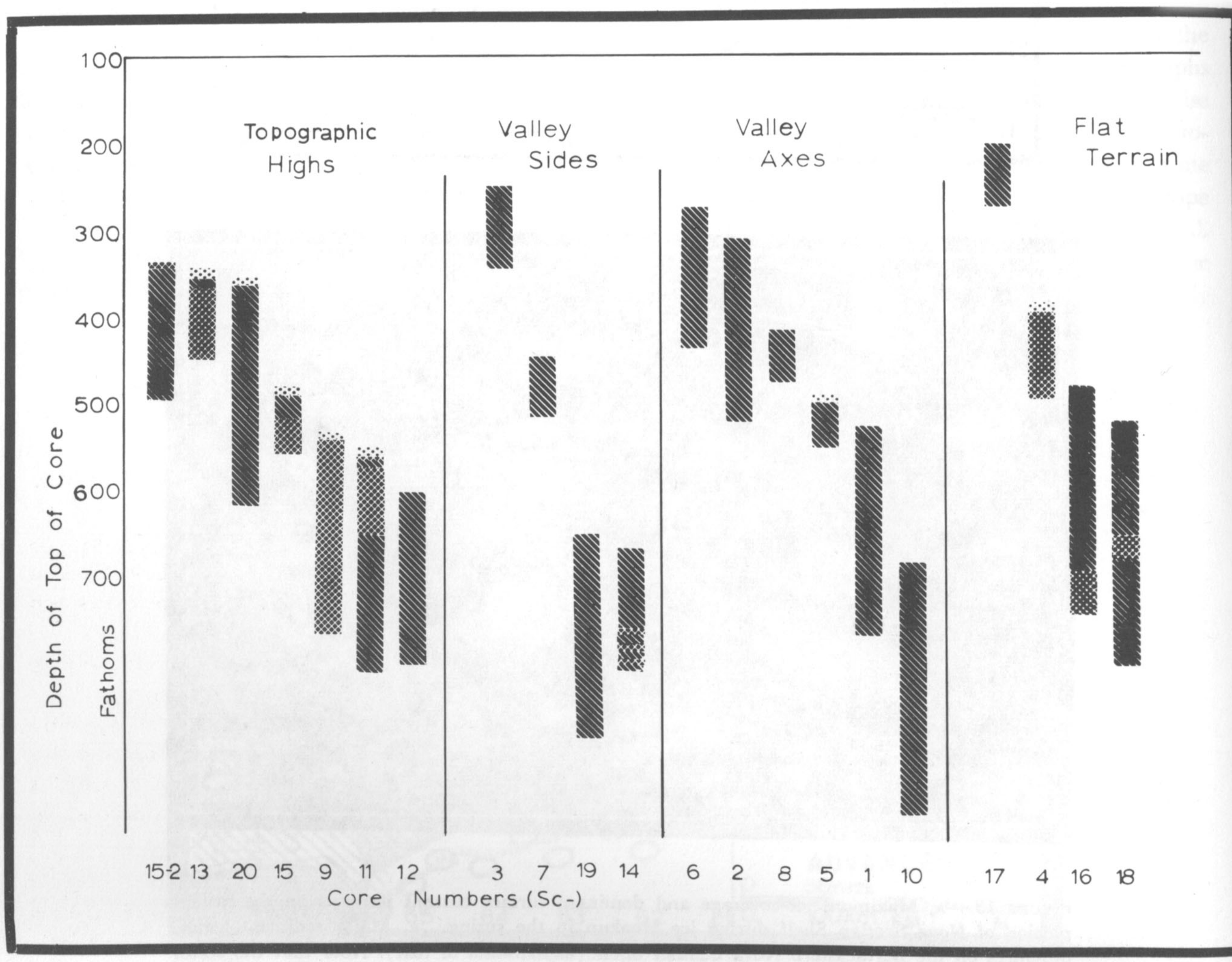



FIGURE 14.—Cores collected on upper and middle slope southeast of Sable Island Bank (Silverberg 1965). Dark cross-hatchure pattern depicts reddish-brown facies; oblique hatchure depicts olive gray facies; stipples denote uppermost sandy facies.

slope adjoining the southern margin of Sable Island Bank and described by Silverberg (1965).

(b) 5 piston cores (Figure 15) collected by Stanley and Swift on the CSS *Hudson* in 1964, along a north-south transect, from the slope due south of Sable Island to the rise.

(c) Cores (Figure 16) collected by Marlowe (1964) in the vicinity of The Gully Canyon and adjacent slope and detailed in James (1966), Stanley (1967) and Stanley and Silverberg (1969).

(d) 30 cores (Figure 17) collected by the Lamont-Doherty Geological Observatory on the slope and rise off Nova Scotia, and examined by Sutton (1964). Selected Lamont-Doherty cores collected in this area have also been described by Ericson et al. (1961), Hubert (1964), Hubert and Neal (1967, and Conolly et al. (1967).

Only those lithologic aspects of cores pertinent to this study are presented in this paper. Detailed graphic and photographic logs of most cores (a) and (c) are available in the references cited above. Logs of cores (d), also available from the Lamont-Doherty Geological Observatory core collection library and from the National Oceanographic Data Center, are included in the Appendix.

### *Four Outer Continental Margin Facies*

Earlier studies have shown that the predominant surficial textural type on the slope and rise is mud (silt and clay, largely of terrigenous origin) with varying, but minor, amounts of gravel, sand, and coarse silt. Thin layers of clean sand, and occasionally gravel, are also noted. Muddy sediments generally display either an olive gray or a reddish-brown coloration. Cores Sc-1 to Sc-20 (Figure 14) and Hud 30-9 to Hud 30-14 (Figure 15) display both sediment types on the slope proper and in The Gully Canyon.

The olive gray mud generally overlies the brown facies (Heezen and Drake 1964; Conolly et al. 1967). The contact between these two sediment types can be sharp or gradational. Interbedded olive gray and brown sediments are noted in some cores. Olive gray mud, generally less than 2 to 3 m thick, covers the reddish-brown unit on much of the upper- and mid-slope region. Occasional thin partings of sand occur within the gray, but more commonly within the brown facies. A third sediment type noted in several cores on the slope is a relatively clean sand unit that occurs in thin laminae (2 to 15 cm) at the uppermost surface. A fourth facies, observed on the upper rise (cores Hud 30-9A, B), is a pale yellowish-brown mud that covers the reddish-brown facies.

A simpified sediment distribution chart of the slope based on the coring program is shown in Figure 18. Both olive gray mud and brown mud and sand-silt-mud facies appear to be irregularly distributed across the slope. The patchy distribution is a function of topography in the sample locality. On the upper slope, for instance, brown sediment was recovered only near the tops of ridges and along relatively flat sections of the slope. Coring suggests that (a) deposition of the olive gray facies has been greater in valleys than on intervalley highs, or (b) that non-deposition or erosion and removal of the gray facies has been more important on topographic highs, or (c) both factors are in force. One core, Sc-16, collected on a relatively undissected sector of the upper slope provides a representative section. Core Sc-16, penetrating both olive gray and brown facies, serves as a base upon which to compare the thickness of the gray sediment. A surficial third facies of clean to muddy sand layers is more frequently cored on topographic highs.

The lithological logs of the CSS *Hudson* short piston cores (Hud 30-9A, -9B, -11, -13, and -14) collected south of Sable Island Bank are shown on Figure 15. The most obvious features are summarized as follows:

(a) The slope core (Hud 30-14) penetrated olive gray, silty to clayey mud,

(b) The base-of-slope core (Hud 30-13) displays the coarsest texture (sand, silt, and pebble fraction present with predominant mud) of the five cores and is brown in color,

(c) The rise core (Hud 30-11), also brown, consists of somewhat fewer coarsely textured horizons,

(d) The two lower rise cores (Hud 30-9A and -9B) are considerably finer grained than (b) or (c), and the uppermost (tan to light yellow-brown) sections are lighter in color than the brown and reddish brown material in (b) and (c).

The cores collected in The Gully Canyon area by Marlowe (1964) are also variable in texture (mud, sand, and pebble fraction) and color (gray, brown, and mixtures thereof). They present color and textural characteristics comparable to those in upper Nova Scotian Slope cores collected by Silverberg (1965). The position and logs of cores collected by

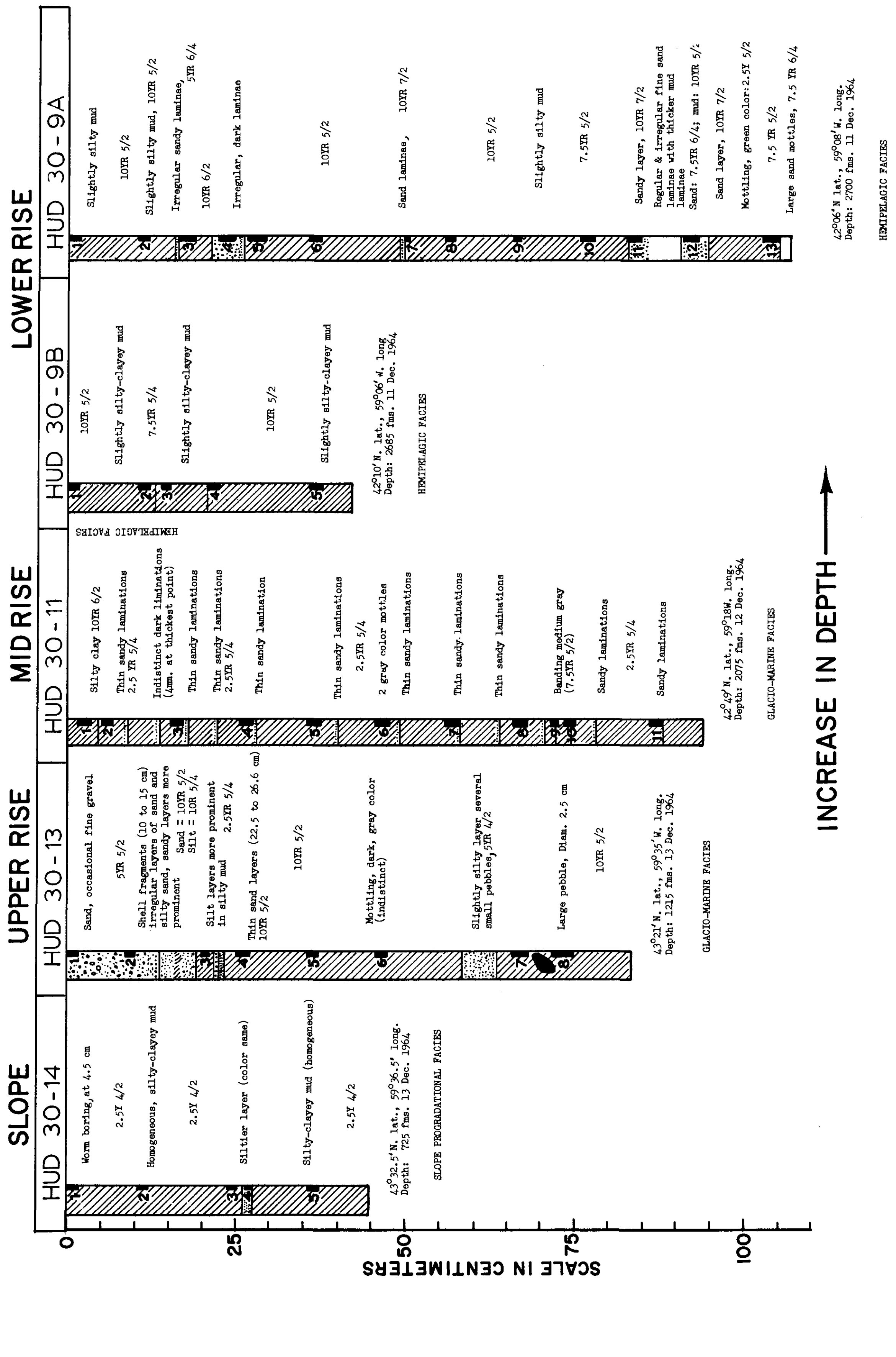



FIGURE 15.—Cores collected along a north-south transect, from the slope due south of Sable Island to the lower rise (location shown on Figure 71). Depth of water increases toward right of diagram.

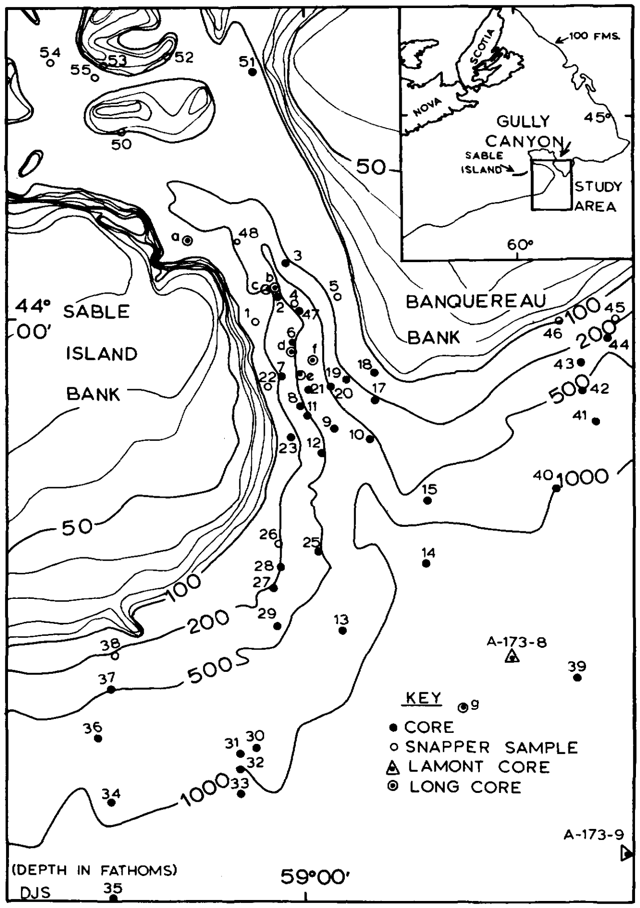



FIGURE 16.—Cores in the vicinity of The Gully Canyon (collected by Marlowe 1964, and others).

Lamont-Doherty Geological Observatory and examined by Sutton (1964, this study) are shown on Figure 17.

### *Physical and Biogenic Structures in Slope Cores*

The occurrence of abundant thin laminations, sandy strata, isolated pebbles, and interbedded gray-and-brown sediment types and the lack of petrographic homogenity clearly indicates that sedimentation rates have fluctuated considerably on the outer margin in the study area. Processes responsible for the downslope transfer of terrigenous sediments have also varied. The presence of laminated (current-produced) sand, silt, and mud units, isolated (ice-rafted) pebbles (Stanley and Cok, 1968, their figure 12) and boulders (Brundage et al. 1967) in mud, contorted (slumped) strata, and graded (turbidite) beds (Stanley 1970) are obvious and frequently observed structures on the Nova Scotian Slope. Bioturbate structures (produced by burrowing organisms) account for still another group of structures commonly visible in cores.

In comparison, cores that consist largely of clay and fine silt, when split, appear homogenous and generally do not reveal internal structures of either sedimentary or organic clearly. X-radiography, a technique that reveals features not apparent to the naked eye, was used in the inspection of both split (method in Bouma 1964) and unsplit cores (Stanley and Blanchard 1967). Internal structures observed in cores Sc-1 to Sc-20 can be grouped broadly into the following categories:

(a) *Regular layering:* alternating light and dark (dense and less dense) bands continuous across the core section.

(b) *Irregular layering:* discontinuous, often lens- or pod-shaped, bands.

(c) *Indistinct layering:* bands which are only faintly distinguishable, or which show gradational contacts.

(d) *Mottling:* pods or irregular bodies of contrasting density which exhibit no preferred orientation in the core. These may be indistinct, displaying no clear boundary with the other material in the sediment, or they may be distinct, with sharp boundaries.

(e) *Flow-in:* undulating or contorted, vertically oriented pattern found near the lower sections of some cores. Flow-in structures are an artifact of coring, i.e., sediment is drawn into the core liner as the coring device is raised from the bottom. Flow-in commonly occurs in instances where the core barrel did not completely enter the sediment.

Internal structures observed in cores Sc-1 to Sc-20 are depicted on Figure 19. It is apparent from this figure that no one internal structure is restricted to a specific sediment facies, although assemblages of primary structures are of some use in distinguishing particular sediment types.

The surface sand facies is easily distinguished. Radiographs show that these sands contain bands of closely spaced fine mottles (burrows in some cases) with scattered, distinct, large patches (aggregates of granules and small pebbles).

The olive gray, muddy sediment type is characterized by a general scarcity of internal structures. Some cores show sections of regular and irregular layering

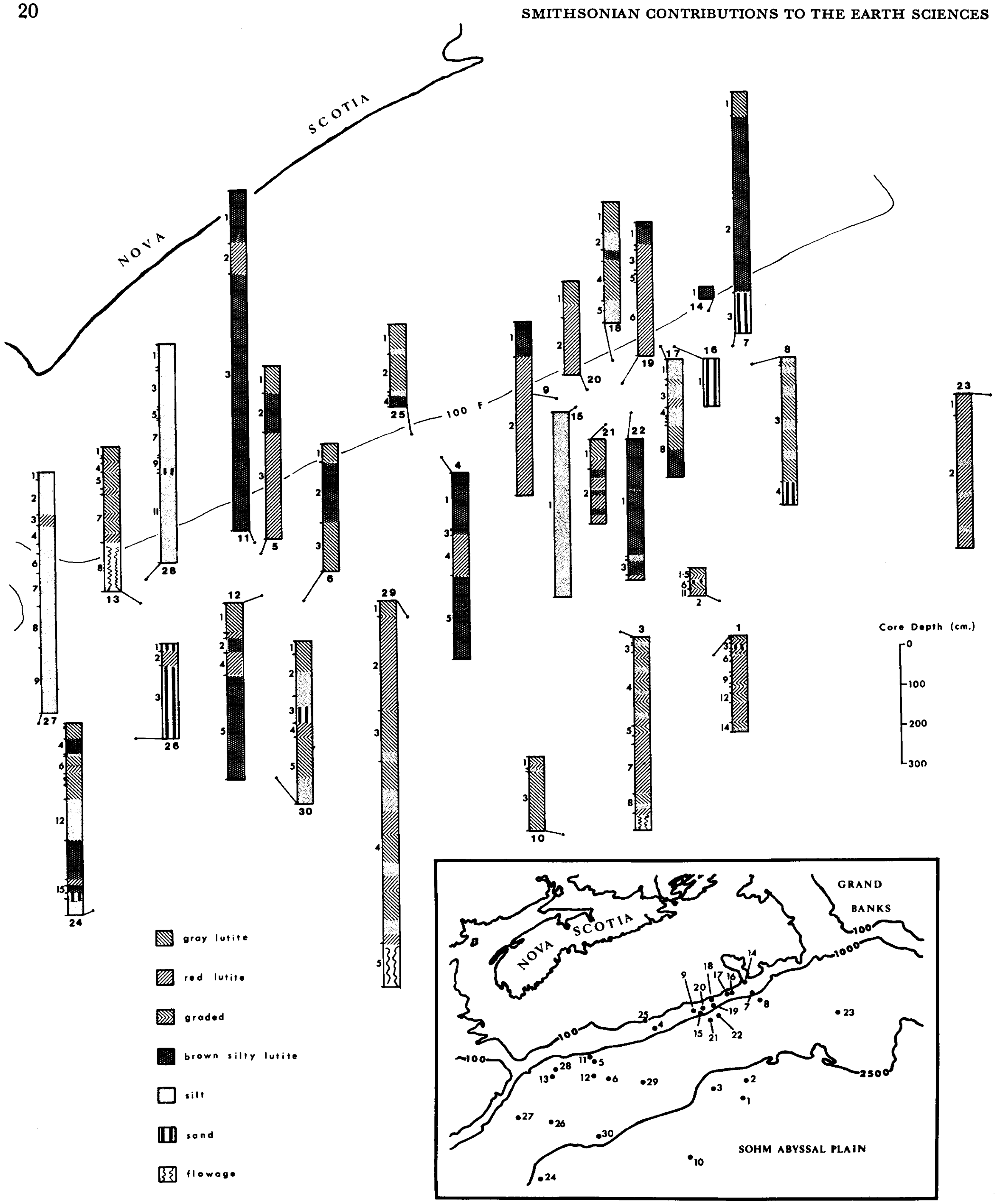



FIGURE 17.—Cores on the Nova Scotian slope and rise and in the Sohm Abyssal Plain collected by Lamont-Doherty Geological Observatory and examined by R. Sutton (lithologic description and appropriate Lamont core number are provided in the Appendix).

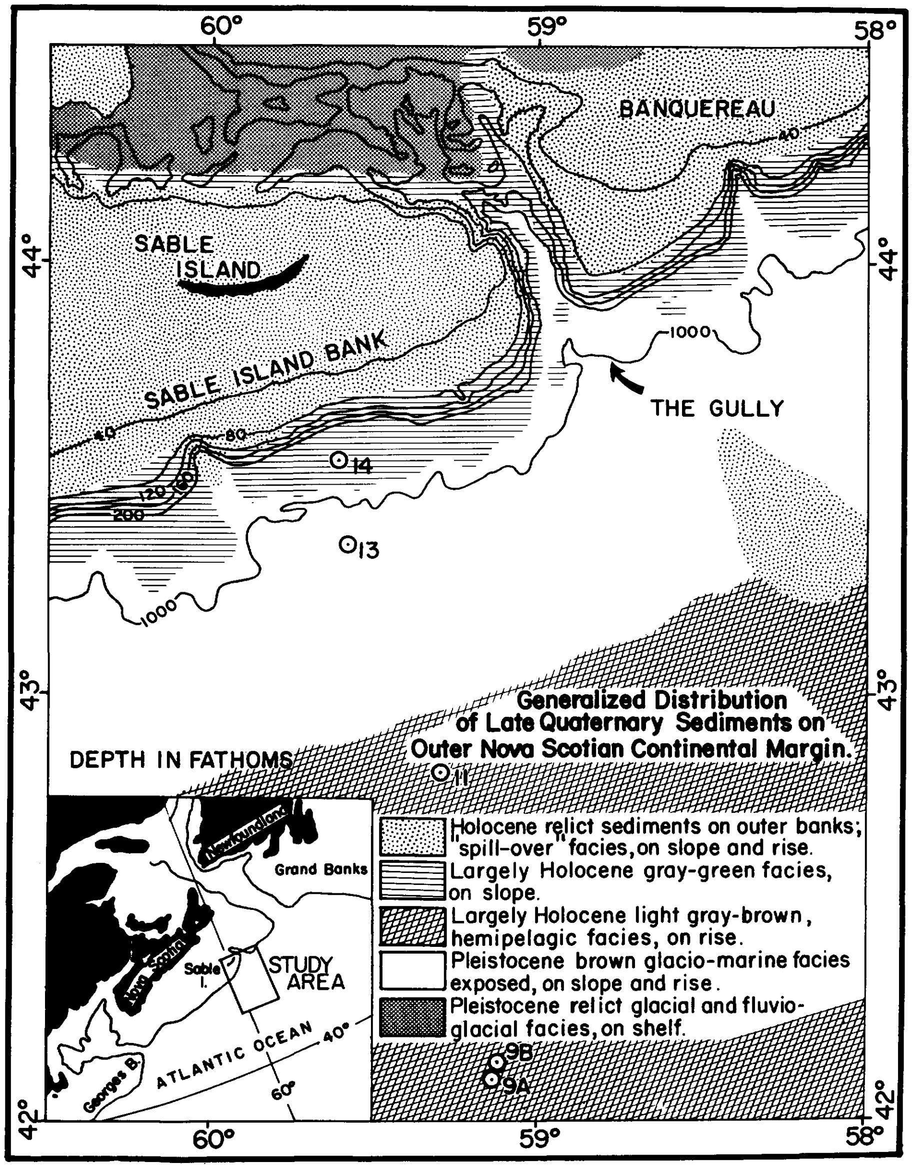



FIGURE 18.—Map showing generalized distribution of late Quaternary surficial sediments on the outer continental margin off Nova Scotia (Stanley and Silverberg 1969).

(e.g., Sc-5, Sc-8, and Sc-15) but for the most part, the olive gray facies consists of long sections of homogenous sediment. The widely scattered, indistinct, large and small mottles and irregular layers (e.g., Sc-1, -2, -3, -7, and -10) are probably the result of bioturbation.

The major characteristics of the brown sediment type are a widespread occurrence of distinct mottles (in some cases, pebbles), and a sediment column comprising numerous, thin alternating zones of varying texture and stratification. Regular layering is most extensive in core Sc-4, and distinct mottling is noted at the base of core Sc-16. The longest section of brown sediment penetrated (core Sc-9) shows the diversity of lithologies characteristic of this facies.

In muddy sediments the burrowing and feeding habits of benthic fauna can completely modify physically produced stratification features by shifting and reworking the sediment. Moore and Scruton (1957) noted

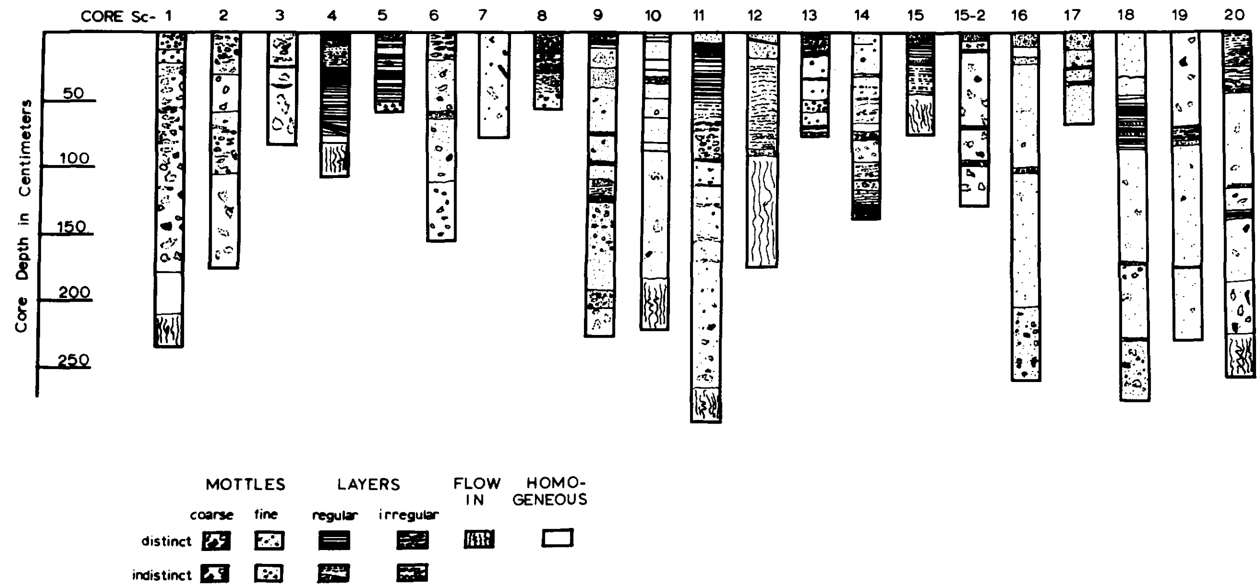



FIGURE 19.—Nova Scotian Slope core (Sc) logs showing sedimentary and biogenic structures as observed in core photographs and X-radiographs.

that a complete gradation (from regular and irregular layering, to distinct and indistinct mottling, to homogeneous sediment) can develop depending upon the rate of sedimentation, sediment type, and intensity of faunal activity. Reversal of this process, i.e., the layering of an originally near-structureless sediment section by faunal activity, can also be induced. Preservation of original primary sedimentary structures generally occurs in areas where sedimentation rates are particularly high or where bioturbation by mud-feeding organisms is uncommon or both.

Interpretation of slope sediments in the light of these observations indicates that the olive grey sediment type was deposited rather slowly. The occurrence of indistinct large mottles indicates that the process of homogenization did not go to completion. The fine nature of the regular layering preserved in some core sections suggests that there were periods of less intense bioturbation or somewhat higher rates of sedimentation.

The disruption of layering is also apparent in the older brown sediment. However, preservation of thicker sections of stratified layers indicates that rates of sedimentation were higher during deposition of this facies. The variable character of the preserved strata, which include sandy layers, irregular and regular layering, and indistinct mottling, is evidence that the rate of deposition of the brown sediment was not constant, but apparently fluctuated considerably. The occurrence of sand and pebbles in the brown sediment, as noted on the radiographs is another significant difference between the two types of sediment. The higher sedimentation rate and variable nature of the brown sediment is also confirmed by a textural study, as demonstrated in following section.

### *Sediment Sequences on the Lower Rise and Abyssal Plain*

The following is a summary of descriptions of 30 cores collected on the slope, rise, and Sohm Abyssal Plain south of the Nova Scotian Shelf.

A typical sedimentation rhythm, or sequence, in Sohm Abyssal Plain cores and in certain cores of the Nova Scotian Lower Rise consists of the following:

| | | |
|---|---|---|
| TOP | 1. Gray foram lutite | ($Te_4$) |
| | 2. Pale red foram lutite, grades down to darker red at base | ($Te_3$) |
| | 3. Mottled red lutite | ($Te_2$) |
| | 4. Red lutite; bedding absent; forams and mottling rare | ($Te_1$) |

| | | |
|---|---|---|
| | 5. Laminated silt | (Td) |
| | 6. Silt with current ripples, clay blebs, and forams | (Tc) |
| | 7. Silty sand usually laminated | (Tb) |
| BOTTOM | 8. Sand | (Ta) |

The symbols closely follow those proposed by Bouma (1962). The lower sand (Ta) is interpreted as the lower portion of a turbidite, indentified by relatively poor sorting, absence of bedding, and rarity of forams and burrows (Figure 20). Rapid emplacement would best explain this combination of features. The silty sands (Tb) and rippled and laminated silts (Tc-Td) represent the fining upward and progressive changes in the flow regime expected during the later phases of turbidity current flow (Figure 21). The red lutite unit ($Te_1$-$Te_3$) is interpreted as the fallout of finer particles suspended in the water following the emplacement of the coarser sediment. This fallout, rapid at first ($Te_1$), declines progressively ($Te_2$) after several hours (or days) so that the sedimentation rate is low enough to permit reworking by burrowers (Figures 22, 24). Red lutite contribution gradually

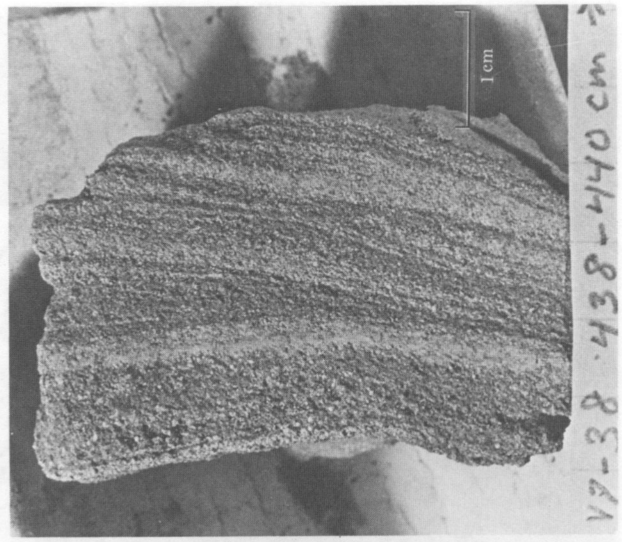



FIGURE 21.—Cross-laminated, fine-grained, foram-rich sand (Tb-Tc). Locality 24 (Lamont core V7-38) at 438 to 440 cm depth in core.

decreases ($Te_3$) so that the nonturbidite contribution ($Te_4$) takes over as an increasing percentage of the total contribution (Figures 25). The gray foram lutite is interpreted as a nonturbidite accumulation. The increased foram content ($Te_2$-$Te_4$) is cited as evidence of this decreasing sedimentation rate.

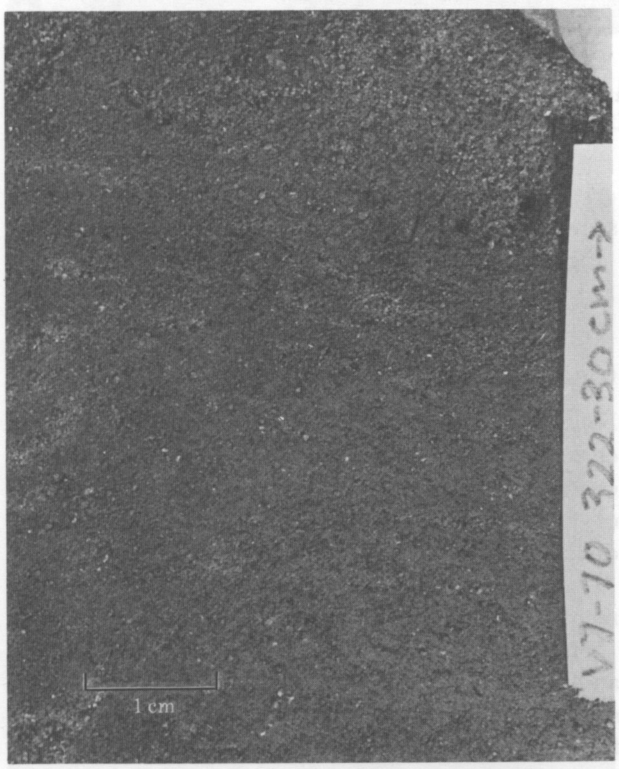



FIGURE 20.—Brown sandy silt (Ta). Locality 28 (Lamont core V7-70) at 322 to 330 cm depth in core.

Sediment sequences in the lower rise tend to be thicker (100 cm or more) and contain more sand and silt than those of the abyssal plain (Figure 17). The southward thinning of the sequences is cited as evidence of (a) the northward source of the Ta-$Te_3$ units and (b) dominant dispersal patterns toward the south. Just north of the New England Sea Mounts, thick gray foram lutites may have originated by processes other than turbidity currents. In some places, numerous silt laminae and beds are associated with $Te_2$-$Te_3$ units suggesting that bottom currents, winnowing sediment, have removed some of the finer fractions. It is conceivable that this reworking would, over a period of time, produce a carpet or veneer of grains too coarse to be moved by bottom currents. This lag deposit would, in essence, form a protective cover over finer grade sediments beneath it. Resuspended fines are probably transported by bottom currents some distance from the initial site of Ta-Td bottom current resuspension would account for the turbidite deposition. This combined turbidity current-

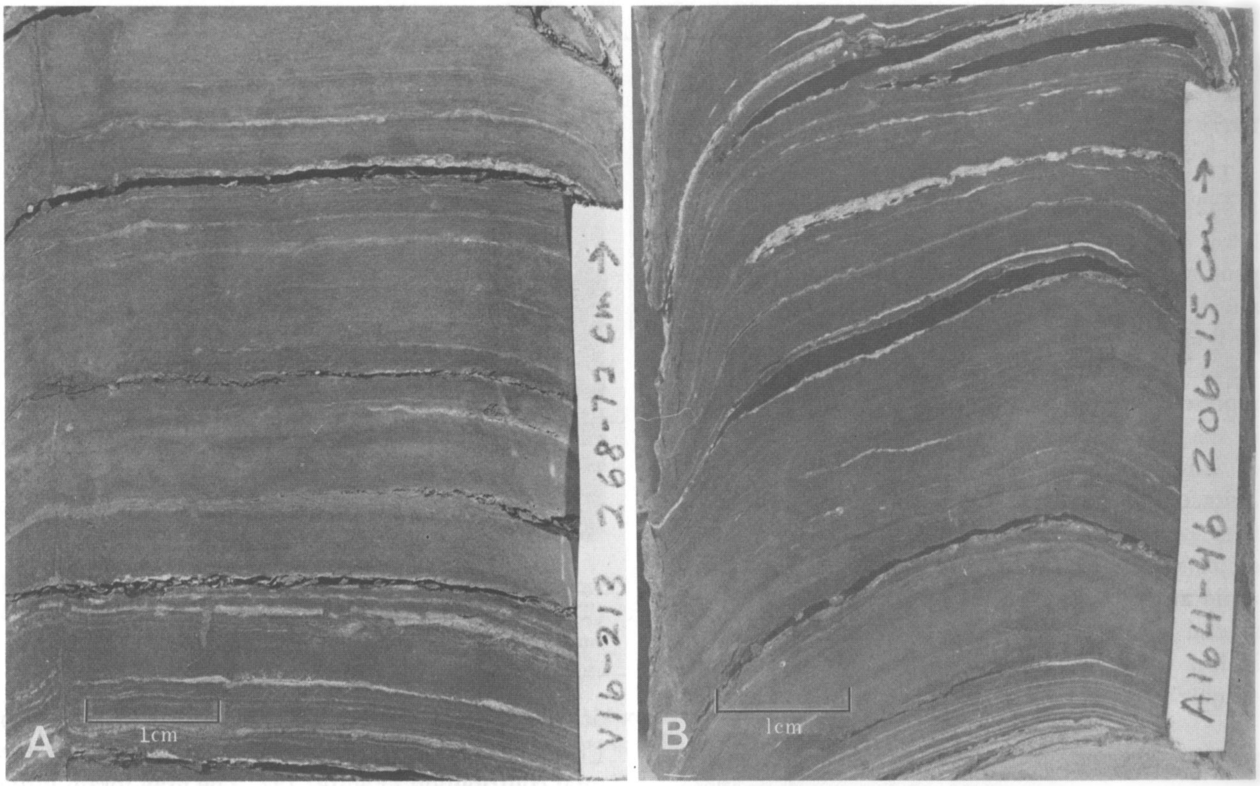



FIGURE 22.—A, Interbedded red lutites and laminated silts (Td-$Te_1$). Locality 29 (Lamont core V16-213) at 268 to 272 cm depth in core. B, Locality 1 (Lamont core A164-46) at 206 to 215 cm depth in core.

presence of red lutite laminae in many parts of the Sohm Abyssal Plain.

The frequent absence of burrowing in sands and silts could be interperted as a preference of the organisms for lutite over sands and silts rather than an indicator of sedimentation rate. This hypothesis, however, is dismissed because burrowed silt units occur on the upper rise (Figure 26).

Many of the sedimentation cycles, or rhythms, are incomplete. Those in the more distal parts of the abyssal plain lack the lower Ta or Ta-Tb sections. These deposits are thus considered to be the finer grained deposits from a weaker, diluted current. Elsewhere, on the other hand, upper units may be missing. In some cores virtually every rhythm is truncated at the top, suggesting greater current activity than at nearby localities where the rhythms are virtually complete. Local variations of bottom topography might explain these differences. Where coarser sediments comprise the upper part of the rhythm, and subdivisions are not clear-cut, only the symbol "Te" is used (Figure 23).

## Textural Analyses of Outer Margin Sediments

### *Outer Shelf Near Sable Island Bank*

Following sections summarize petrographic studies of core and bottom grab samples collected on the outer continental margin southeast of Nova Scotia. A total of 114 samples (Figure 3) collected on and in the direct vicinity of Sable Island Bank were examined (James 1966, James and Stanley 1968). Size measurement was obtained with a rapid sediment analyzer (Schlee 1966a); a size interval of $\frac{1}{4}\phi$ was selected and textural parameters including mean, sorting, skewness, and kurtosis were calculated using the formulae of Folk and Ward (1957).

Sand is the dominant textural grade covering most of the banks (Figures 8, 29). Mean grain size is independent of depth. In general, medium- to coarse-

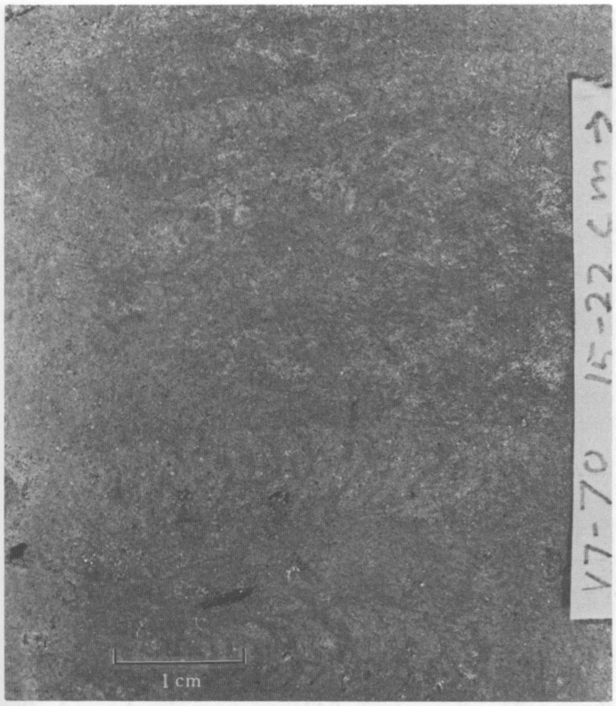



FIGURE 23.—Poorly sorted silt with faint burrows (Te). Locality 28 (Lamont core V7-70) at 15 to 22 cm depth in core.

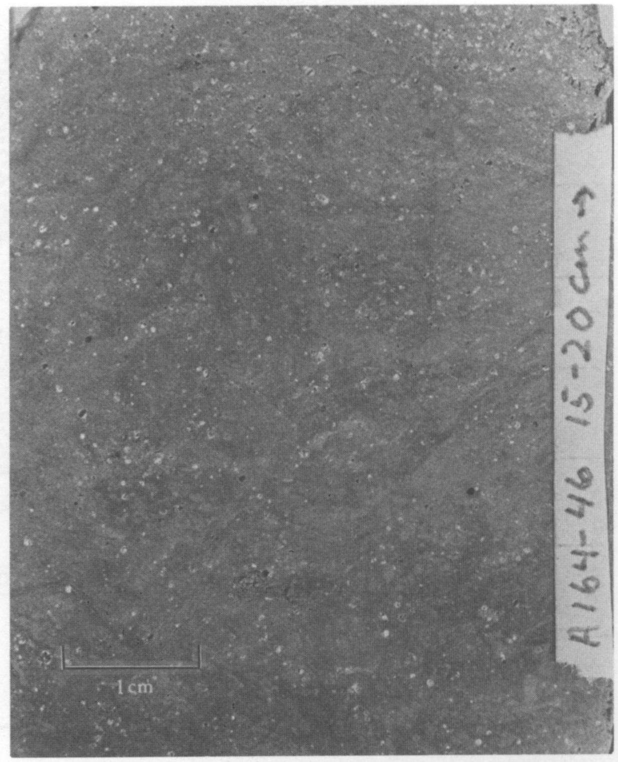



FIGURE 25.—Gray foram-rich lutite with faint mottling due to burrowing ($Te_3$-$Te_4$). Locality 1 (Lamont core A164-46) at 15 to 20 cm depth in core.

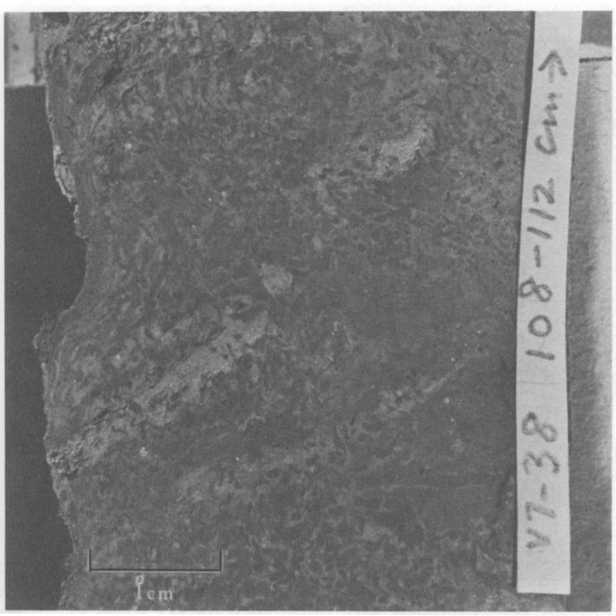



FIGURE 24.—Micro-mottling in red lutite ($Te_2$). Locality 24 (Lamont core V7-38) at 108 to 112 cm depth in core.

grained sand occupies the area north of a line running east northeast-west southwest across the bank through Sable Island; south of the line, sand is fine to very fine grained. The best sorted sand (very well to well sorted according to Folk and Ward 1957, and Folk 1966) forms a broad band trending east-west across the center of the bank, whereas poorly sorted sediment is present north and south of Sable Island (Figure 30). Finely skewed sediment covers the western part of the bank and an area east of the east terminal bar, and coarsely skewed sediment is present directly south and northwest of Sable Island.

Textural patterns present on the island continue offshore (James and Stanley 1967). Sand north of the island is coarser than that to the south. Best sorted sand is present off the southeastern beach and east bar. Finely skewed sediment dominant on the southwestern part of the island is also present seaward off the beach. Sorting has been found to be more sensitive to environment than either mean grain size or skewness; sand in

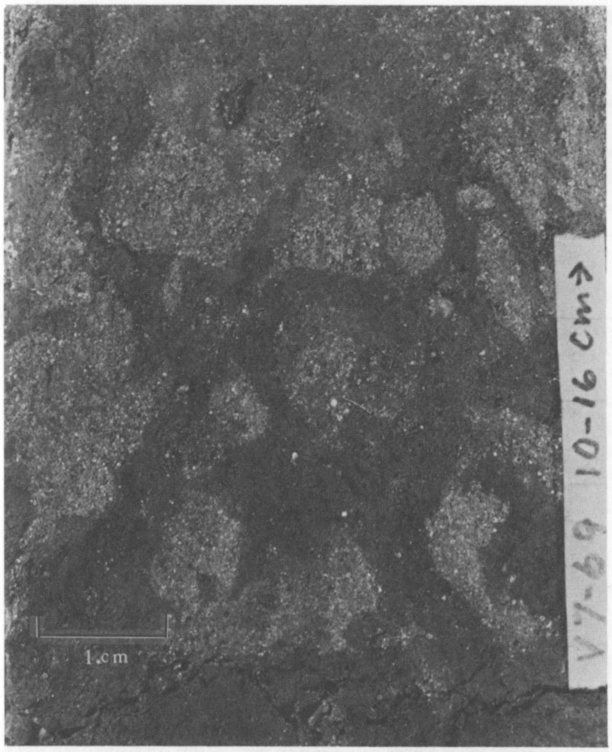



FIGURE 26.—Brownish gray clayey foram-rich silt with mottling ($Te_3$-$Te_4$). Locality 27 (Lamont core V-67) at 10 to 16 cm depth in core.

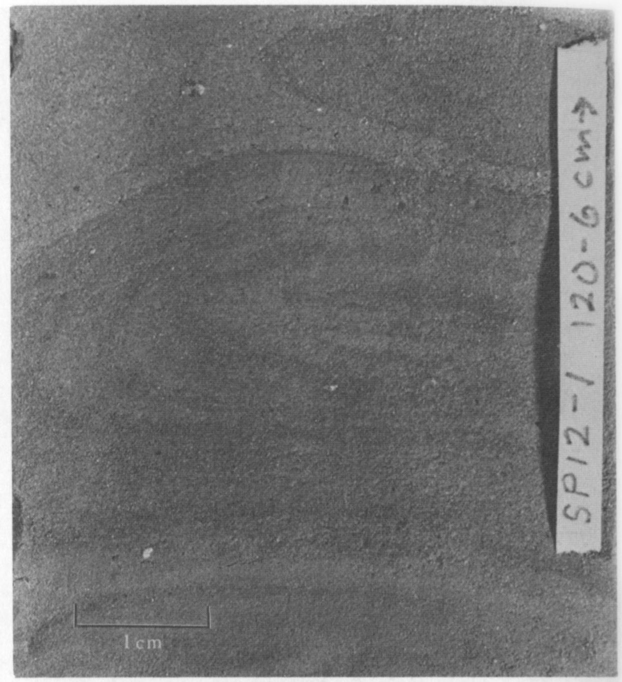



FIGURE 27.—Recumbent fold structures in slumped silty lutite. Locality 19 (Lamont core SP12-1) at 120 to 126 cm depth in core.

the predominantly eolian environment (dunes cover much of the island) is consistently better sorted than beach and offshore sand.

Textural parameters of the sediment on Sable Island Bank are, in general, interrelated: coarse sand generally is poorly sorted and coarsely skewed; fine sand commonly is well sorted and finely skewed. The local variations superimposed on this pattern can be used to determine directions of sediment movement.

### *Gully Trough and The Gully Canyon*

The size distribution of samples collected in The Gully Canyon (Figure 31) and its shallow extension, the Gully Trough (Figure 32) on the shelf, are plotted. Most samples are admixtures of sand, gravel, and mud as shown on a Folk (1954) textural triangle.

In the Gully Trough the textural distribution appears to be depth dependent. At depths of less than 80 m sediment is dominantly sand; samples below 180 m in the trough contain a predominant mud (silt and

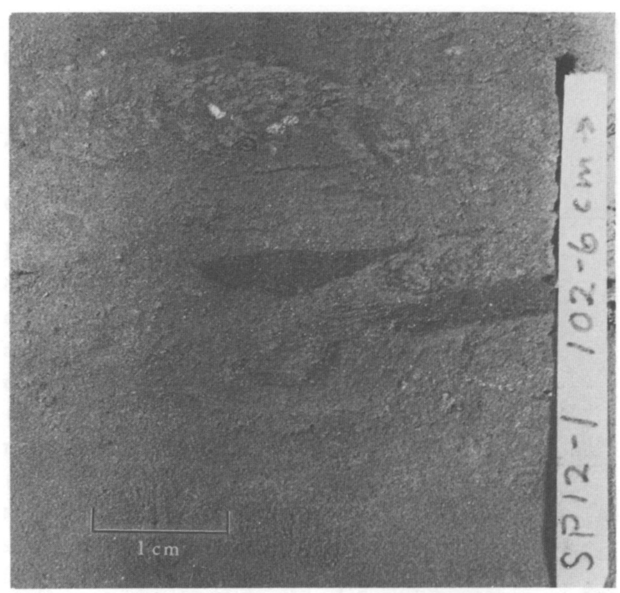



FIGURE 28.—Slumped silty lutite with darker zones of lutite cut by burrows. Locality 19 (Lamont core SP12-1) at 102 to 106 cm depth in core.

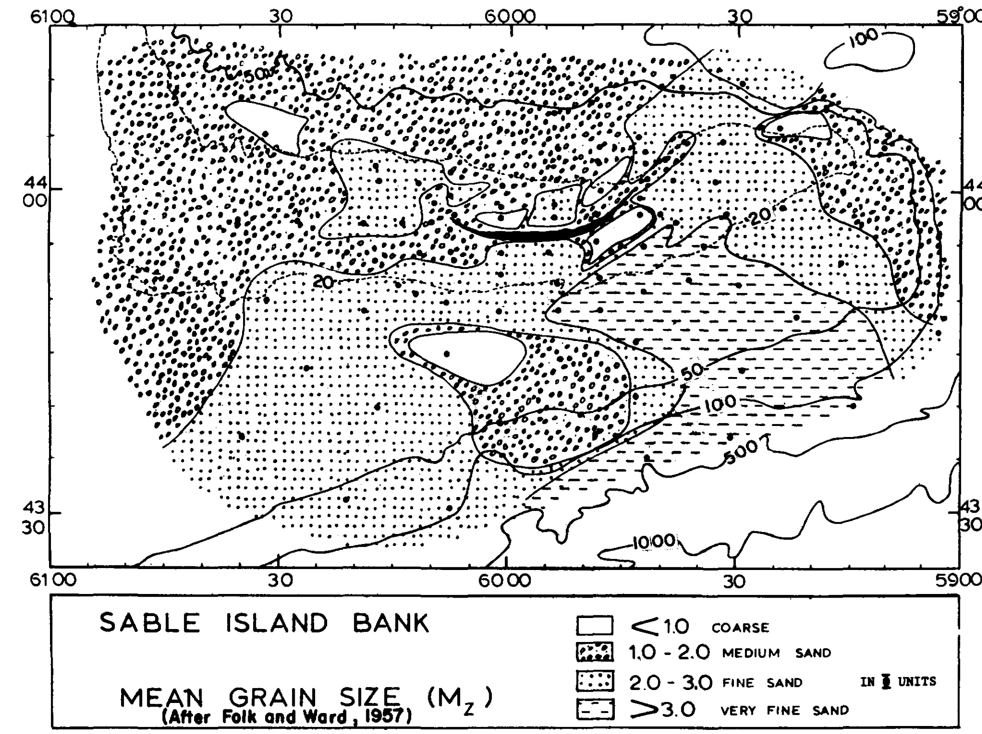



FIGURE 29.—Regional variation of mean grain size of surficial sediments on Sable Island Bank and adjacent area (James and Stanley 1968).

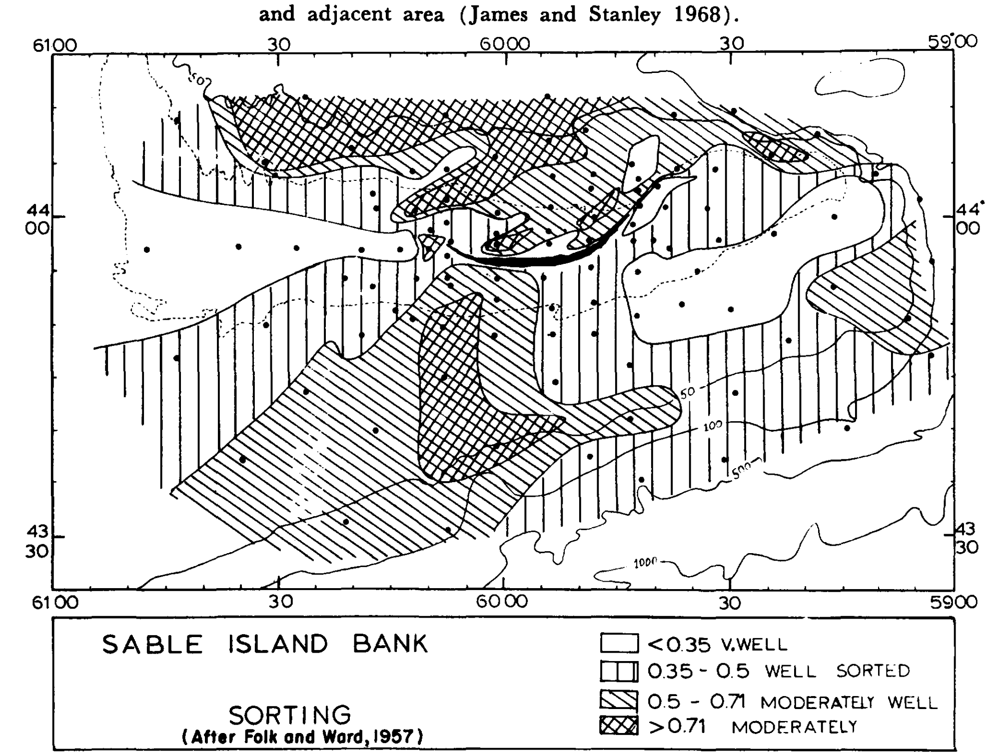



FIGURE 30.—Relative sorting (calculated after Folk and Ward 1957) of sediment on Sable Island Bank (James and Stanley 1968).

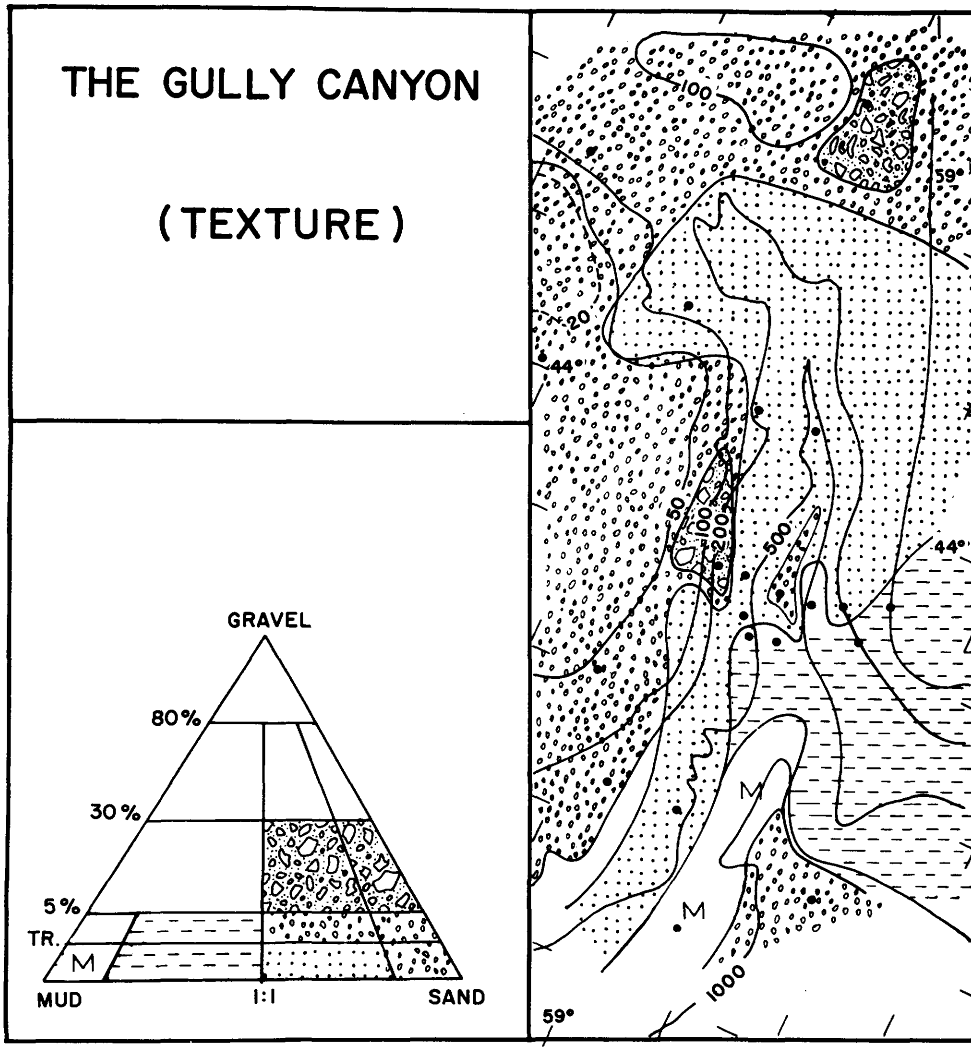



FIGURE 31.—Textural distribution of surficial sediment in The Gully Canyon (classification after Folk 1954). See Figures 3 and 16 for sample location.

clay) fraction. The textural type is generally more varied between 80 and 180 m: sand and gravel occur between 80 and 140 m; sand, gravel and mud between 120 and 160 m, and sand and mud between 160 and 180 m. There is some overlap of these textural zones. Small bank tops and isolated hummocks within the Gully Trough are covered with sand. Intermediate depths contain sand and gravel with or without a mud admixture, and below 160 m, as well as in isolated basins, mud is prevalent. Sediment on the western section of this region, between Banquereau Bank and Sable Island Bank, comprises gravel to a depth of 175 m and clean sand in water deeper than 260 m.

A preliminary examination of cores collected in The Gully Canyon indicates that sediment consists mainly of sand and mud with minor amounts of gravel and cobble-size particles (Marlowe 1964). There appears to be a general increase in mud (silt and clay) content with increasing depth. Muddy sand predominates at a depth of 900 m on the east wall of the canyon and again at a depth of 2,860 m in the axis. Clean sand is found at 1,400 m in the axis of the canyon.

Samples analyzed in detail (James 1966) and plotted on a Folk (1954) textural triangle show a local variation superimposed on the general trend of

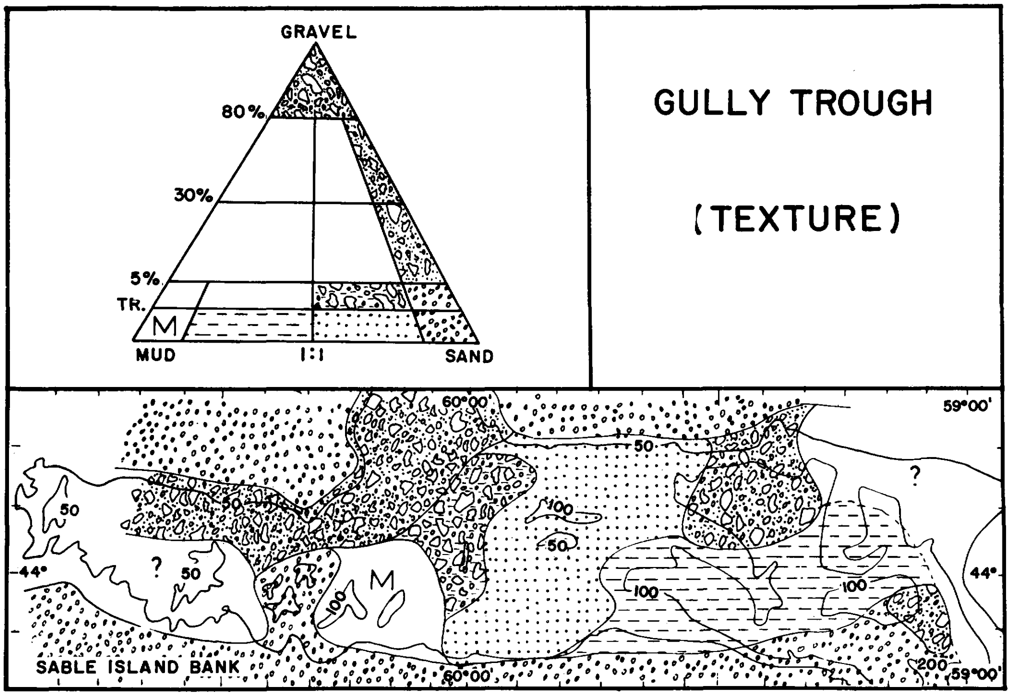



FIGURE 32.—Textural distribution of surficial sediment in the Gully Trough north of Sable Island Bank (classification after Folk 1954). See Figure 3 for location.

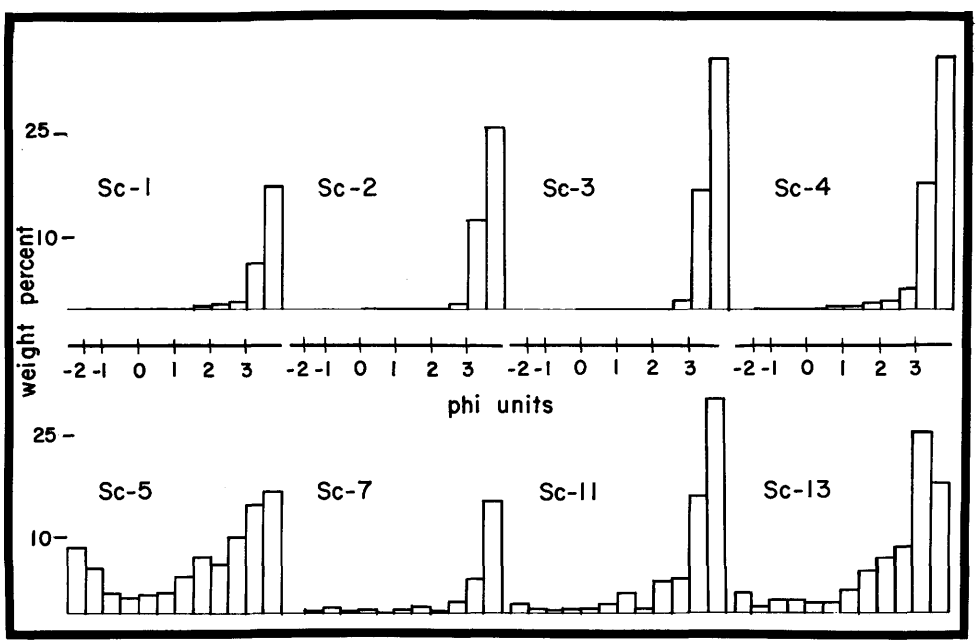



FIGURE 33.—Grain-size histograms of surficial sediment collected with a bottom grab at core locations on the upper and middle continental slope off Sable Island Bank.

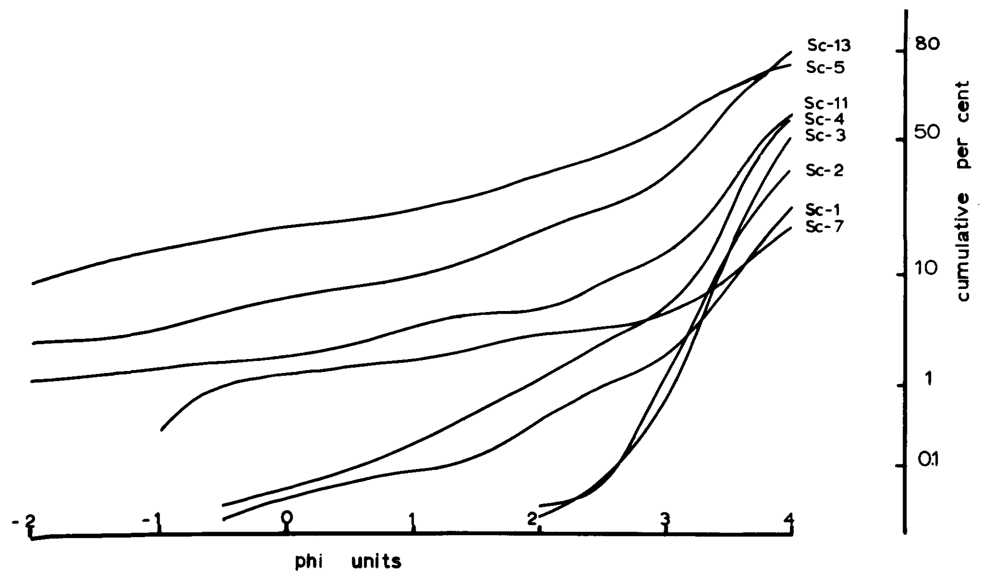



FIGURE 34.—Cumulative coarse fraction size curves of surficial sediment collected with a bottom grab at core locations on the upper and middle continental slope off Sable Island Bank.

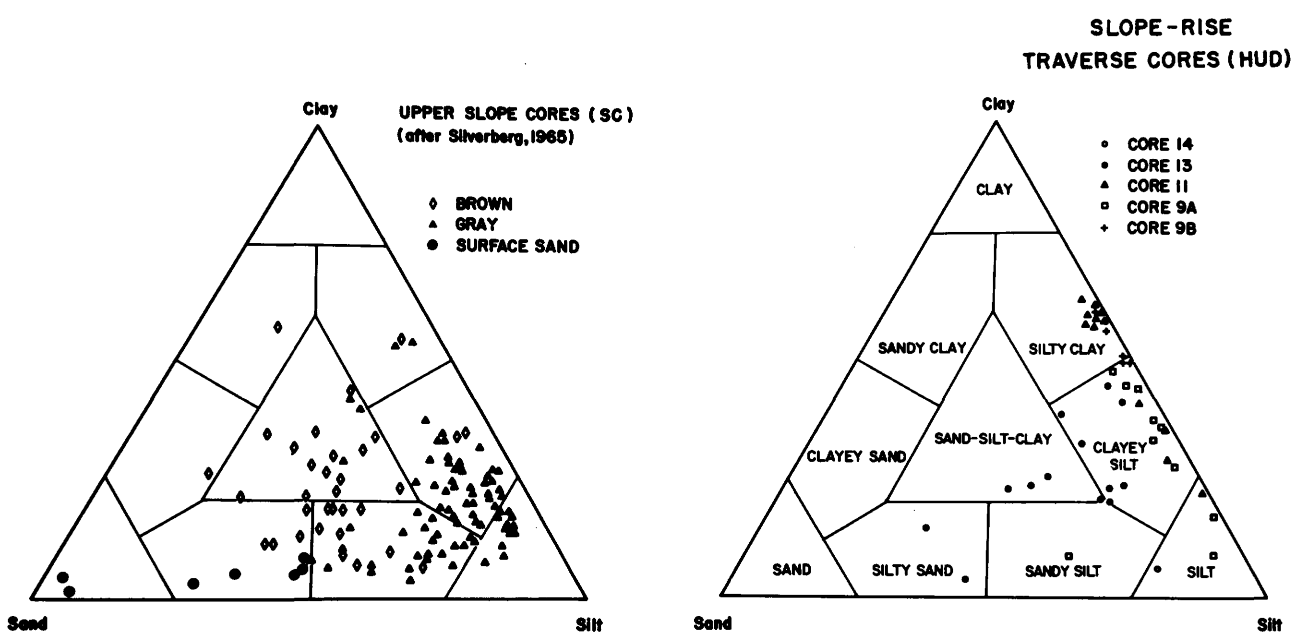



FIGURE 35.—Size distribution of upper and middle slope (Sc) cores are shown on left textural triangle (classification of Shepard 1954). Triangle on right shows textural distribution of cores collected on slope-rise traverse (see Figure 71).

decreasing grain size with increasing depth (Figure 31). Sable Island Bank above 200 m and the upper reaches of The Gully Canyon are composed primarily of sand or sandy gravel. Most of the northern portion and the west wall of the canyon are covered with muddy sand. A zone of sandy mud drapes from the top of Banquereau Bank, down the east wall, and across the mouth of the canyon. Mud is predominant west of the axis near the mouth of the canyon.

### *Continental Slope South of Sable Island Bank: Upper Slope Samples*

The grain size distribution of surficial samples recovered with a Dietz-Lafond snapper grab samples used as a trigger for cores Sc-1 to Sc-20 was measured. Size-frequency histograms of these surface sediments, plotted in Figure 33, show that two groups of sediment can be distinguished on the basis of textural examination. Samples Sc-5 and Sc-13 from the relatively clean surface sand layer are relatively coarse-grained and show a small secondary mode in the coarse sand and fine pebble range; sorting is poor. The second group of sediments comprises predominantly very fine sand with only traces of coarse sand. Cumulative frequency curves, plotted on a probability scale (Figure 34), show the spread of the size classes and indicate the poor sorting of the surficial sediment. Samples Sc-2 and Sc-3 are somewhat better sorted but contain less sand (the modes lie in the silt range). In general, coarser-grained sediments are more poorly sorted than those which are finer.

Samples from cores Sc-1 to Sc-20 were selected at 10 cm vertical intervals, and these were dispersed, centrifuged, and sieved (method in Silverberg 1965). Textural analyses serve to distinguish a brown and olive gray facies: the gray sediment contains mainly very fine-grained sand, between 105 and 63 microns, and the grain-size distribution is relatively uniform (most olive gray samples would be classified as silt, clayey silt, and sandy silt). On the other hand, the brown sediment sand fraction, also largely fine-grained, does contain a somewhat higher amount of coarse sand. The brown- facies also displays a greater sample-to-sample grain-size variation. Analysis of the uppermost surface sand facies shows that its size distribution is similar to that of most sands of the brown facies.

A size-fraction coarser than 2 mm, mostly in the granule range, was recovered in some samples; the grain-size distribution shows a continuum between granules and the coarse sand grades. There is no strong indication of bimodality.

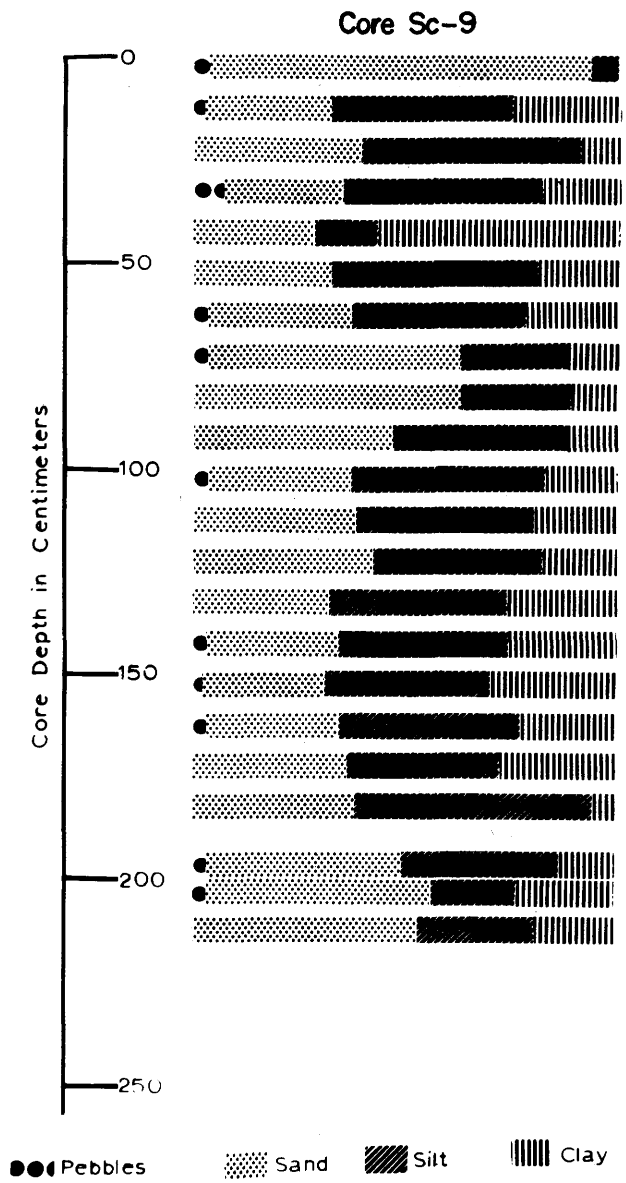



FIGURE 36.—Textural variation within an upper slope (Sc-9) core penetrating a surficial sand layer above the reddish brown section (see also Figure 14).

The size distribution of 117 upper slope core samples is plotted on a triangular textural diagram (see left triangle in Figure 35). The pebble fraction has been included with the sand component. Each sediment

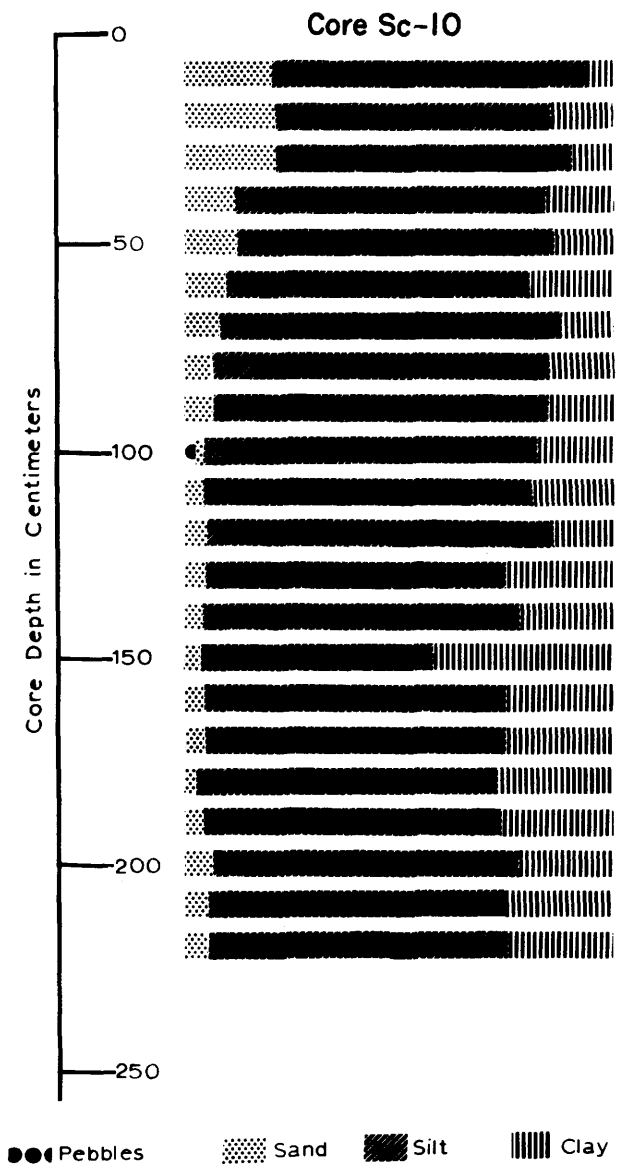



FIGURE 37.—Textural variation within an upper slope (Sc-10) core penetrating an olive gray section (see also Figure 14).

type (surface sand facies, and brown and gray sediment types) is depicted on a textural triangle (classification after Shepard 1954). The surface sandy facies comprises sand and silty sand; the brown facies samples occupy mainly sand-silt-clay, sandy silt, and sand positions on the triangle; and the olive gray sediment type generally comprises silt and clayey or sandy silt.

It is readily apparent that the brown sediment type shows a more variable textural distribution than does the gray. There are some "anomalous" brown sediment samples such as Sc-18-175 and Sc-4-100; these are markedly less sandy than most such samples. The former sample is from a brown layer within a core of olive gray sediment and the latter from a core showing laminations. Samples of olive gray sediment tend to be concentrated about the silt end-member, but show a continuous scattering toward the sand apex.

The textural variation in several slope cores is illustrated in logs in Figures 36, 37, and 38. The upper surficial sediment of core sections in occasionally more sandy than lower portions, as shown in cores Sc-9 and Sc-10. There are, however, cores of olive gray sediment in which this tendency is reversed. In general, core sections of the brown facies (Sc-9) are more sandy than those of the olive gray facies (Sc-10), but again some exceptions to this are noted. The vertical variability in texture is considerably greater within brown than in the olive gray sediment sections. The logs also show that the pebble fraction is common in the brown facies (Figures 36, 38) and rare in the olive gray (Figure 37.) Noteworthy is the abrupt change in texture between the gray and brown layers (note change at about 210 cm in Core Sc-16, Figure 38).

### *Upper Slope to Lower Rise Traverse*

Samples from the five short piston cores (Hud 30-9A to -14), selected at 2 to 10 cm intervals (Figure 15) were sieved and centrifuged to determine grain-size data. Methods are the same as those to examine the upper slope (Sc) cores. It is interesting that resulting textural data is closely comparable to that obtained in the study of cores Sc-1 to Sc-20.

The sand-silt-clay ratios of these traverse core samples (data shown on right triangle in Figure 35) indicate that the bulk of material consists of clayey silt. The olive gray slope core (Hud 30–14) contains some sandy silt and pure silt; most of the sand fraction is of very fine sand grade. The brown upper rise cores (HUD 30–13 and HUD 30–11) contain more poorly sorted sand fractions. In addition, core Hud 30–13 contains pebbly horizons and a large proportion of sediment in the sand-silt-clay class. The two upper rise cores are texturally dissimilar; the shoaler, more nearshore one (HUD–30–13) contains up to 80 percent sand and also pebbly horizons. In both cores,

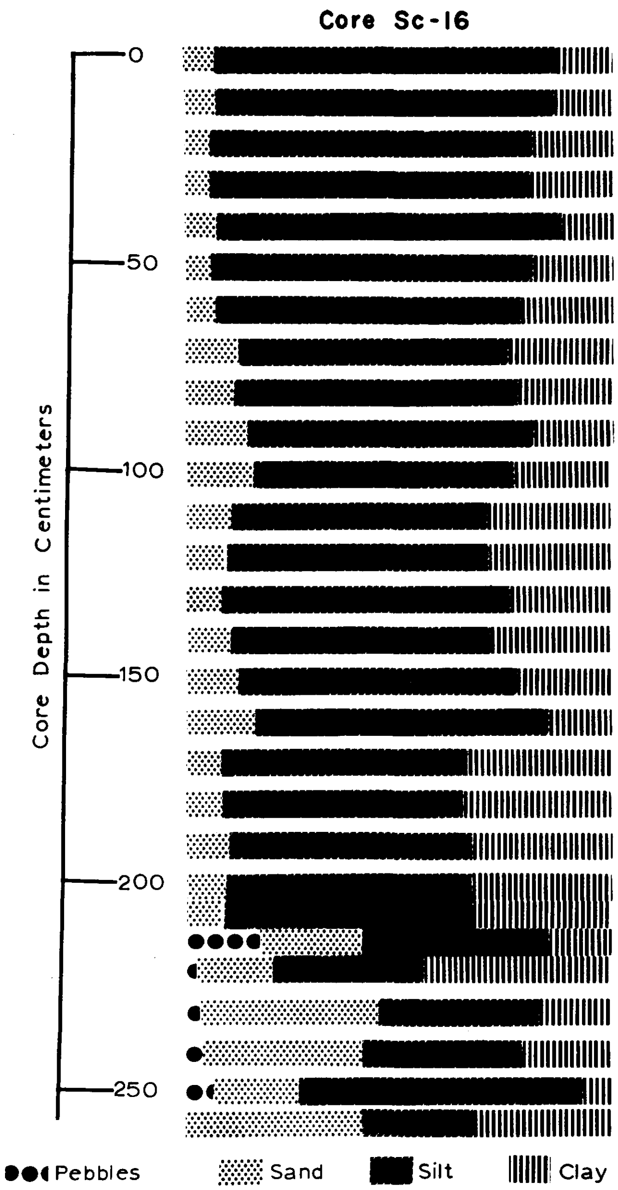



FIGURE 38.—Textural variation within an upper slope (Sc-16) core penetrating 210 cm of olive gray section above the reddish-brown facies. This core displays a representative and reasonably complete section of late glacial to modern sequence on the slope south of Sable Island Bank.

however, the sand fraction is distributed more or less equally over all five Wentworth-Udden grades.

The two tan and yellowish-brown lower rise cores consist of well-sorted very fine, silty clay, clayey silt, and silt, and are fairly uniform except the base of core HUD 30–9A which is possibly a stratum of turbidite origin.

An analysis of the textural parameters of samples from 30 Lamont-Doherty cores collected on the slope, rise, and abyssal plain south of Nova Scotia shows no obvious differences that are strictly related to water depth (Table 1). These outer margin core samples are generally finer grained and less well sorted than adjacent shelf deposits. Sedimentation units on the slope and upper rise are coarser grained than those on the lower rise and Sohm Abyssal Plain. The variability of sorting values provides a means of distinguishing sediments from the different environments (this variability probably reflects differing modes of sediment transport processes). Kurtosis values of slumped (contorted) and of turbidite (graded) sediments are significantly lower than those moved and modified by marine currents (laminated). Variation in grain roundness does not appear to bear any relation to the environmental province or mode of origin but is believed to reflect the character of the original sediment sources.

## Mineralogical Composition of Outer Margin Deposits

### *Sable Island Bank Sediments*

The composition of light and heavy minerals of the sand-size fraction (0.062–2.00 mm) of surficial samples collected on Sable Island Bank was examined. Iron-stained quartz is by far the most abundant sand-size component on Sable Island Bank. Its distribution and that of the less abundant feldspar (generally $< 15$ percent), also coated with ocherous hematite, is variable on the bank (James and Stanley 1968, their figure 6). Shell fragments of sand to pebble size (ranging from $< 1$ to $> 10$ percent of the total sample), particularly those in shallow water, show evidence of considerable wear due to abrasion as a result of sediment transport. The percent of mica ranges from trace to 5 percent.

The transparent heavy mineral suite is dominated by garnet ($> 50$ percent of the transparent species); the relative percentage of hornblende, kyanite, and tourmaline together accounts for 16 to over 32 percent of the suite. Extremely high percentages of opaque mineral species (mostly magnetite and ilmenite) locally account for over 50 percent of the heavy

TABLE 1.—*Textural data measured for 39 samples from Lamont-Doherty cores (S, slope; U.R., upper rise; L.R., lower rise; A. P., Sohm Abyssal Plain). Numbers at left refer to core localities shown in Figure 17. Sample numbers are listed under "laboratory code"*

| Loc. No. | Lamont - No. | Lab. Code | Depth Core (cm) | Water Depth (F) | Location | Round. | % Heavy | % less than .063mm | Anal. H.M. | Mean ø | Sort. | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A 164 - 46 | 192 | 28-30 | 2610 | A.P. | .43 | 2.77 | .0 | yes | 3.25 | 0.46 | -4.46 | 98 |
| 2 | A 164 - 47 | 193 | 28-30 | 2580 | A.P. | .49 | 2.08 | 21.0 | yes | 3.21 | 0.59 | -12.57 | 331 |
| 3 | A 164 - 48 | 194 | 18-20 | 2530 | A.P. | .50 | 1.71 | 25.6 | | 3.58 | 0.42 | -14.25 | 288 |
| 4 | A 164 - 49 | 82 | 163-5 | 510 | S. | .40 | | 24.82 | yes | 2.22 | 1.20 | -4.08 | 61 |
| 5 | A 164 - 54 | 195 | 360-2 | 1230 | U.R. | .39 | 0.54 | 63.5 | | 2.01 | 1.56 | -3.23 | 37 |
| 6 | A 164 - 55 | 196 | 250-2 | 1820 | L.R. | .45 | 1.38 | 43.1 | | 3.06 | 0.97 | -8.33 | 123 |
| 7 | A 173 - 8 | 78 | 80-2 | 1490 | U.R. | .46 | 0.36 | 11.85 | | 3.21 | 0.44 | -7.25 | 231 |
| | - 8 | 77 | 190-2 | 1490 | U.R. | .51 | 1.67 | 6.40 | | 3.06 | 0.54 | -6.98 | 167 |
| | - 8 | 76 | 800-2 | 1490 | U.R. | .46 | 0.29 | 4.57 | yes | 3.06 | 0.46 | -3.91 | 130 |
| 9 | A 173 - 10 | 198 | 260-2 | 900 | S. | .49 | 4.97 | 77.2 | | 2.44 | 1.19 | -3.33 | 45 |
| 10 | A 173 - 11 | 199 | 30-2 | 1426 | A.P. | .49 | 0.89 | 65.9 | | 1.10 | 0.94 | -1.75 | 29 |
| 11 | A 173 - 12 | 200 | 300-2 | 1150 | U.R. | .42 | 1.23 | 60.2 | | 1.35 | 1.57 | -2.54 | 33 |
| 12 | A 173 - 13 | 201 | 120-2 | 1600 | L.R. | .47 | 0.78 | 44.8 | | 2.47 | 1.02 | -2.99 | 51 |
| 13 | A 173 - 14 | 202 | 10-12 | 1410 | U.R. | .46 | 2.94 | 68.1 | | 1.95 | 1.83 | -3.23 | 30 |
| 14 | C 25 - 10 | 207 | 30-2 | 910 | S. | | 1.24 | 85.3 | | 2.68 | 1.26 | -3.75 | 38 |
| 15 | KM 1 - 2 | 208 | 150-2 | 750 | S. | | 0.46 | 73.0 | | 3.13 | 0.79 | -6.46 | 89 |
| 16 | KM 1 - 5 | 210 | 12-14 | 136 | S. | | 0.97 | 27.7 | | 3.21 | 1.23 | -12.00 | 173 |
| 17 | KM 1 - 6 | 211 | 136-8 | 310 | S. | .50 | 0.57 | 31.5 | | 3.24 | 0.60 | -11.38 | 247 |
| 18 | KM 1 - 7 | 212 | 80-2 | 450 | S. | .45 | 0.76 | 62.3 | | 2.89 | 1.14 | -8.50 | 119 |
| 19 | SP -12 - 1 | 73 | 305-7 | 700 | S. | .40 | | 2.73 | yes | 0.98 | 1.39 | 0.44 | 31 |
| 20 | 12 - 2 | 215 | 102-4 | 680 | S. | .35 | 1.27 | 58.3 | | 2.30 | 1.15 | -4.27 | 64 |
| 21 | 12 - 3 | 216 | 77-9 | 1300 | U.R. | .44 | 1.05 | 46.1 | | 2.46 | 1.09 | -4.78 | 71 |
| 22 | 12 - 4 | 217 | 352-4 | 1310 | U.R. | .42 | 1.06 | 32.9 | | 2.40 | 1.15 | -4.61 | 66 |
| 23 | V - 2 - 4 | 220 | 20-2 | 2000 ? | L.R. | | | 100 | | | | | |
| 24 | V - 7 - 38 | 225 | 80-2 | 2508 | A.P. | .47 | 0.67 | 72.0 | | 3.04 | 0.49 | -13.86 | 274 |
| | - 38 | 226 | 401-3 | 2508 | A.P. | .52 | 2.49 | 1.6 | | 1.09 | 1.11 | 0.29 | 45 |
| | - 38 | 63 | 410-2 | 2508 | A.P. | .46 | | 6.4 | yes | 1.03 | 1.25 | 0.69 | 37 |
| | - 38 | 64 | 442-4 | 2508 | A.P. | .37 | | 14.05 | | 2.80 | 0.84 | -5.33 | 85 |
| 25 | V - 7 - 63 | 243 | 10-12 | 220 | S. | .45 | 0.27 | 32.0 | | 3.60 | 0.43 | -23.08 | 728 |
| | - 63 | 244 | 30-2 | 220 | S. | .48 | 0.47 | 53.7 | | 3.60 | 0.33 | -18.23 | 601 |
| 26 | V - 7 - 68 | 22 | 60-2 | 2143 | L.R. | .36 | 2.01 | .12 | yes | 1.66 | 0.61 | -0.10 | 69 |
| | - 68 | 21 | 80-2 | 2143 | L.R. | .40 | 2.56 | .07 | yes | 1.24 | 0.80 | 0.31 | 50 |
| 27 | V - 7 - 69 | 245 | 98-100 | 1600 | U.R. | .48 | 1.19 | 75.0 | | 0.95 | 1.94 | 0.22 | 19 |
| 28 | V - 7 - 70 | 246 | 150-2 | 700 | U.R. | .42 | 1.70 | 63.3 | | 2.59 | 1.20 | -4.73 | 58 |
| 29 | V - 16 - 213 | 247 | 10-12 | 2065 | L.R. | | 0.19 | 74.1 | yes | 2.46 | 0.91 | -0.63 | 30 |
| | - 213 | 248 | 60-2 | 2065 | L.R. | | 1.87 | 7.37 | yes | 2.76 | 0.62 | -5.58 | 133 |
| 30 | V - 17 - 209 | 3 | 170-2 | 2453 | L.R. | .48 | 2.31 | 0.97 | yes | 1.74 | 0.61 | -0.05 | 90 |
| | - 209 | 2 | 190-2 | 2453 | L.R. | .39 | 4.44 | 0.37 | yes | 1.12 | 1.18 | -1.30 | 32 |
| | -209 | 1 | 205-7 | 2453 | L.R. | | | | | | | | |

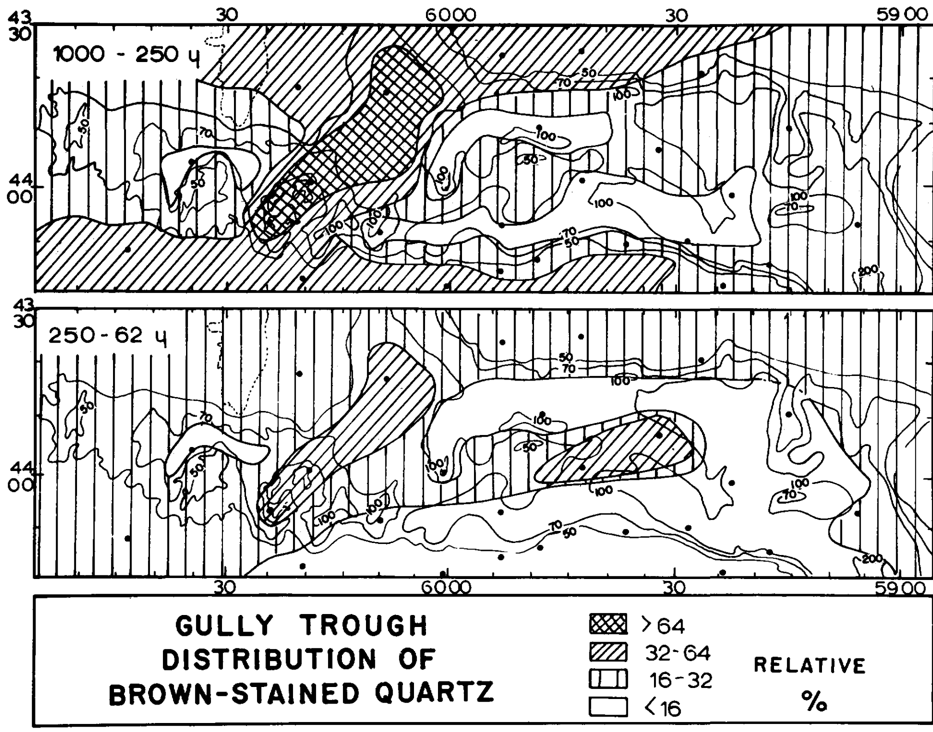



FIGURE 39.—Relative percentage of brown iron-stained quartz (calculated from the total quartz content only) in the 250-1000 and 62-250 micron-size fractions of Gully Trough samples.

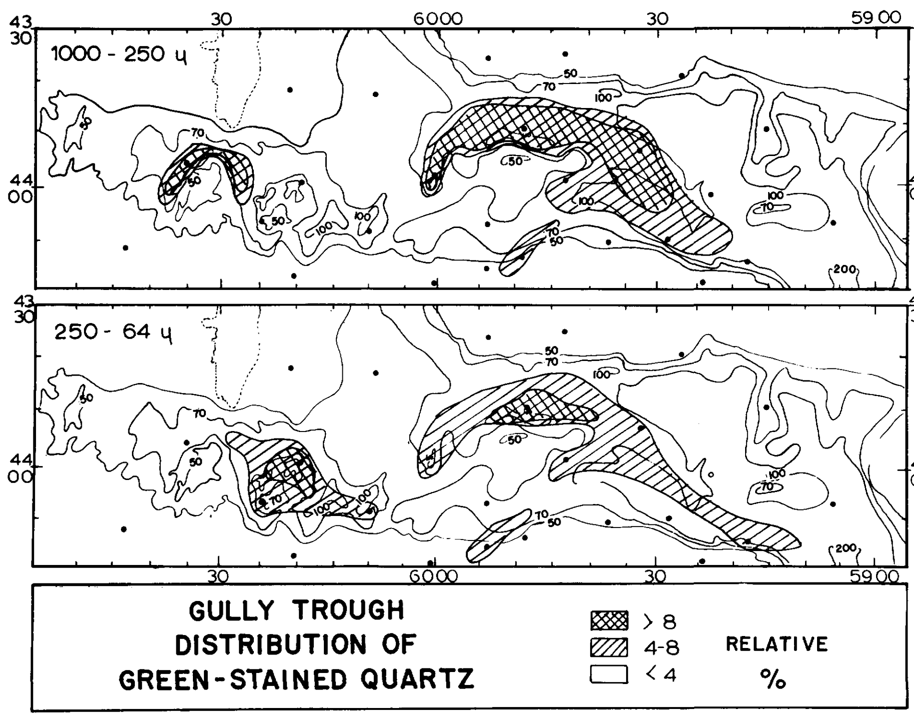



FIGURE 40.—Relative percentage of green-stained quartz (calculated from the total quartz content only) in the 250-1000 and 62-250 micron-size fractions of Gully Trough samples.

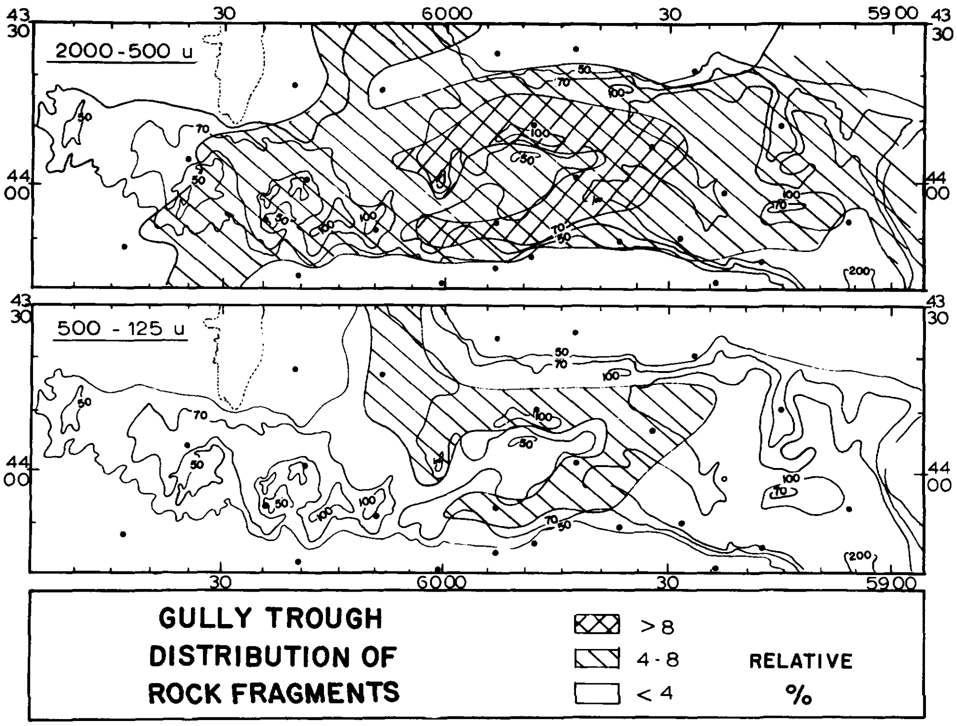



FIGURE 41.—Relative percent of rock fragments (calculated from the quartz + rock fragments portion of the sample only) in the 500-2000 and 125-500 micron-size fractions of Gully Trough samples.

mineral assemblage. Iron nodules and dark green to black glauconite grains (1 to over 4 percent of the light mineral fraction) are noted in samples on the southern portion of the bank.

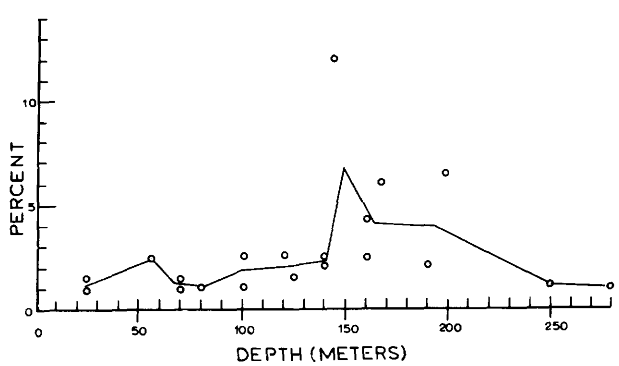



FIGURE 42.—Relation between percent of rock fragments and depth in the 250-500 micron-size fraction of sediments in the Gully Trough area. Note increase in the amount of rock fragments between the 140 and 200 meter depth range.

Angular as well as well-rounded pebbles recovered locally on the bank include rock types that appear similar to those cropping out on the Nova Scotian mainland (i.e., including Devonian igneous rocks, Carboniferous clastics, Triassic basalt, and states, schists, and metamorphics of the lower Paleozoic Meguma Group. Some glauconitic sandstone, of the type not found on the mainland, is probably derived from some now-submerged coastal plain Tertiary or Cretaceous bedrock cropping out nearby on the shelf. A detailed mineralogical study of Nova Scotian surficial sediments has recently been compiled by A. E. Cok (1970).

### *Gully Trough Sediments*

The mineralogical composition of the sand-size fraction of surficial Gully Trough samples, examined by James (1966), can be summarized as follows.

QUARTZ.—Three types of quartz are present in significant quantities:

(a) Orange to red iron-stained quartz, possibly indicative of subaerial exposure.

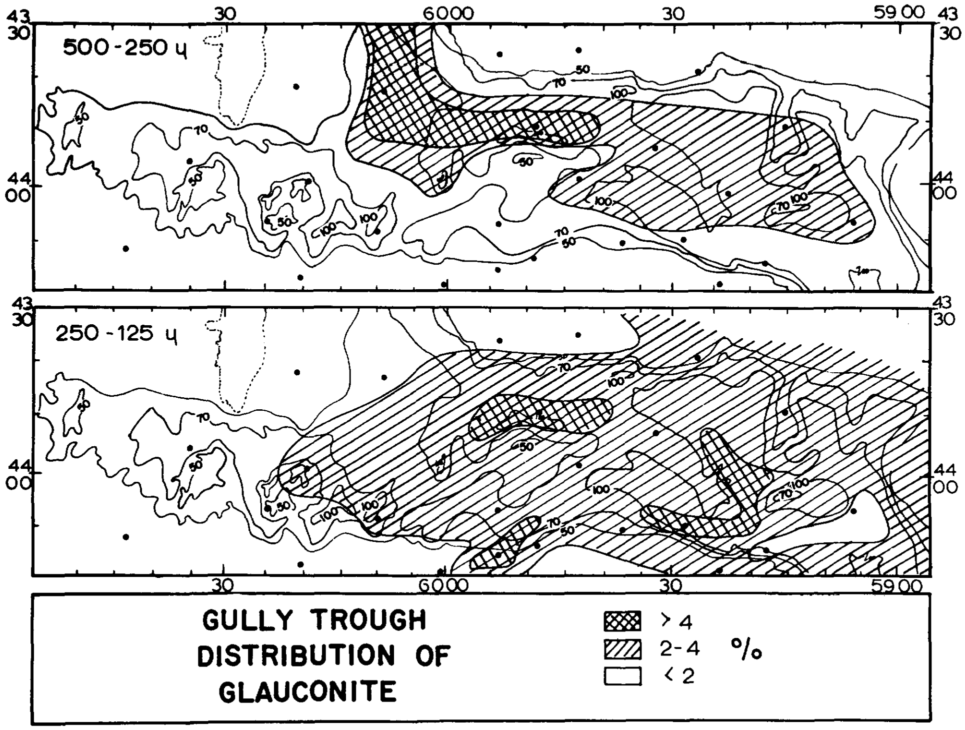



FIGURE 43.—Percentage of glauconite in the 250-500 and 125-250 micron-size fractions of Gully Trough samples.

(b) Clear quartz, suggesting possible removal of iron-stain by abrasion.

(c) Green-stained quartz, the origin of which is unknown (flame spectrophotometry indicates that the stain is due to the presence of iron). Weller (1960) has indicated that iron coloration can be used as an index of the oxidation state: red indicates a high degree of oxidation, and green a low degree of oxidation. Keller (1953) suggests that a green color in some sediments may also be due to the presence of iron in such marine clays as illite and montmorillonite.

The data suggest that the distribution of particular quartz-types is depth controlled. The amount of red-stained quartz is relatively high at depths above 120 m; this type of quartz decreases to a low at about 20 m (Figure 39). The relative percentage of green-stained quartz, generally low at most depths, increases with depth to a high at the 110 to 145 m depth range, and then decreases at greater depths (Figure 40).

ROCK FRAGMENTS.—Rock fragments are relatively sparse on Banquereau Bank, the eastern portion of Sable Island Bank, and in The Gully Canyon off the eastern end of Sable Island Bank. Rock fragments, on the other hand, are relatively abundant in the central deeper portion of the Gully Trough (Figure 41). Figure 42 shows the relative percentage of rock fragments in the 250–500 micron fraction (rock fragments of this size are present in almost all samples in this area) plotted against depth. This diagram indicates that the rock fragments are most abundant between 140 and 200 m (Figure 42).

GLAUCONITE.—Glauconite content in the coarse fraction (250–500 micron) is relatively high between Middle Bank and Banquereau Bank and the central portion of the Gully Trough and its extension toward The Gully Canyon (Figure 43). No correlation is noted between the amount of glauconite and depth, nor does there appear to be a relation between the regional distribution and grain size.

This glauconite may have originated from erosion of (a) older bedrock cropping out in the area, or (b) from pebbles of glauconitic sandstone, or (c) it

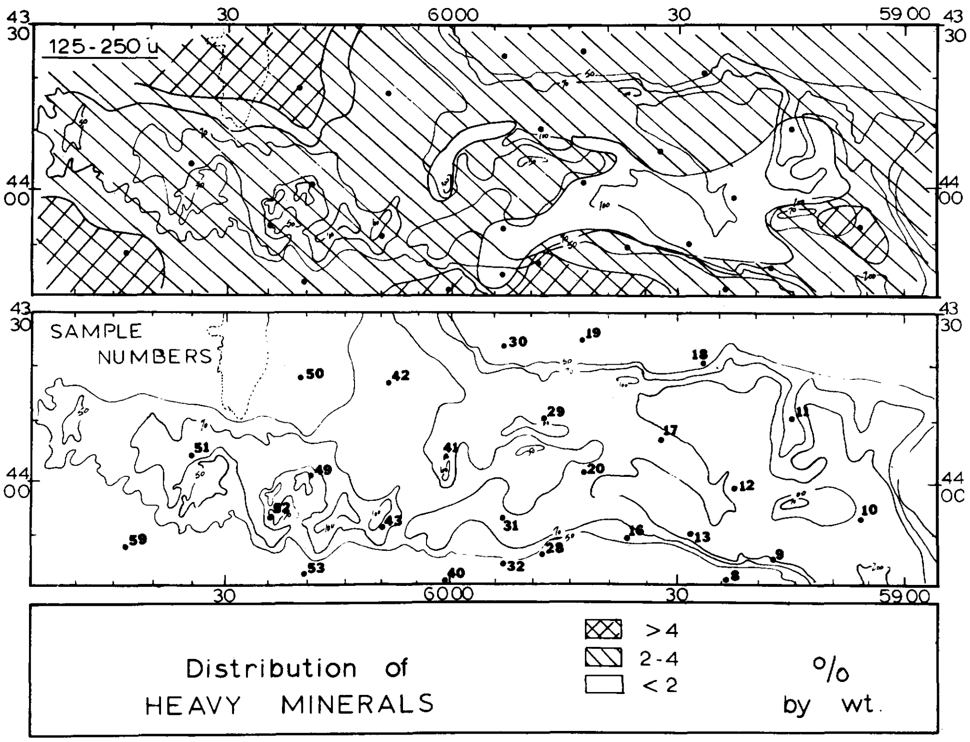



FIGURE 44.—Relative percentage, by weight, of heavy minerals present in the 125-250 micron-size fraction of Gully Trough samples. The sample station locations are shown in the lower map.

may be authigenic and forming at present. Its corroded appearance, however, tends to suggest a relict origin.

HEAVY MINERALS.—Heavy minerals are most abundant on the banks and topographic highs in the Gully Trough (Figure 44). Bank surfaces have been subjected to current activity resulting in removal of fines and concentration of heavy minerals as lag deposits. The heavy mineral content is generally low, below 200 m, with the exception of the region of The Gully Canyon between Banquereau Bank and Sable Island Bank. The latter region may be receiving sediment of well-sorted material that originates on bank tops.

Opaque heavies and zircon show similar distribution trends: high values on the isolated topographic highs and bank tops, and in the deepest areas (Figure 45). At intermediate depths off the western end of Sable Island Bank, however, these minerals are sparse. A plot of opaques versus depth (Figure 47) shows that above 120 m the relative percentage of opaques is consistently above 50 percent, whereas below 160 m it ranges about 35 percent. This variation probably reflects depositional differences with depth: a shallower zone of reworking with "mature" sediments, and a deeper, quieter deposition zone of unmixing ("immature" sediments) occurring between 120 and 160 m.

Weathered heavy mineral species are abundant in basins and areas deeper than 200 m, suggesting that they may be the result of in situ chemical destruction of several mineral species (Figure 45).

Garnet, hypersthene, and staurolite have a similar distribution pattern in this region (Figure 46), i.e., abundant on the western portion of Sable Island Bank and Middle Bank with lower percentages in the deeper axis of the depression. The relatively high percentage of garnet on the bank tops seems to confirm the "mature" (reworked lag) nature of sediment exposed at shallower depths than those in deeper regions.

The distribution patterns of hornblende, kyanite, and tourmaline are similar. Their concentrations are low on the banks and highs in the deep central region, except in a deep area between Sable Island Bank and Banquereau Bank (Figure 46). The percentage of garnet, on the other hand, shows a generally consistent

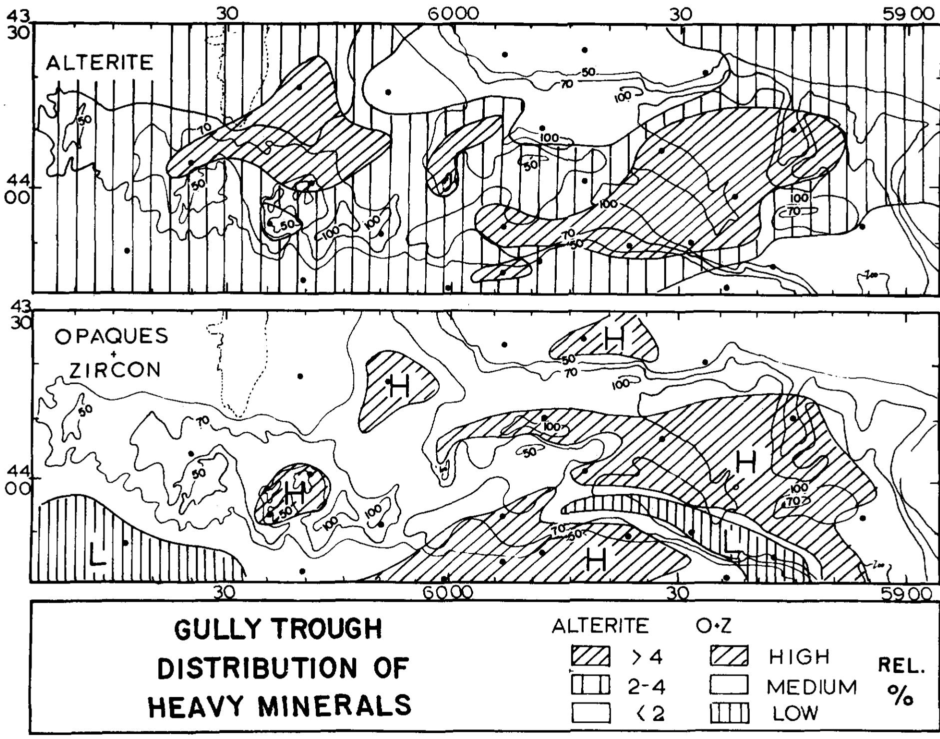



FIGURE 45.—Relative percentage of alterite in the nonopaque portion of the heavy minerals in the 125-250 micron-size fraction. In lower map, relative abundance of zircon and opaque heavy minerals in the 125-250 micron-size fraction in Gully Trough samples.

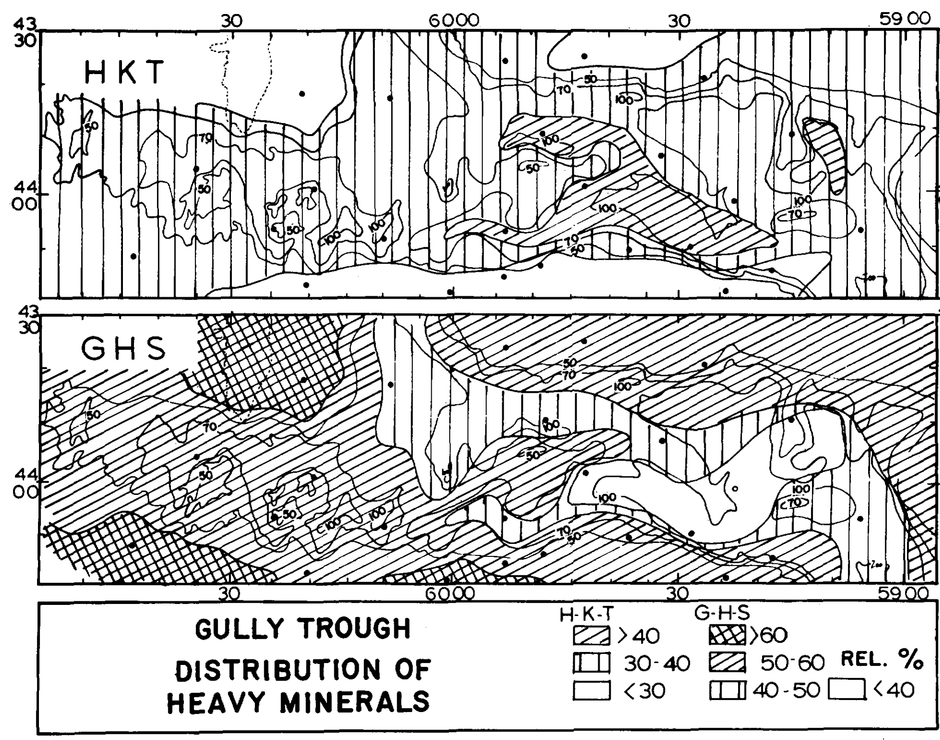



FIGURE 46.—Relative percentage of hornblende + kyanite + tourmaline (in upper diagram), and garnet + hypersthene + staurolite (in lower diagram) in the nonopaque 125-250 micron-size fraction of Gully Trough samples.

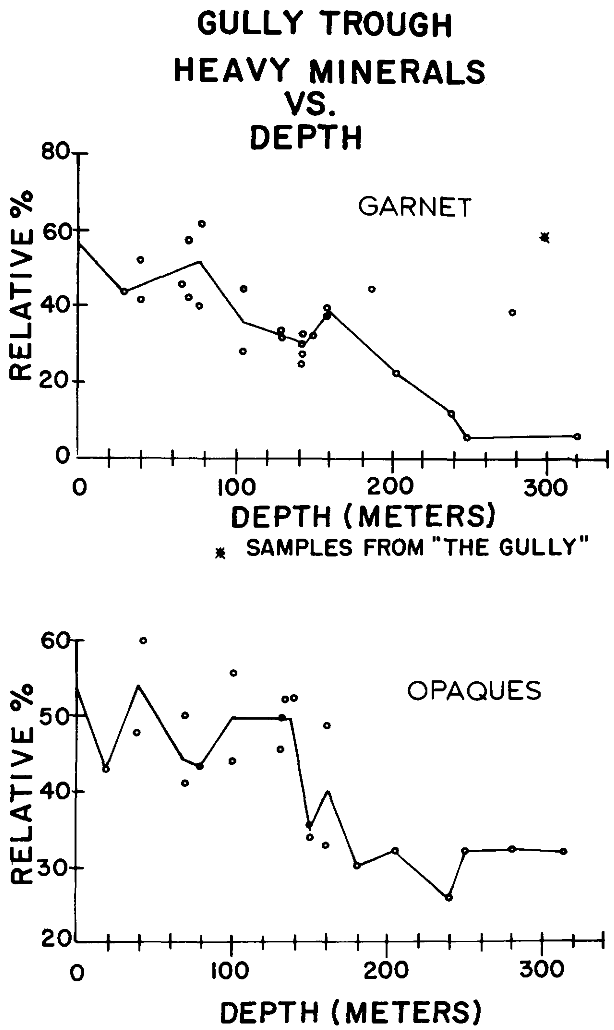



FIGURE 47.—Variation with depth of the relative percentage of garnet (upper graph) and opaque minerals (lower graph) in the Gully Trough. Garnet decreases progressively with depth. Opaque heavies also decrease with depth, and particularly so below 120 m.

decrease with increasing depth (Figure 47). Thus, it appears that hydraulic selectivity is the dominant factor governing the heavy mineral distribution in The Gully Trough. Hornblende, kyanite, and tourmaline, all of relatively low specific gravity, have probably been winnowed out of surficial relict (Pleistocene) deposits on the banks and transported to deeper areas.

### *The Gully Canyon Sediments*

The Gully Canyon and its deep upper slope-shelf extension due east of Sable Island morphologically separates Sable Island Bank from Banquereau Bank. The mineralogical composition of the sand fraction of samples from the upper parts of cores was determined (James 1966).

IRON-STAINED QUARTZ.—The relative amount of brown-colored, iron-stained quartz (Figure 48) does not appear closely related to grain size, as is the case on Sable Island Bank. Most samples rich in stained quartz are fine grained although a smaller amount of stained quartz occurs as coarse (1.0–2.0 mm) sand. The amount of coarse iron-stained quartz decreases downslope along the canyon trend. A zone poor in iron-stained quartz parallels the 500 fm isobath just west of the canyon axis. Sediment of very fine sand grade within the canyon axis contains a relatively high amount of iron-stained quartz. A zone relatively rich in iron-stained quartz of all sizes occurs at about 400 fathoms on the east (Banquereau) margin of the canyon.

ROCK FRAGMENTS.—Sediment of sand grade in the central portion of the canyon contains proportionately lesser lithic fragments than on the banks, particularly Banquereau Bank. A zone of lithic-rich sediment extends from Banquereau Bank seaward toward deeper areas near the mouth of the canyon (Figure 49). This trend suggests a provenance from Banquereau Bank.

SHELL-FRAGMENTS.—Sediment in and near the canyon axis contains relatively lower amounts of shell fragment than on the canyon walls and mouth (Figure 50). The shell-rich area extends from the eastern and southeastern margins of Sable Island Bank downslope into the canyon.

GLAUCONITE.—Glauconite-poor sand covers the eastern margin of Sable Island Bank as well as sections of the upper reaches of The Gully Canyon (Figure 51). Areas of high (8 percent) glauconite content occur at intermediate depths (100 to 800 m) on the west wall (Sable Island Bank side) of the canyon, as well as along most of the Banquereau margin. The in situ origin of glauconite in this area cannot be ruled out. It is more probable, however, that glauconite-rich strata cropping out along the canyon margins serve as a source for this mineral.

MICA.—Mica is rare to absent in surficial sediment on Sable Island Bank and in the upper reaches of The Gully Canyon (areas of intense bottom current activity), but is present in low amounts on Banquereau Bank and in the mid sectors and lower sectors of The

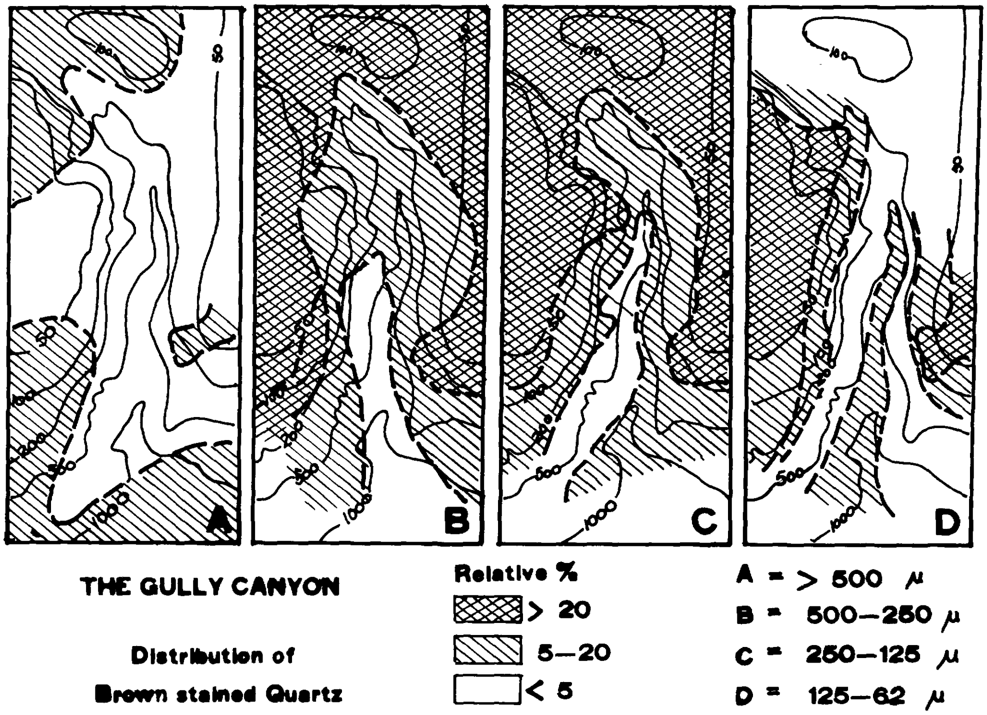



FIGURE 48.—Relative percent of brown iron-stained quartz (calculated from the total quartz content only) present in different size fractions in The Gully core samples. Note relatively high amounts in fine-grained stained quartz in the axis of the canyon.

Gully (Figure 49). The platy shape of mica results in its deposition with quartz and other minerals of different (generally smaller) size and density in deeper, less current agitated environments beyond the shelf-break, an observation made elsewhere by Doyle et al. (1968) and Lyall et al. (1971).

HEAVY MINERALS.—The heavy mineral content of both the 62 to 125$\mu$ and the 125 to 250$\mu$ fractions in Gully samples were examined. The 62 to 125$\mu$ distribution is perhaps most reliable in that the very fine sand fraction is present in most samples examined, including muddy ones. The proportion of opaque minerals in the coarser (125 to 250$\mu$) fraction increases southward and apparently bears no relation with the physiography of the canyon. The relative percent of opaques present in the finer fraction, however, is related to some degree with canyon morphology, i.e., samples in the axis of the canyon containing less opaques than those in the upper canyon reaches (Figure 52).

The distribution of zircon is more irregular, particularly in the smaller grain-size fraction (Figure 53). In the coarser fraction, zircon is relatively abundant in the upper reaches and at the mouth of the canyon but sparse in the central portion. Hornblende and tourmaline display nearly identical distribution patterns and thus are plotted together (Figure 54). Garnet (Figure 55) has a distribution pattern that closely resembles those of hornblende and tourmaline but shows opposite trends, i.e., where garnet content is high, hornblende and tourmaline content is low, and vice versa. The three mineral species are believed to have a similar source origin and thus can be discussed together. In the coarser size fraction, garnet is low in a region extending from Banquereau, down the east wall and across the mouth of the canyon; in the axis of the canyon, at about 700 fm, the opposite trend is noted, i.e., high garnet values are present. In the finer fraction, garnet percentages are relatively high and hornblende and tourmaline relatively low in two linear belts parallel to the axis, and between 300 and 400 fm on either side of the canyon. It is possible that these linear trends along both margins of the canyon are related to local sources cropping

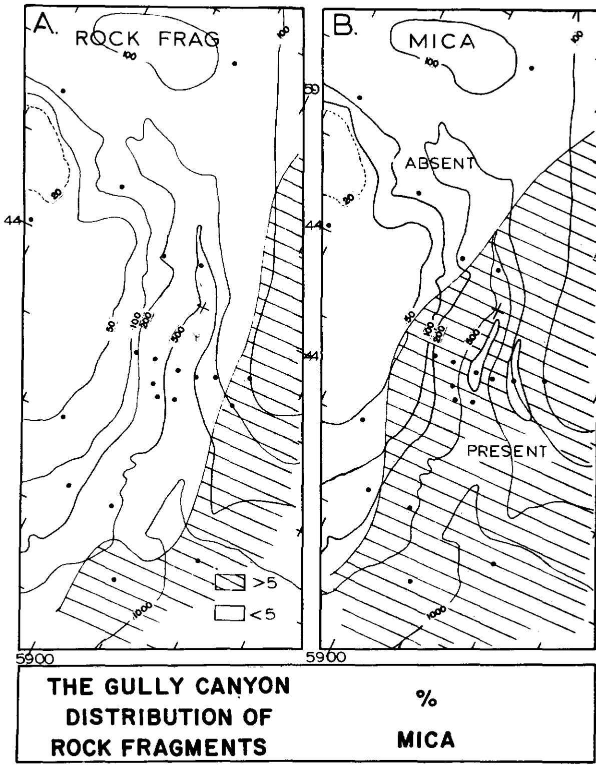



FIGURE 49.—A, relative percentages of rock fragments. B, presence of mica in surficial sediment of The Gully Canyon.

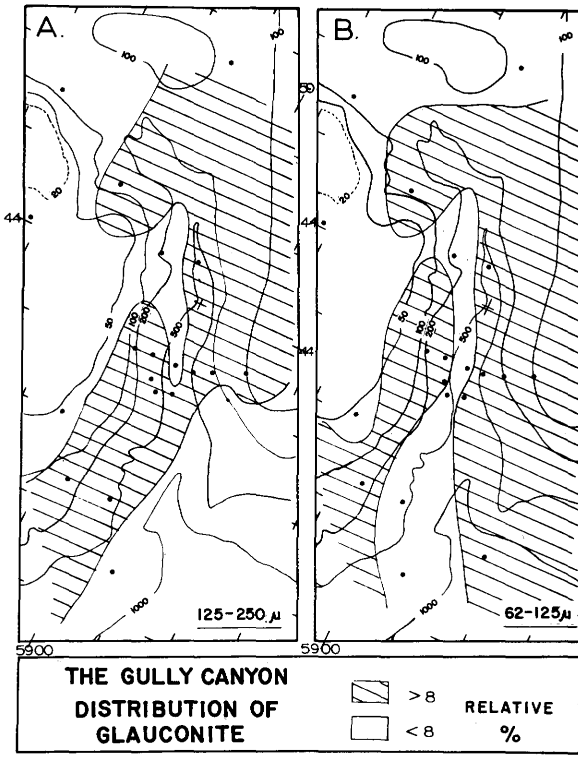



FIGURE 51.—Percent of glauconite in the (A) 125-250 and (B) 62-125 micron-size fractions in The Gully Canyon samples.

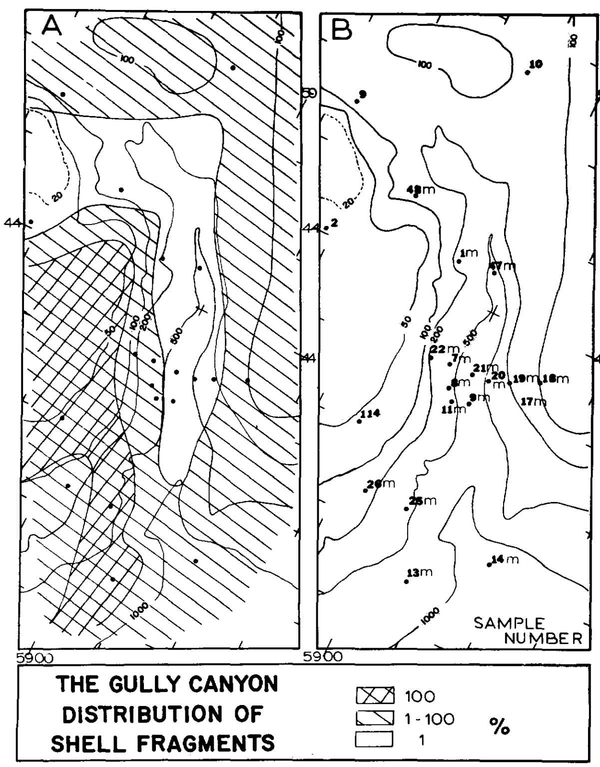



FIGURE 50.—A, percent of shell fragments in the 500-1000 micron-size fraction in The Gully Canyon. B, sample station locations (samples designated with symbol m were donated by J. Marlowe, Bedford Institute of Oceanography).

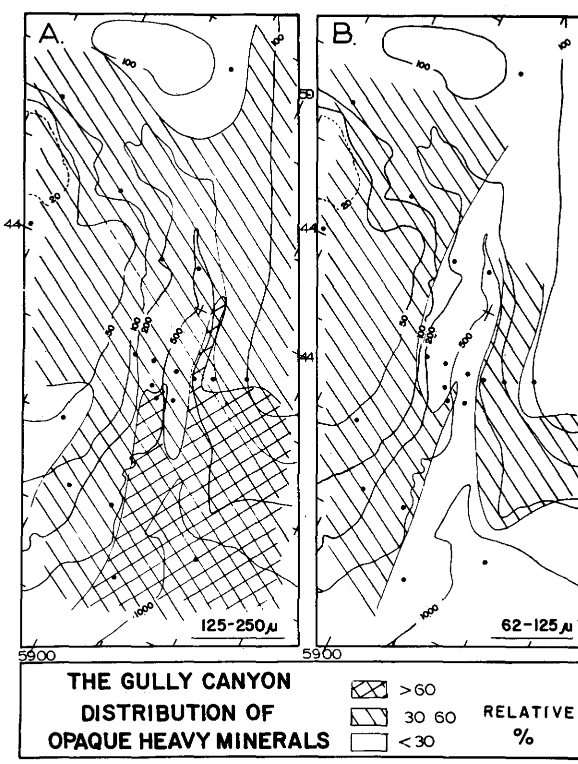



FIGURE 52.—Relative percent of opaque heavy minerals of the (A) 125-250 and (B) 62-125 micron-size fractions in The Gully Canyon samples.

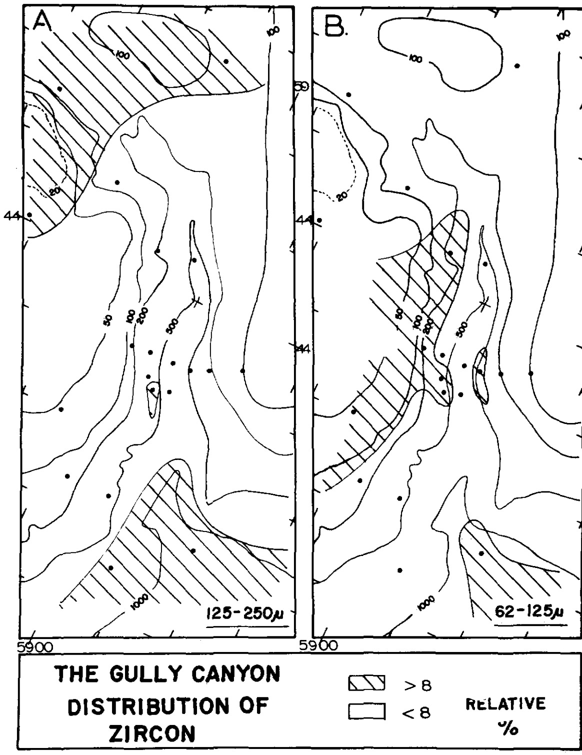



FIGURE 53.—Relative percentage of zircon in the (A) 125-250 and (B) 62-125 micron-size fractions in The Gully Canyon samples.

out along the canyon walls. Sediments displaying relatively high hornblende and tourmaline values occur on Banquereau Bank and extend down the canyon wall across the mouth of the canyon.

The distribution of hypersthene in the coarser fraction is similar to patterns of opaque heavies and zircon, i.e., high values in the upper reaches and mouth of the canyon and lower values in the central part of The Gully (Figure 56). In the finer grain sizes, two linear highs of hypersthene on either side of the canyon, between 100 and 300 fm (like hornblende-tourmaline), also suggest that there may be a local source of sediment cropping out along the margin of the upper reaches of the canyon.

Relative percentages of kyanite are relatively low on both banks and in the center of the canyon but increase along the canyon walls between 400 and 500 fm (Figure 57). Staurolite is asymmetrically distributed about the axis of the canyon, i.e., low on the Banquereau Bank margin and high on the Sable Island Bank margin. In the very fine sand fraction, staurolite is abundant along both margins of the canyon but uncommon near the canyon axis (Figure 58).

Both light and heavy minerals are similar to those reported in Oligocene and Miocene rocks cropping out along the walls of The Gully Canyon (Marlowe 1969). It is probable that erosion and in situ weathering of exposed sedimentary rock ledges has contributed at least a minor amount of sediment to the canyon fill. The primary source, however, of the mineral suite observed here, as elsewhere on the outer margin, is plutonic, metamorphic, and sedimentary rock terrains some two hundred or more kilometers to the northwest.

*Continental Slope Sediments*

Mineralogical analyses of the coarser-than-silt fraction ($> 62\mu$) of slope cores Sc-1 to Sc-20 (Silverberg 1965) are reported below. Quartz, the dominant component of the sand-size fraction, occurs in many forms. Many of the grains are iron-stained and the surfaces may be smooth, pitted, or frosted. An almost complete gradation, from well rounded to very angular grains,

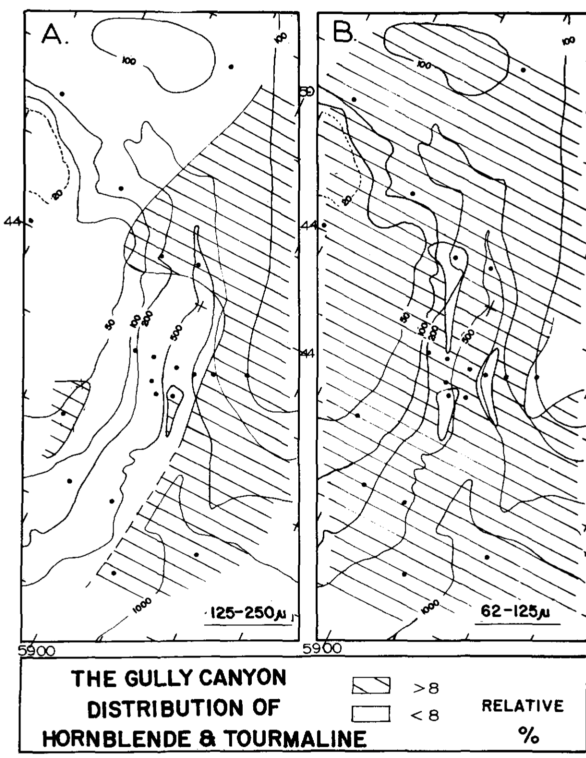



FIGURE 54.—Relative percentage of hornblende + tourmaline in the (A) 125-250 and (B) 62-125 micron-size fractions in The Gully Canyon samples.

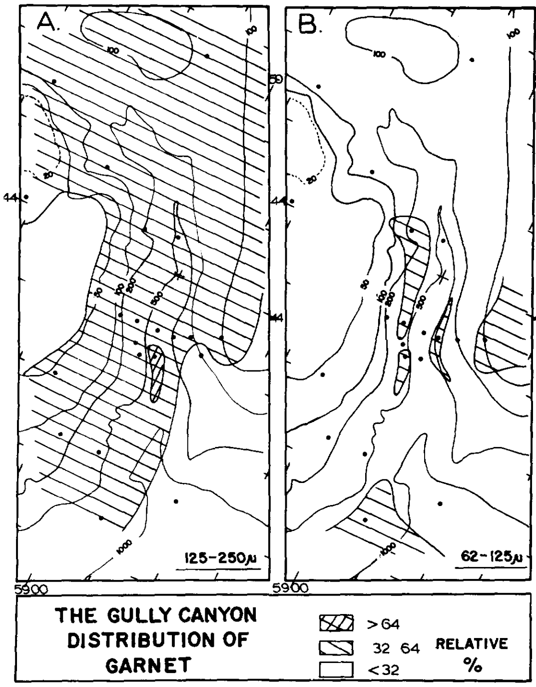



FIGURE 55.—Relative percent of garnet in the (A) 125-250 and (B) 62-125 micron-size fractions in The Gully Canyon samples.

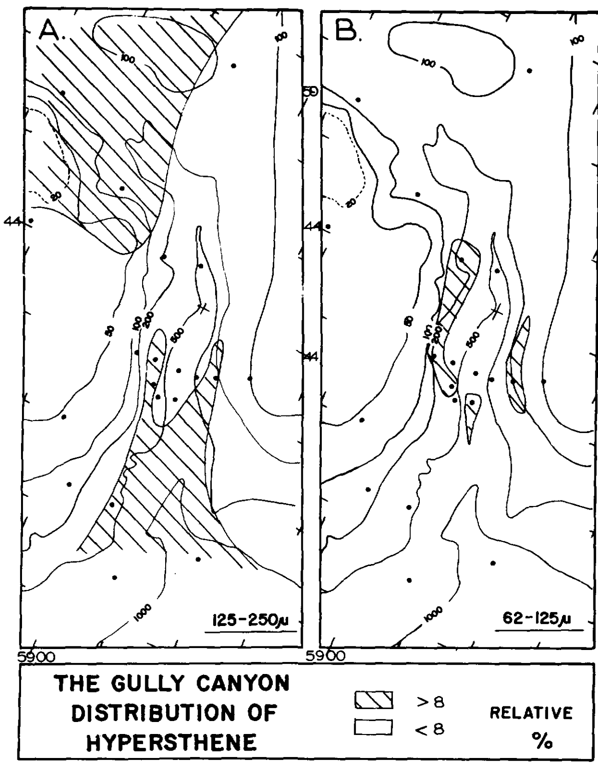



FIGURE 56.—Relative percentage of hypersthene in the (A) 125-250 and (B) 62-125 micron-size fractions in The Gully Canyon samples.

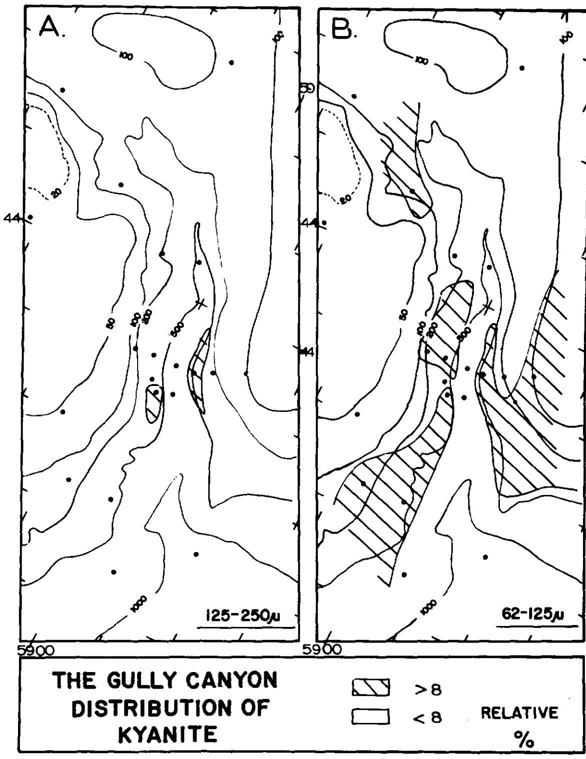



FIGURE 57.—Relative percentage of kyanite in the (A) 125-250 and (B) 62-125 micron-size fractions in The Gully Canyon samples.

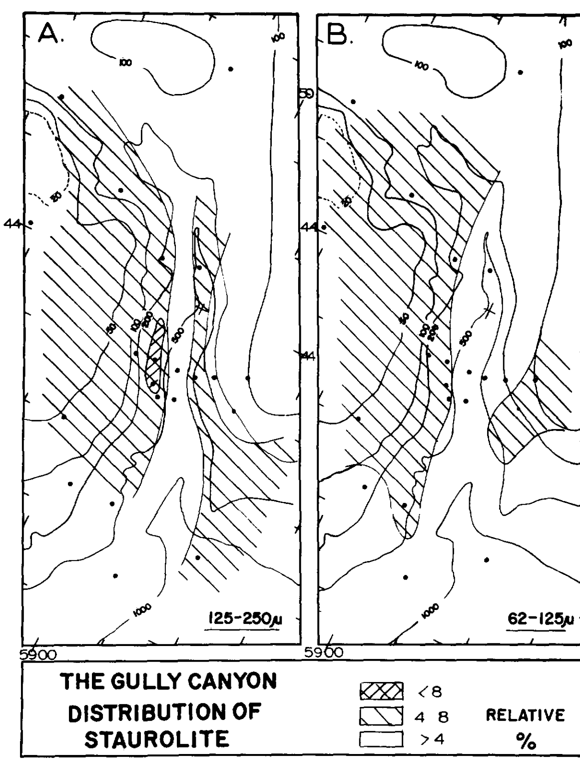



FIGURE 58.—Relative percentage of staurolite in the (A) 125-250 and (B) 62-125 micron-size fractions in The Gully Canyon samples.

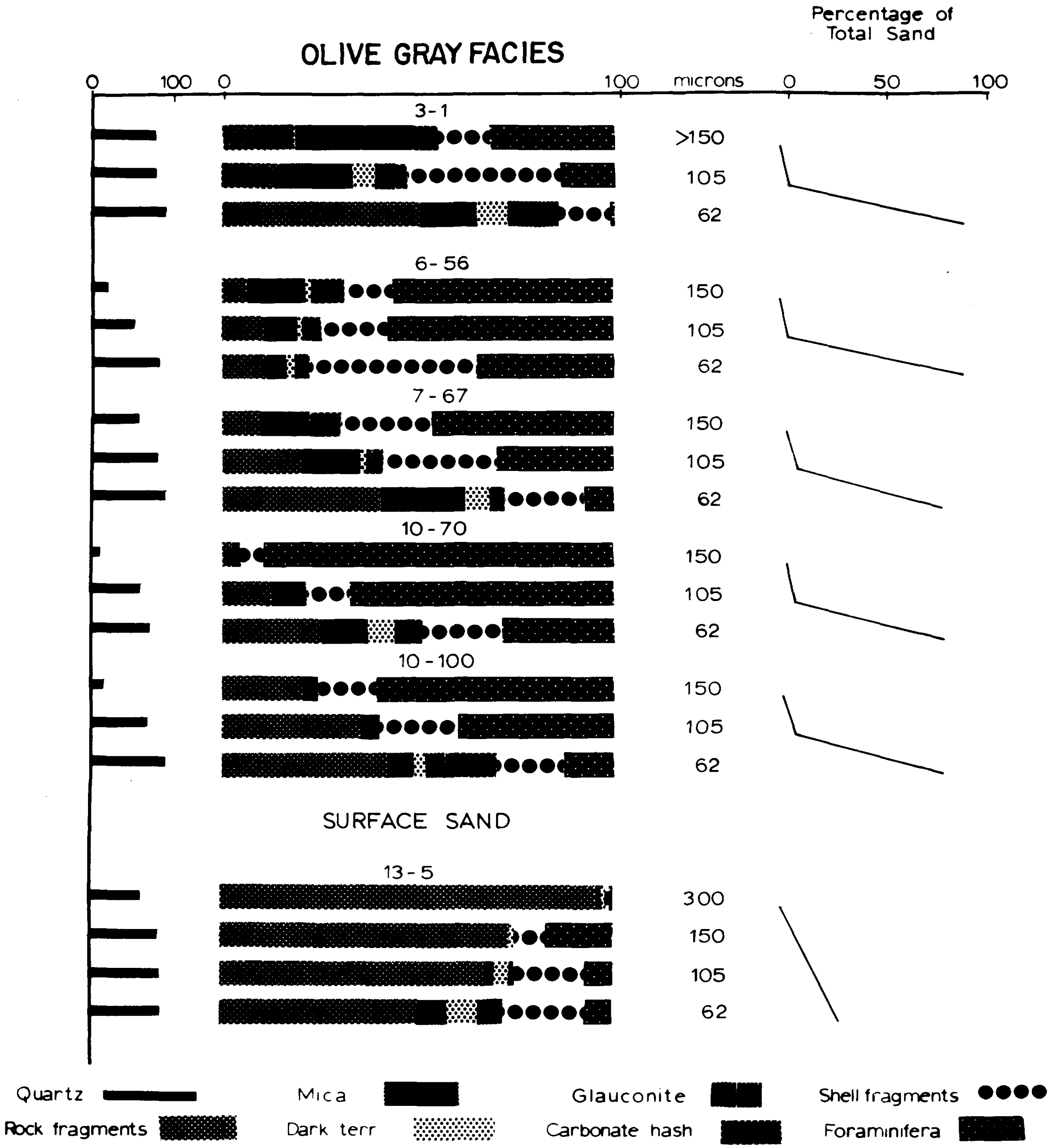



FIGURE 59.—Mineralogical variation of the coarse fraction with grain size in selected slope (Sc) core samples (olive gray and surface sand facies).

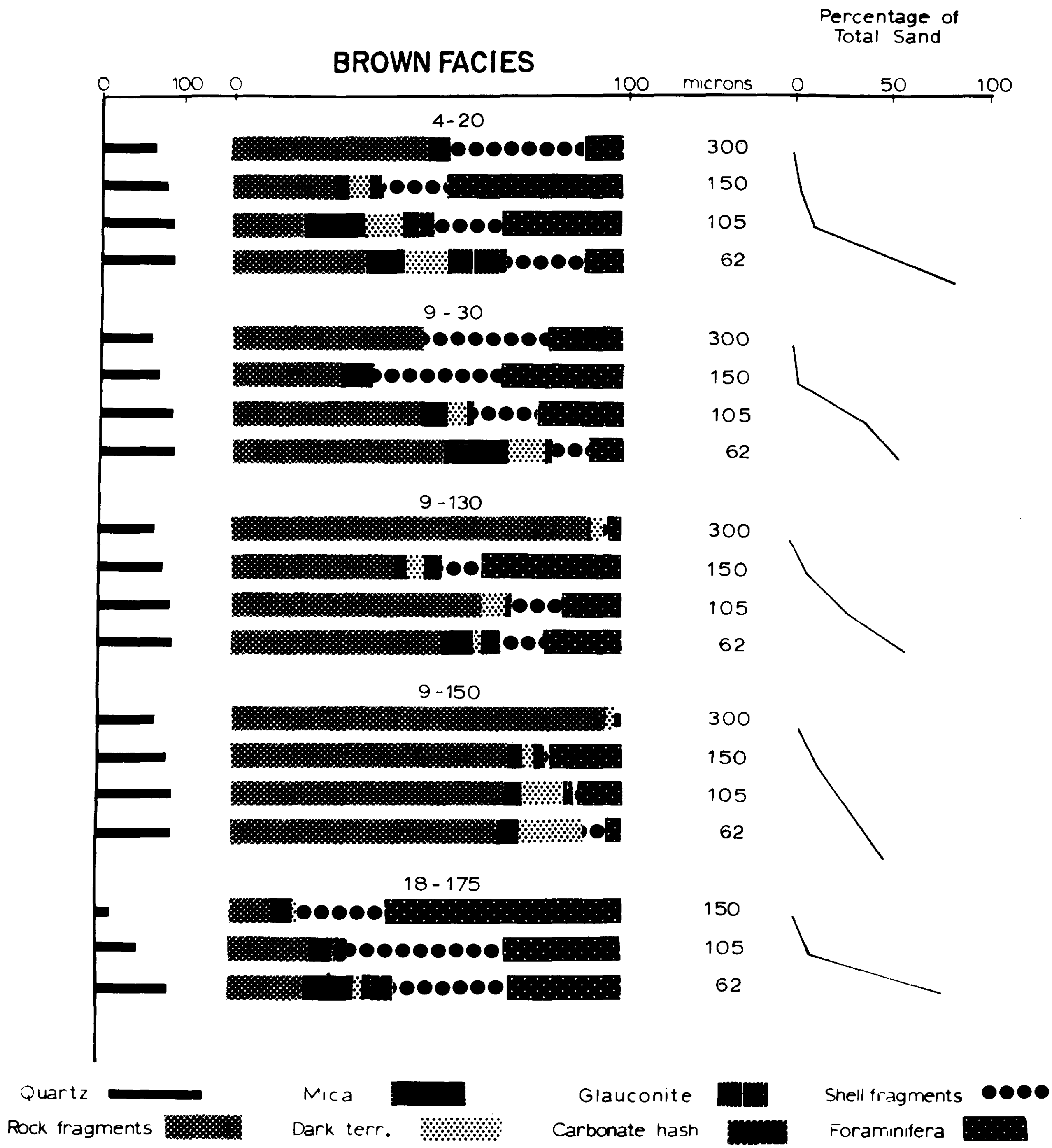



FIGURE 60.—Mineralogical variation of the coarse fraction with grain size in selected slope (Sc) core samples (brown facies).

is found in most samples. Ubiquitous accessory components are feldspar, mica, rock fragments, shell material, and Foraminifera. Glauconite, dark terrigenous grains, and carbonate "hash" are additional components which may also be present. Mica occurs mostly as flakes of muscovite; small amounts of biotite and phlogopite are noted. Fragments of red, green, and grey siltstone; red and gray sandstone; quartzite; mica schist; quartz-biotite gneiss; basalt; and granite are the principle lithologies comprising the lithic fraction.

Shell material consists of fragments in various stages of destruction. The bulk of shell fragments is relatively fresh although some of the larger smooth and rounded grains show evidence of abrasion. Foraminifera tests make up most of the shell component: many broken individuals are noted in grain counts. In this study, only those fragments which could definitely be identified as Foraminifera were counted. The remainder are included in a general component category. Black grains, concentrated with foraminifers during the $CCl_4$ flotation procedure, displayed conchoidal fracturing, granular and ribbed fine structure. Combustion, using relatively low temperature flames, indicates that this substance is a hydrocarbon, probably coal (indication of a terrigenous origin, perhaps Cape Breton). Other components of this fraction appear to be biotite aggregates, and altered amphiboles and pyroxenes.

Carbonate hash is the term adopted to describe aggregates of pale, greenish, flaky material, fine shell fragments, and occasionally scattered quartz grains, all loosely cemented by carbonate material. A flaky material often present is probably an altered clay product. Glauconite grains are generally dark green, somewhat knobbly grains with a smooth or finely pitted surface.

Mineralogical data plotted as relative percentages on graphic logs show compositional variation with grain size in selected samples (Figures 59–61):

QUARTZ.—The amount of quartz clearly increases with decreasing grain size. Most grains are angular in all size fractions but there is a general trend of increasing angularity with decreasing grain size.

FORAMINIFERA.—Tests, generally smaller than $300\mu$, tend to be concentrated in the 150 to $300\mu$ fraction; relative percentages decrease regularly in finer size fractions. This, however, does not imply a decrease in total numbers, for the total number of grains, including quartz, increases with decreasing grain size and the proportion of Foraminifera tends to be masked by other components. Actual counts of the foraminifers in concentrates shows that there is indeed a higher proportion of tests in the fine fractions.

ROCK FRAGMENTS.—In those samples where the lithic fraction is abundant, there appears to be a direct relation between frequency and grain size. A larger number of sand-size basalt fragments occurs in smaller size fractions.

SHELL.—Although the frequency is relatively constant in different grain sizes, there is a tendency, in some samples, of a higher shell fraction in the finer sizes. Complete valves of pelecypods and partially broken gastropods occasionally are found in the coarser than $300\mu$ fraction.

MICA.—Many samples show an increase in mica flakes with decreasing grain size; in some samples, however, this trend is not obvious.

DARK TERRIGENOUS GRAINS.—This material consists of ferromagnesian and opaque heavy minerals. It is more commonly encountered in the finer sizes and is most abundant in the very fine sand grade.

GLAUCONITE AND CARBONATE HASH.—There is no marked relation between grain size and frequency of these components although glauconite and carbonate fragments are slightly more abundant in the finer sand sizes.

It must be noted that data were obtained using a percentage determination so that all components are actually dependent variables. Furthermore, the figures have been adjusted so that minor components are exaggerated and the major components subdued. The most variable components (excluding quartz) are lithic fragments and Foraminifera, and strong trends shown by these components invariably result in modifying the remaining mineralogical components. There is a general tendency for the total carbonate material to decrease directly in ratio with grain size. This change is gradual: the increasing percentage of shells and carbonate hash complements the sharp decline of Foraminifera with decreasing grain size.

Examination of core Sc-16 indicates that quartz and dark terrigenous components generally vary directly, as do mica and glauconite. Shells and foraminifers and occasionally carbonate hash also display similar trends.

The minor components generally show more variable changes in percentage than the major components.

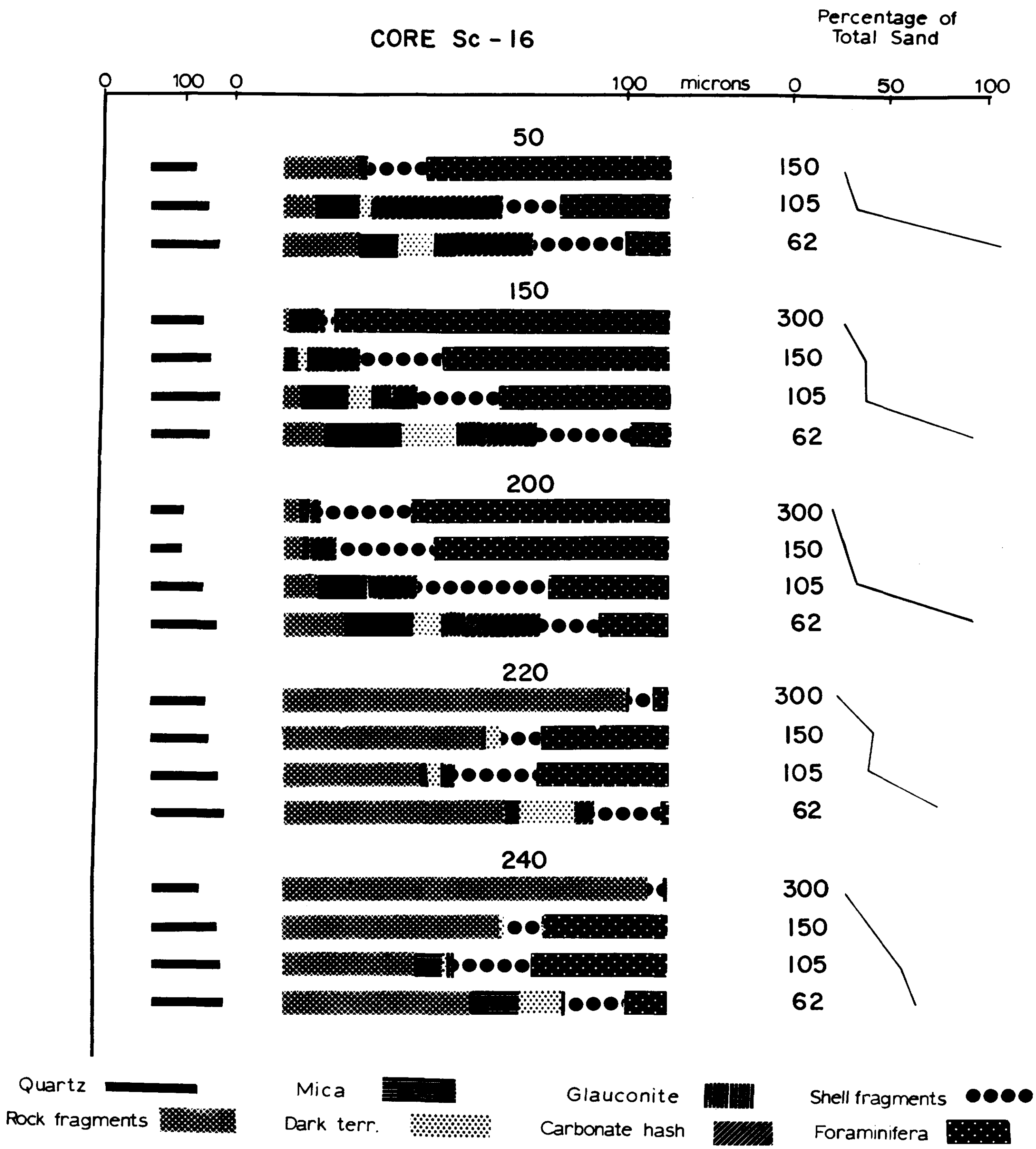



FIGURE 61.—Mineralogical variation of the coarse fraction with grain size in the representative upper slope core (Sc-16). Top three samples are olive gray facies; the lower two are brown facies.

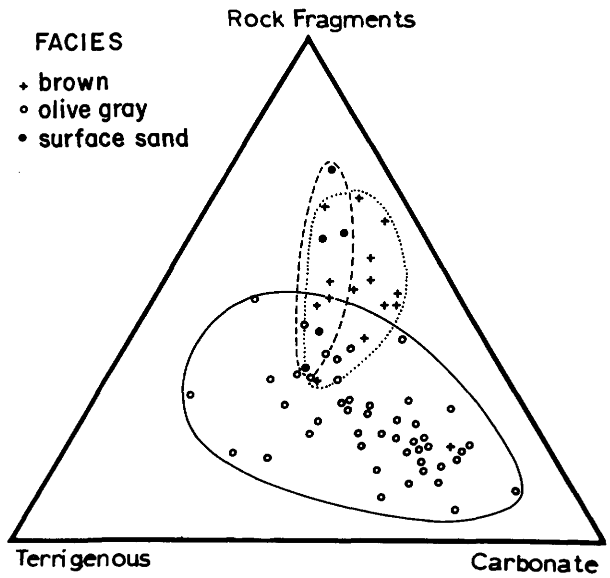



FIGURE 62.—Coarse fraction mineralogical components in three facies cored (Sc cores) on the continental slope.

These fluctuations of both groups are random, however, and no distinct tendencies were noted within the three major Nova Scotian Slope sediment types (surface sand, olive gray and brown facies).

*The olive gray and reddish brown sediment types are most easily distinguished by their accessory components:* a predominantly calcareous fraction in the gray sediment facies, and predominantly terrigenous assemblage in the brown facies. The same lithic fragments are found in both sediment facies, but brown sediments generally show a greater variety of petrologic types in any one sample as well as a higher proportion of red-colored sedimentary fragments. This contrast was noted clearly in analyses of coarse sand in brown and olive gray sediment types in representative core Sc-16.

The quartz-feldspar fraction also tends to be more inportant in brown sediment, while glauconite and carbonate fragments are more abundant in the gray facies. There does not appear to be a major difference in content of dark terrigenous grains in the two sediment types. The absolute amount of mica, Foraminifera, and shells is lower in the brown sediment type, but the relative proportions generally remain the same in both olive gray and brown sediments.

The abrupt change of lithology at a depth of 210 cm in core Sc-16 reflects the contact between the reddish-brown and the gray sediments. A plot of rock fragments, total carbonate, and total terrigenous fraction on a triangular diagram emphasizes mineralogical differences between the two facies (Figure 62). Figure 62 highlights the greater variability of carbonate fraction in the gray sediment type and the higher amount of rock fragments in brown sediment.

The relatively clean sand facies found at the top of some cores (samples Sc-9-1, Sc-13-5, and Sc-15-0) consists of predominantly terrigneous components; the accessory fraction of the sand is mostly rock fragments. The similarity of the upper sand layer and the sand fraction in the brown facies is noteworthy.

The concentration of heavy minerals in the 62 to 500$\mu$ size range is low; the total weight of the heavies recovered is generally less than 1 percent and only rarely exceeds 2 percent (Figure 63). The variation in amount of heavy minerals is similar to that of light and dark terrigenous components. The abundance of heavy minerals does not vary significantly between the brown and gray sediments. Sediments that are fine grained generally contain a higher proportion of heavy minerals which, because of their small inherent size, tend to be concentrated in the finer sand grades.

Opaque grains account for 20 to 60 percent (most commonly between 25 and 35 percent) of the heavy-mineral fraction. The abundance of nonopaque mineral species forming the predominant suite and found in all samples is shown in Figure 64. Hornblende is the most abundant transparent heavy mineral encountered (relative percentages range from 10 to 42 percent, but most frequently from 25 to 35 percent). Garnet accounts for 10 to 30 percent of the heavies, but individual counts vary widely between these limits. Hypersthene ranges from 5 to 20 percent (generally about 12 percent). Augite may account for as much as 20 percent of the heavy mineral counts but, like garnet, is a mineral showing much variability from sample to sample.

Other heavy mineral species show considerably more variation from sample to sample. Altered minerals, for example, are the most commonly encountered grains (to 24 percent) making up this accessory suite. Andalusite, zircon, and tourmaline are found in almost all of the 21 Sc-core samples analyzed, and each may attain 8 percent of the sample. Epidote and staurolite, not as common, form up to 10 percent

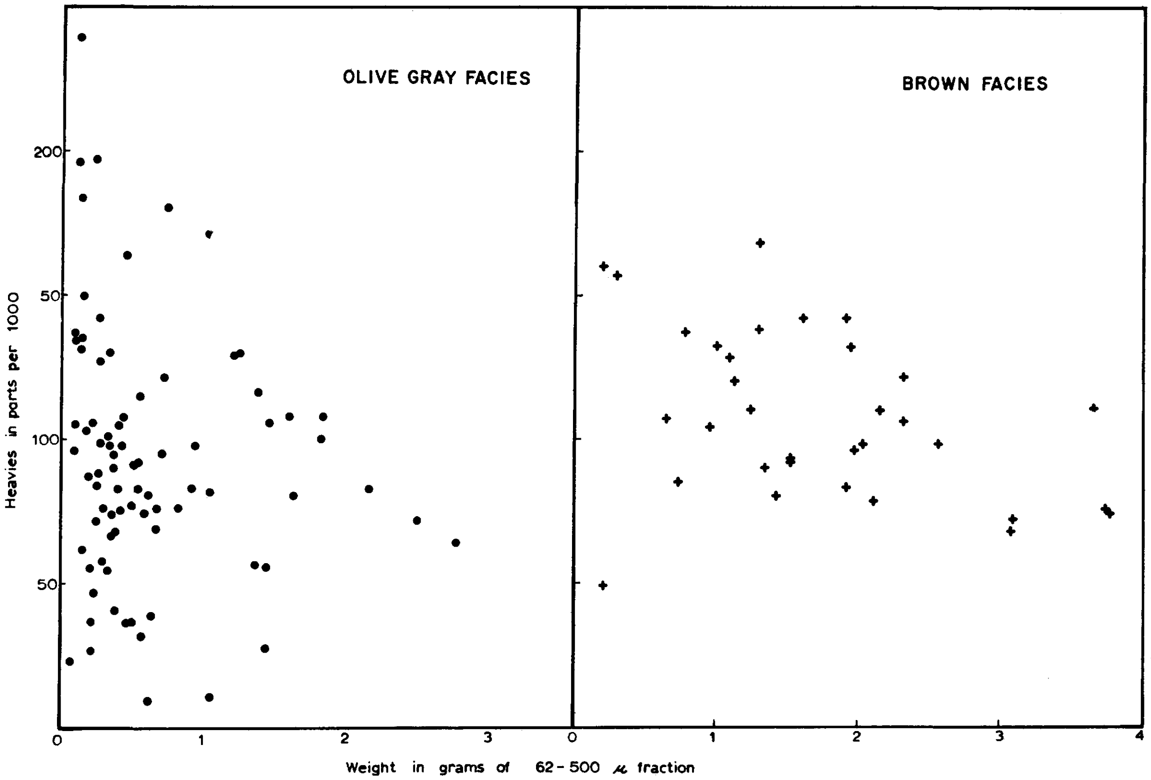



FIGURE 63.—Concentration of heavy minerals in the olive gray and brown sediment types.

and 5 percent of the nonopaques, respectively. Saussurite, occurring in six samples, ranges from 3 to 11 percent. Titanite, mica, brookite, kyanite, chloritoid, and sillimanite are encountered infrequently. The regional uniformity of both predominant heavy and accessory mineral suites is noteworthy. Furthermore, there does not appear to be a notable difference between heavy mineral assemblages of the brown and the olive gray sediment facies (Figure 64).

### *Upper Slope to Rise Traverse*

The coarser than 62 micron fraction of samples from the slope-rise traverse (cores HUD 30-9 to 14) was sieved into five Wentworth-Udden size classes, and each fraction was weighed and percentages computed. The sand-size and coarser components observed were clean (nonstained) quartz and feldspar grains, iron-stained quartz and feldspar grains, reddish rock fragments, gray rock fragments, shell debris, Foraminifera, and glauconite. Counts were made of each of these components in each size fraction according to the technique described by Shepard (1963). Two hundred grains were counted when sufficient sand-size material was available. Those samples where there were less than 200 grains available for counts can be identified in Figure 65: if all fractions of a sample weighed less than 0.05 grams, then each fraction was arbitrarily assigned an equal share of the size distributed, and columns of the histograms are therefore equal in height (example: HUD 30-11, sample 15-17). If some fractions weighed over 0.05 grams and some weighed less, then the former were assigned their correct weight on the histogram, while each of the latter received an equal share of the remainder. In the mineralogical analyses shown in Figure 65, where two or more histogram columns are of equal height, their counts are less than 200 grains, and their weight percent values are arbitrary. The single exception is core sample HUD 30-9A-35-37, whose two columns are, coincidentally, of equal weight.

After foraminifers and heavy minerals were extracted, the residue was stained for feldspar following the methods of Keller and Ting (1950).

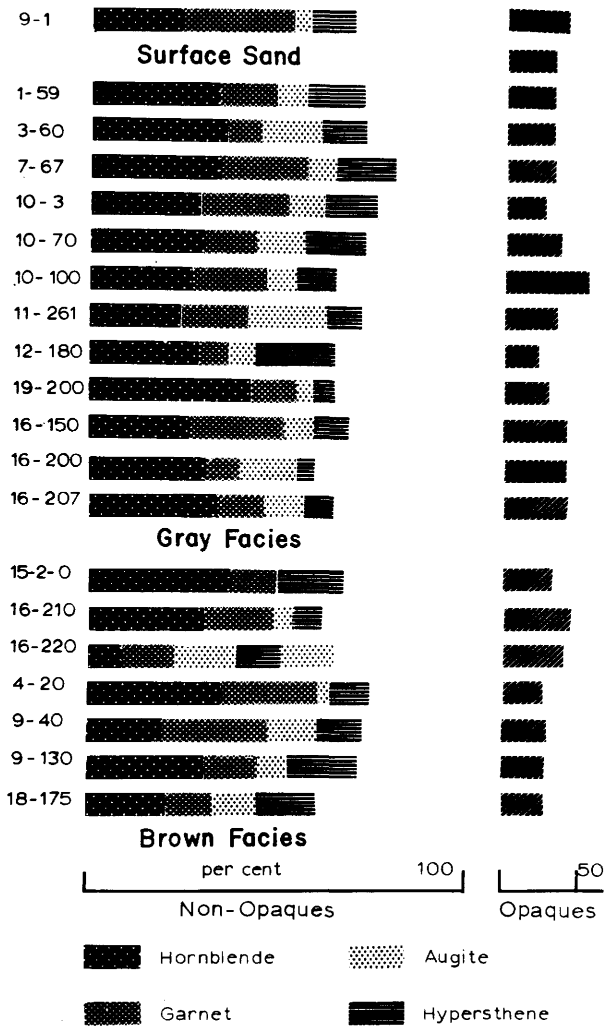



FIGURE 64.—Principal heavy minerals suite in surface sand, olive gray and brown sediment types from cores (Sc) collected on Nova Scotian Continental Slope.

Quartz is the most abundant of the major terrigenous constituents, ranging between 70 and 96 percent (Figures 66, 67 and Table 2). The grains are predominately subangular to subrounded (Powers 1953) and of the common quartz variety (Folk 1964). Well-rounded grains of medium to coarse sand are present in trace amounts. Silica overgrowths were noted on several of these, and the grains are believed to be derived from Paleozoic sandstones of the Maritime Appalachians.

A variety of quartz which appears to be of significance to this study is stained with iron oxide (Figure 68). The coating ranges in color from moderate red (5R 4/6, Rock Color Chart Committee, 1963) through dusky red (5R 3/4), and dark yellowish orange (10YR 6/6) to moderate brown (5YR 3/4). Under the binocular microscope, iron-stained grains appear filmed with opaque, earthy matter that is thin to absent on convex surfaces, but thick and clotted on concavities and fissures. This distribution suggests that the coatings predate transportation, during which process the coatings were partially removed by abrasion. There are at least two earlier stages in the present sedimentary cycle where the coatings might have been formed. Emery (1965:5) described the Atlantic shelf of North America as floored primarily by sands that are "coarse . . . iron-stained, and somewhat solution pitted." Emery concludes that these sands are relict stream and littoral deposits from Pleistocene low stands of the sea. The iron coatings of the grains may have formed also during subaerial weathering of the original Piedmont source area (Judd et al. 1969). It may have formed in part during the present stage of the sedimentary cycle, during subaerial exposure of the shelf, due to mobilization of iron hydroxide present in the fine fraction of the sediment (Van Houten 1968) or from intrastratal solution of iron hydroxides and oxides (Van Houten 1968, Norris 1965). The coatings may conceivably still be forming on the coarser sands of shallow banks where bottom circulation is sufficient to provide a flow of aeriated water, but not sufficiently intense to abrade grain surfaces. As noted in earlier sections, similar iron-stained sands are abundant on the Nova Scotian shelf (Stanley and Cok 1968), including Sable Island Bank.

In addition, the iron-stained quartz of our cores probably received parts of its pigment during an earlier sedimentary cycle. Conolly et al. (1967:131), for instance, describe reddish-brown glaciomarine sediments from the Laurentian Channel between Nova Scotia and Newfoundland which contain "Calcite, quartz, and feldspar grains with relic iron oxide rims and red calcite-cemented lithic sandstone fragments and arkosic rock fragments derived principally from Triassic (and/or Carboniferous-Permian) sediments of Appalachian Canada or from their reworked derivations." Calcite-cemented reddish sandstone fragments are present in some of our cores as Conolly and others have described them. Some of these fragments were sufficiently friable to break down to iron-stained sand grains as we manipulated them. Iron-

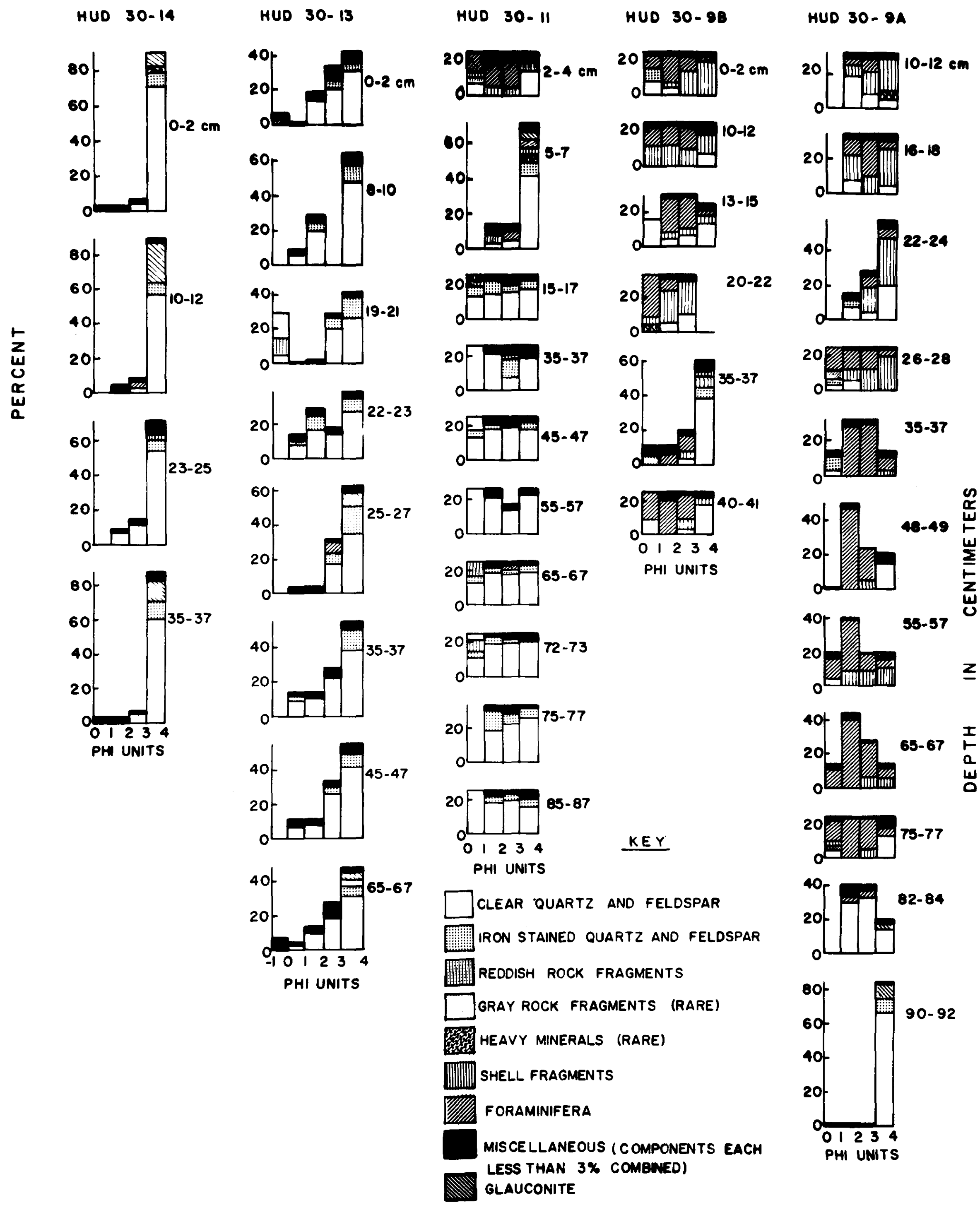



FIGURE 65.—Mineralogical analysis showing frequency distributions of the coarse fraction of samples from slope and rise (HUD-30) cores southeast of Sable Island Bank (see Figures 15 and 18 for core locations).

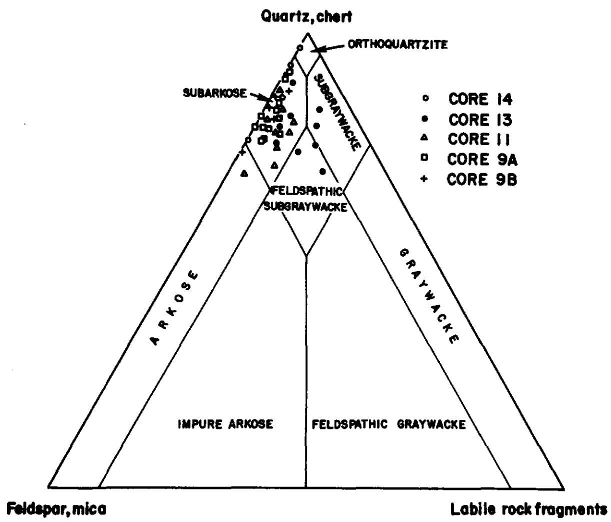



FIGURE 66.—Composition of coarse fractions of slope and rise (HUD-30) core samples in terms of major terrigenous components (classification after Folk 1954).

stained quartz correlates more closely with clear quartz than with reddish rock fragments (Figure 68). We believe, however, that this is a sorting phenomenon rather than an indication of genesis, and that iron-stained quartz in our cores is of both Pleistocene and Paleozoic origin, in a ratio that we have no means of determining.

Feldspar grains comprise 4 to 27 percent, and average 17 percent of the major terrigenous constituents. The potassium feldspar is predominantly orthoclase, and is more abundant (62–82 percent) than plagioclase. Less than 5 percent of the feldspar grains are sufficiently altered to be distinguished from quartz without staining.

Rock fragments comprise less than 10 percent of the terrigenous constituents of the coarse fraction (Figure 65). Pale yellowish-brown (10YR 6/2) to olive gray (5Y 4/1) siltstones comprises 53 percent of all rock fragments, and dusky red (5R 3/4), moderate red (5R 4/6), and dark reddish brown (10R 3/4) comprise 30 percent (Figures 67, 69). Fine-grained rock fragments with marked foliation (slates or shales) comprise 8 percent of the rock fragments. Gneiss, granite, amphibolite, and red and gray sandstone fragments are present in trace amounts. The sourceland for the study area, the Canadian Maritimes consists of three terrains: (1) a terrain of low to medium grade metasediments and metavolcanics of lower Paleozoic age intruded by granite; (2) Permo-Carboniferous basins containing reddish, drab, and greenish-gray, coarse to fine continental clastics; and (3) more restricted Triassic basins containing a similar sequence. The suite of lithologies present in our samples reflect original lithologic frequency distributions strongly modified by selective destruction of the mechanically unstable very fine and very coarse-grained rock types.

The sole rock type that is sufficiently abundant and distinctive to be considered a tracer is a fine- to coarse-grained, reddish sandstone. Its composition ranges from subgraywacke to subarkose. The pigment ranges from dusky red (5R 3/4) through moderate red (5R 4/6) to moderate reddish brown (10R 4/6). Some fragments have a carbonate cement; others have no obvious cement. These fragments closely resemble the ones described by Conolly and others (1967) from the Laurentian Channel. These workers suggest that the fragments were derived from the Triassic and Permo-Carboniferous rocks of Prince Edward Island and Nova Scotia. The fragments in our cores, however, might also have traveled directly across the Nova Scotian Shelf (Stanley and Cok 1968); reddish tills, derived from the Triassic and upper Paleozoic of Northern Nova Scotia (Grant 1963) are, in fact, exposed along the sea cliffs on the Atlantic Coast of Nova Scotia.

Glauconite comprises up to 10 percent of the coarse fraction (Table 1). Grains range from a moderate greenish-yellow color (10Y 7/4) and a frequently irregular shape to a dusky green (5G 3/2) or greenish-black (5G 2/1) variety which is commonly ellipsoidal and subrounded to rounded or rounded/broken. The mineral is confined to the very fine sand fraction, where its relative abundance correlates closely with the relative abundance of quartz and also with the relative abundance of this size fraction. Both light and dark glauconite were noted in HUD-30 cores; grains with lightness values of 5 or greater (equivalent to medium dark gray or darker) comprise 69 percent. There is apparently no statistically significant difference between the light to dark glauconite ratios of the two most glauconitic-rich cores (i.e., HUD 30-14 on the slope and HUD 30-13 on the upper rise).

Dill (1968), in a detailed analysis of glauconite on the North Carolina continental slope, detected a systematic variation in color and properties of this

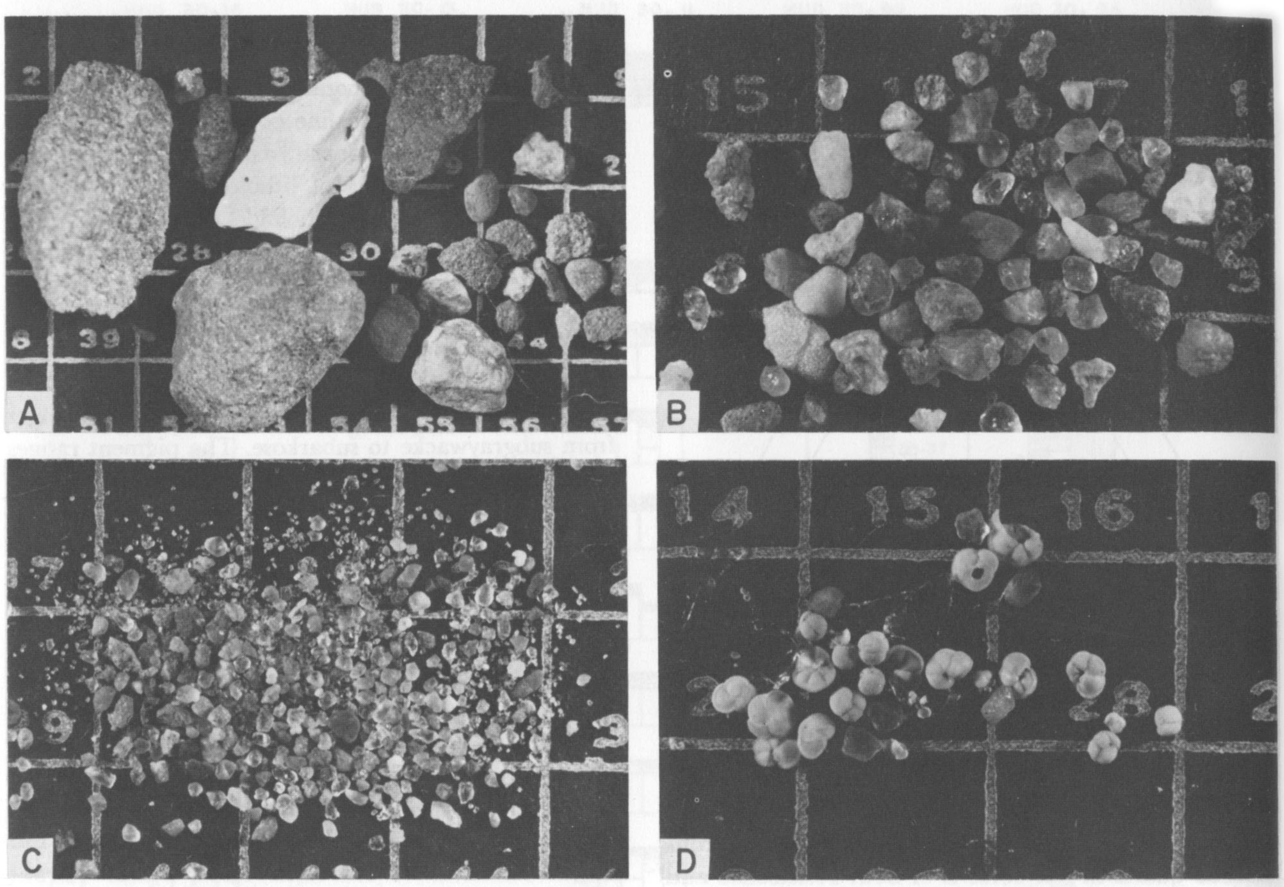


FIGURE 67.—Photo-micrographs illustrating coarse fraction assemblages in slope and rise (HUD-30) cores (see also Figure 65). A, brown facies on upper rise (core 13, 19 to 21 cm): very coarse fraction showing small gray and red sandstone pebbles, basalt pebbles, and shell fragment. B, brown facies on upper rise (core 13, 8 to 10 cm): coarse sand fraction showing clear and iron-stained quartz and rock fragments. C, olive gray facies on slope (core 14, 10 to 12 cm): very fine sand showing terrigenous fraction with abundant glauconite. D, tan facies on lower rise (core 9A, 55 to 57 cm) coarse sand fraction showing biogenic assemblage with abundant Foraminifera.

mineral: the darker glauconite exhibited better crystallinity, greater thermal stability, and a lower water content; dark, well-rounded glauconite predominates on the upper slope, while lighter, more poorly rounded glauconite predominates on the lower slope. The two populations represent (1) a detrital population of dark, well-rounded grains weathering out of pre-Recent rocks cropping out, or formerly cropping out, on the outer shelf and upper slope, and (2) a ubiquitous authigenic population associated with the foraminiferal slope sediments. The predominance of dark glauconite in Nova Scotian margin samples suggests that either the authigenic source is not as important on the Nova Scotian slope, or that authigenic grains, which Dill determined to be fragile relative to the detrital group, have been selectively destroyed during transport. Hubert and Neal (1967) in their study of the North Atlantic petrologic province have also noted a correlation between the abundance of very fine glauconite and very fine quartz sand, and concluded that the two had been sorted during concurrent transport.

Shell hash and Foraminifera are also significant components of the coarse fraction (Figure 67). Either component may comprise up to 70 percent (Figure 70); together as much as 90 percent. The two cate-

TABLE 2.—*Relative abundance of light fraction components in slope and rise (HUD-30) cores collected south of Sable Island Bank*

| Core (Increasing depth ↓) | Clean Quartz and Feldspar | Iron-stained Quartz and Feldspar | Reddish rock fragments | Gray rock fragments | Heavy minerals | Shell fragments | Foraminifera | Glauconite | Number of samples averaged |
|---|---|---|---|---|---|---|---|---|---|
| HUD-30-14 | 70.62 | 9.73 | 0.44 | 0.93 | 2.20 | 1.68 | 2.85 | 8.38 | 5 |
| HUD-30-13 | 66.38 | 16.72 | 3.60 | 5.92 | 2.17 | 0.70 | 2.47 | 3.37 | 8 |
| HUD-30-11 | 55.58 | 13.28 | 4.06 | 2.08 | 2.96 | 6.49 | 8.10 | 1.19 | 11 |
| HUD-30-9B | 20.43 | 4.64 | 0.05 | 0.70 | 1.34 | 31.68 | 39.80 | 0.21 | 5 |
| HUD-30-9A | 26.18 | 4.53 | 0.45 | 1.76 | 1.33 | 20.53 | 44.64 | 1.41 | 11 |

gories are not completely exclusive of each other, in that a significant portion of the shell hash consists of comminuted foraminifers. Pelecypods, gastropods, bryozoans, and calcareous algae are also common in shell-rich samples; diatoms, radiolarians, and chitinous or otherwise noncalcareous fragments are also observed. Fish vertebrae were occasionally observed in the very coarse sand fraction.

A triangular plot of the major terrigenous "light" components (Figure 66) indicates that most samples have coarse fractions that are subarkosic in composition. The most quartzose sand fractions are those of olive gray slope core HUD 30-14, and the most lithic are sand fractions of brown continental rise core HUD 30-13. These variations may be attributed, at least in part, to grain-size control as HUD 30-14 has the finest sand fractions and HUD 30-13 the coarsest.

The transparent heavy mineral suite observed in the five slope and rise HUD 30 cores (Figure 71) is the same as that observed in the upper slope (Sc-) cores (Figure 64). Heavy minerals in cores HUD 30-14 (gray slope facies) and HUD 30-9 (light tan lower rise facies) are very similar and can be distinguished from the brown facies of cores HUD 30-13 and HUD 30-11 on the upper rise. The former two cores contain almost 50 percent (range 40 to 54 percent) hornblende, and approximately 6 to 9 percent (range 4 to 17 percent) garnet and about the same amount of epidote. The latter two core samples (brown sediment type on the rise) contain less hornblende (range 18 to 35 percent) and epidote (range 1 to 12 percent), but relatively more garnet (5 to 39 percent). The upper rise core HUD 30-13 comprises a high (> 23 percent) percentage of altered ("alterite") grains; core HUD 30-11 contains a somewhat higher (> 11 percent) metamorphic suite (staurolite, kyanite, etc.)

*The heavy mineral suites of the slope and rise are the same as those on Sable Island Bank although the proportion of mineral types differs.* On the bank the relative percent of garnet generally exceeds that of hornblende (James and Stanley 1968) while on the slope and rise the relative percent of hornblende is invariably higher than garnet. This difference can probably be attributed to size sorting (e.g., generally finer sediments on the slope than on the shelf would contain a lower amount of garnet, an inherently large mineral).

Samples of Lamont-Doherty cores collected on other parts of the outer margin south of Nova Scotia also show a similar suite of minerals (Figure 72, Table

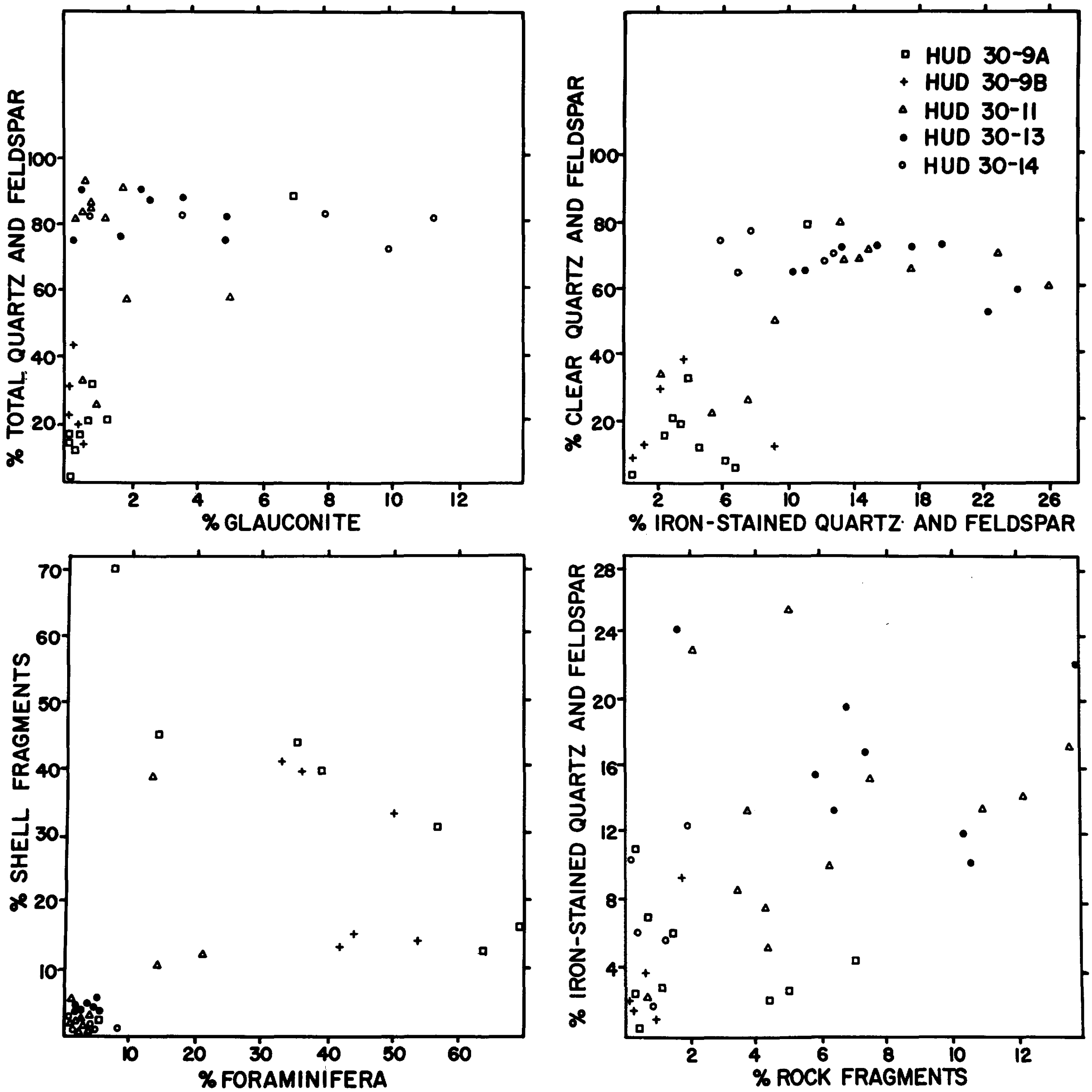



FIGURE 68.—Scatter plots of selected pairs of coarse fraction components in slope and rise (HUD-30) cores.

3). In most of these samples, garnet plus hornblende account for approximately half of the mineral suite. In several cases, the amount of garnet exceeds that of hornblende. The proportion is generally related to grain size, i.e., higher amounts of garnet are generally found in samples of coarser grain size.

## Clay Mineralogy on the Outer Margin Off Nova Scotia

### *Slope off Sable Island Bank*

METHODS.—X-ray diffraction was used to identify dominant clay mineral suites in the fine fraction of

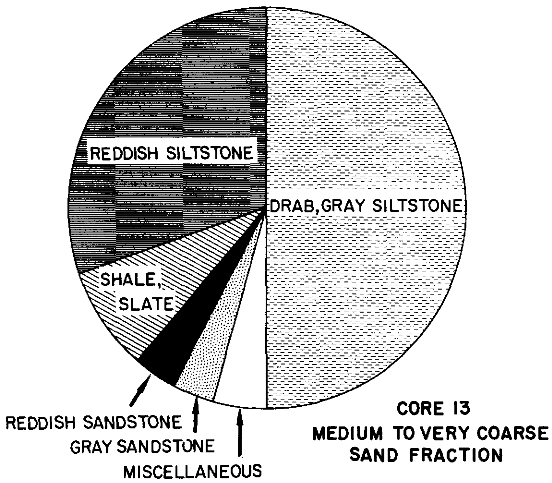



FIGURE 69.—Relative abundance of lithic fragments in coarse fraction of samples of core HUD-13 collected on the rise south of Sable Island Bank.

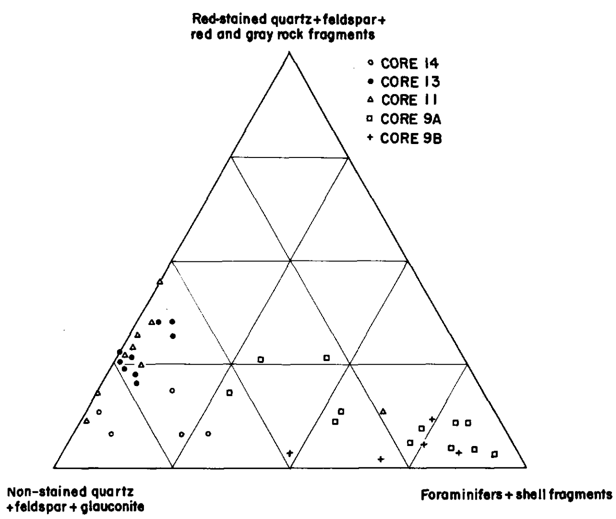



FIGURE 70.—Triangular plot of coarse fraction suites in slope and rise (HUD-30) cores.

cores (Sc) on the slope off Sable Island Bank. Standard methods used are detailed in Silverberg (1965). The scattering factors developed by Freas (1962) have been used to determine approximately clay mineral (illite, kaolinite, montmorillonite) percentages.

Other minerals identified in the clay fraction are chlorite, quartz and feldspar. The former was identified by the strong 101 reflection at 3.3Å and by a weaker 100 line at 4.3Å. Feldspar was inferred from the presence of one, and sometimes two, lines in the range 3.16–3.21Å. An occasional shoulder along the high angle side of the 7Å reflection also suggested a 7.5Å reflection of feldspar.

The most accurate method of analysis involves the comparison of peak areas with those of internal standards or of prepared standard mixtures; in our case the assumption has been made that the peak area are proportional to the relative quantities of the components present (Johns, Grim, and Bradley 1954).

Before peak areas were measured, the background level and the lower portions of each peak were smoothed with French curves. Taking the average of at least four planimeter readings, the areas of the 001 reflections about 14.2, 10.0, and 7.1Å were recorded for the untreated sample. Using the same background line and peak widths, the areas of the 14Å and the 7Å peaks were measured on glycolated and the HCl treated samples, respectively.

Illite was measured as the area of the untreated 10Å peak, chlorite the area of the glycolated 14Å peak, kaolinite the area of the HCl treated 7Å peak, and montmorillonite, the difference in area of the 14Å reflection before and after glycolization.

To determine the approximate composition, the illite area was multiplied by three, the chlorite area divided by three, and then the total corrected areas added. The relative percentages of the various components were then computed and converted to parts per ten of the total. The peak areas of different components are not directly comparable because of variations in the ability to scatter X-rays.

The decision to use the HCl treated value of the 7Å peak as the kaolinite contribution involves the assumptions that all of the chlorite contribution is removed by this treatment, and that the area is not altered by acid attack on the kaolinite. An estimate of the reproducibility of the procedure was made by the examination of several slides sampled from the same suspension. The diffractograms were virtually identical, save for errors accountable by instrument variation.

RESULTS.—Relative percentages of illite, chlorite, montmorillonite, and kaolinite were obtained for eight samples (Table 4). Illite is the dominant clay mineral, making up as much as 88 percent of the Sc core samples (using Freas' scattering factors). Kaolinite ac-

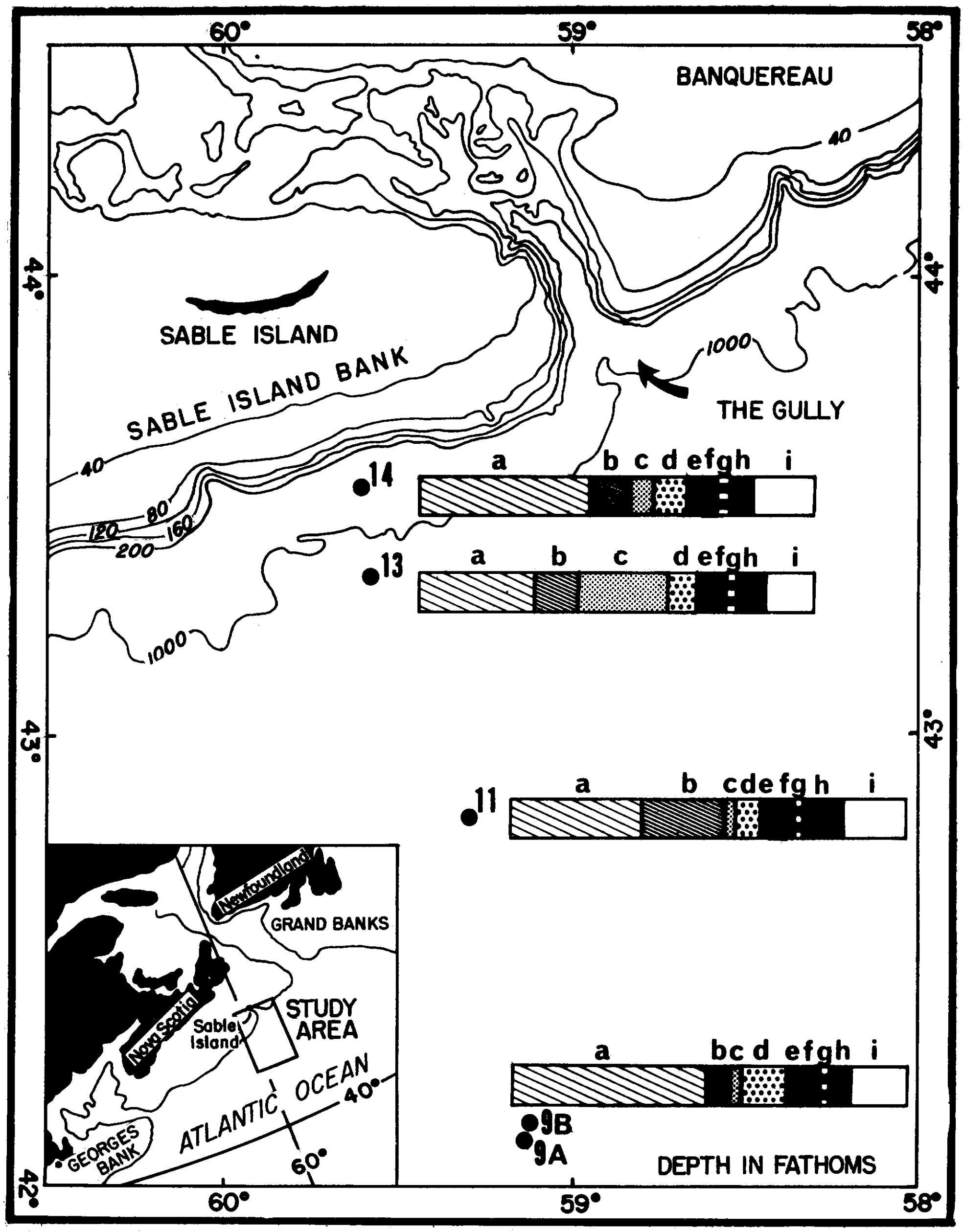



FIGURE 71.—Relative percentages of transparent heavy minerals observed in core (HUD-30) samples south of Sable Island Bank. *a*, hornblende, *b*, garnet; *c*, alterite; *d*, epidote; *e*, zircon + tourmaline + rutile; *f*, augite; *g*, hypersthene; *h*, metamorphic suite (staurolite, kyanite, etc.); *i*, other minerals.

counts for 2 to 11 percent, montmorillonite 3 to 7 percent, and chlorite between 2 to 5 percent. These percentages are only approximate.

Noteworthy is the uniformity of the clay mineral suite in the different slope facies. The uniformity of this assemblage within a representative slope core (Sc-16) penetrating both olive gray and brown sediment types is illustrated in Figure 73. The consistency

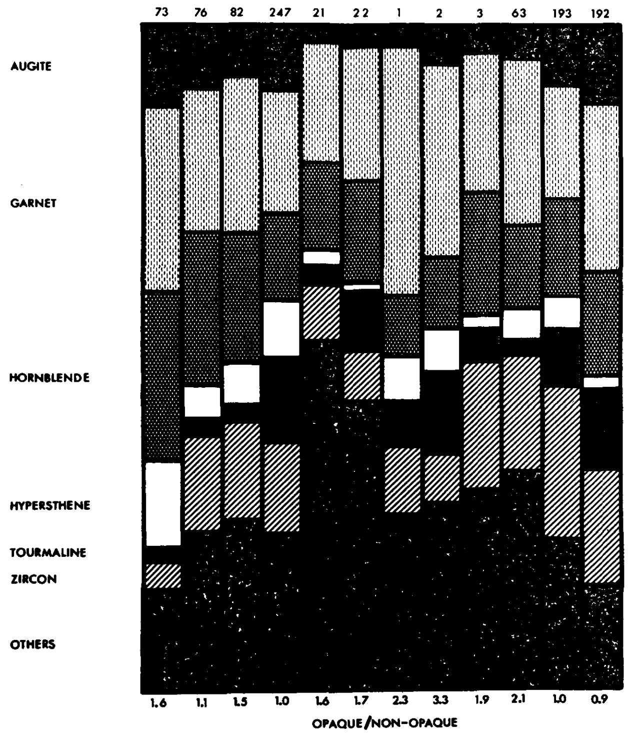



FIGURE 72.—Variation in relative percentages of the more abundant nonopaque heavy minerals from 12 Lamont-Doherty core samples collected south of Nova Scotia. Numbers at top refer to "laboratory code" in Table 1. Data arranged with shallower (Nova Scotia Slope) core samples at left to deep-water (Sohm Abyssal Plain) samples at right. Opaque to nonopaque heavy mineral ratio is given at bottom. Heavy mineral data is also listed in Table 3.

of the clay mineral suite on a regional basis is shown in diffractograms of samples taken from different slope cores (Figure 74). Differences determined in the semiquantitative study are slight and are well within experimental errors of this technique.

### *Slope and Rise Traverse South of Sable Island Bank*

METHODS.—Samples were selected for clay mineral analysis from the top and base of each HUD 30 core in order to evaluate the mineral suites present in sediment facies on the slope and rise along the traverse south of Sable Island Bank. The results cited in the following study were obtained by T. T. Davies (personal communication).

Samples were disaggregated and treated to remove calcium carbonate and iron by the procedure described by Biscaye (1965) which was modified from Jackson (1956). The procedure fully described by Biscaye (1965) was closely adhered to in both sample preparation and X-ray data treatment. Gravity settlement followed by controlled centrifugal sedimentation was used to isolate the < 2 micron fraction which had been saturated with calcium ions. Oriented clay precipitates were made on glass plates from equal density clay slurries.

A Norelco X-ray diffraction apparatus was used with a wide range goniometer and a proportional counter using pulse height analysis and Copper K radiation. An A.M.R. lithium fluoride monochromator was used to reduce low angle scattering and produce monochromatic K radiation. Each sample was scanned at various speeds over the required angular ranges in an untreated state, and after glycolation and heat treatment to 250°C and 450°C.

The mineral phases identified from the diffraction traces consist almost entirely of clay minerals identified as illite, chlorite, kaolinite, and montmorillonite. Small quantities of quartz, feldspar, and amphibole can be identified in each sample, but they do not form a significant contribution to the sample mineralogy, and consequently they have been ignored in the quantitative estimates of the mineral contents of the samples.

The peak areas obtained from the various glycolated samples of the 10Å illite, the 17Å expanded montmorillonite, and the chlorite and kaolinite peak that occurs at approximately 7Å were measured on the diffractometer charts, after background smoothing. The 3.54Å kaolinite peaks could be separated on charts obtained from the untreated samples. The ratio of these peak areas was used to define the areal contribution provided by each mineral to the 7Å glycolated peak (Biscaye 1965). Replicate areal measurements on the montmorillonite peak exhibited great variation because the peak is located in a region of rapidly changing background and because the poorly crystalline mineral occurs in such small quality.

Two methods have been used in estimating the relative abundance of the clay mineral phases in the various samples. The relative abundance of two particular minerals is expressed as a simple ratio of their analysis peaks. A semiquantitative estimate of the actual abundance of the clay minerals in the samples has been made by using scattering factors and weighting the peak areas. The mineral concentration is then expressed as a percentage of the sum of the weighted

TABLE 3.—*Relative percentages of heavy minerals in samples from the rise and Sohm Abyssal Plain (Lamont-Doherty cores) south of Nova Scotia (see also Figure 72). Numbers at top refer to samples identified in the laboratory code column in Table 2*

| | H-73 | H-76 | H-82 | H-247 | H-21 | H-22 | H-1 | H-2 | H-3 | H-63 | H-193 | H-192 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Andalusite | 0.3 | 1.1 | 0.6 | 2.2 | 2.8 | 1.7 | 2.9 | 1.9 | 2.2 | 0.3 | 1.4 | |
| Apatite | 0.3 | 2.0 | 4.8 | 3.7 | 1.8 | 2.6 | 2.6 | 1.5 | 7.2 | 0.9 | 7.4 | 5.4 |
| Augite | 12.0 | 9.1 | 7.6 | 8.2 | 2.1 | 2.9 | 3.2 | 5.6 | 3.8 | 4.5 | 8.6 | 11.5 |
| Chlorite | 4.5 | 3.5 | 1.6 | 3.7 | 11.1 | 6.9 | 3.9 | 7.1 | 2.7 | 11.9 | 4.1 | 1.7 |
| Clinozoisite | | | | | 1.0 | 1.4 | 0.3 | | | | | |
| Corundum | | | | | | | 0.6 | | | | | |
| Diopside | 0.3 | | | | | | 1.0 | 0.1 | 1.2 | | | |
| Enstitite | 1.3 | 2.4 | 1.7 | | | 4.3 | | | | 2.7 | | |
| Epidote | 2.9 | 2.4 | 5.1 | 3.0 | 4.5 | 4.9 | 1.3 | 0.1 | 1.8 | 3.3 | 2.7 | 0.3 |
| Garnet | 28.0 | 22.0 | 23.9 | 15.7 | 18.1 | 20.0 | 37.2 | 28.9 | 20.9 | 25.3 | 17.2 | 25.3 |
| Hornblende (Blue-Green) | 10.1 | 4.0 | 5.4 | 4.1 | 5.6 | 7.2 | 5.8 | 7.2 | 11.7 | 3.9 | 4.5 | 5.7 |
| Hornblende (Common) | 15.4 | 18.9 | 13.6 | 7.1 | 7.8 | 8.3 | 3.5 | 3.7 | 7.0 | 8.9 | 10.3 | 10.2 |
| Hypersthene | 13.0 | 4.9 | 6.5 | 7.5 | 2.4 | 1.4 | 6.4 | 6.6 | 2.2 | 4.5 | 4.8 | 1.7 |
| Kyanite | 0.3 | 1.1 | 0.6 | 0.7 | 4.9 | 2.6 | 1.6 | 4.2 | 2.2 | 0.3 | | 1.0 |
| Monazite | 0.8 | 2.0 | 0.6 | 0.4 | 1.8 | 1.1 | 1.3 | 0.1 | 1.2 | 0.3 | | 0.3 |
| Rutile | 0.3 | 1.6 | 1.6 | 0.4 | 1.4 | 0.6 | 1.0 | 0.1 | 0.7 | 2.1 | 4.0 | 0.3 |
| Sillimanite | | 0.2 | | 0.7 | 3.8 | 0.6 | 1.3 | | 1.7 | | | |
| Sphene | 0.7 | 3.1 | 2.8 | 2.6 | 4.9 | 3.1 | 1.3 | 6.7 | 5.5 | 2.7 | 1.4 | 0.7 |
| Spinel | | | | | | | 2.6 | 2.8 | 1.0 | | | |
| Staurolite | 1.6 | 1.5 | 3.1 | 0.7 | 8.0 | 9.2 | 2.3 | 3.3 | 0.8 | 5.1 | 0.3 | |
| Topaz | | 0.9 | 0.3 | 0.4 | 0.7 | 0.1 | 1.6 | 0.1 | 0.7 | 0.3 | 0.3 | 2.0 |
| Tourmaline | 2.0 | 2.9 | 2.5 | 10.8 | 3.1 | 8.9 | 7.1 | 12.4 | 5.0 | 2.4 | 8.6 | 12.5 |
| Tremolite | 1.3 | 1.5 | 2.5 | 1.9 | 2.8 | 2.3 | 0.3 | | 1.4 | 2.7 | 3.8 | 4.0 |
| Zircon | 4.2 | 14.5 | 14.9 | 11.6 | 8.3 | 7.5 | 10.4 | 7.5 | 18.8 | 17.3 | 23.2 | 17.4 |
| Zoisite | 1.3 | 0.4 | 0.3 | | 3.1 | 1.1 | 0.6 | 0.1 | 0.3 | 0.6 | | |
| Non-opaque grains counted | 309 | 455 | 354 | 230 | 287 | 349 | 310 | 217 | 598 | 335 | 291 | 298 |

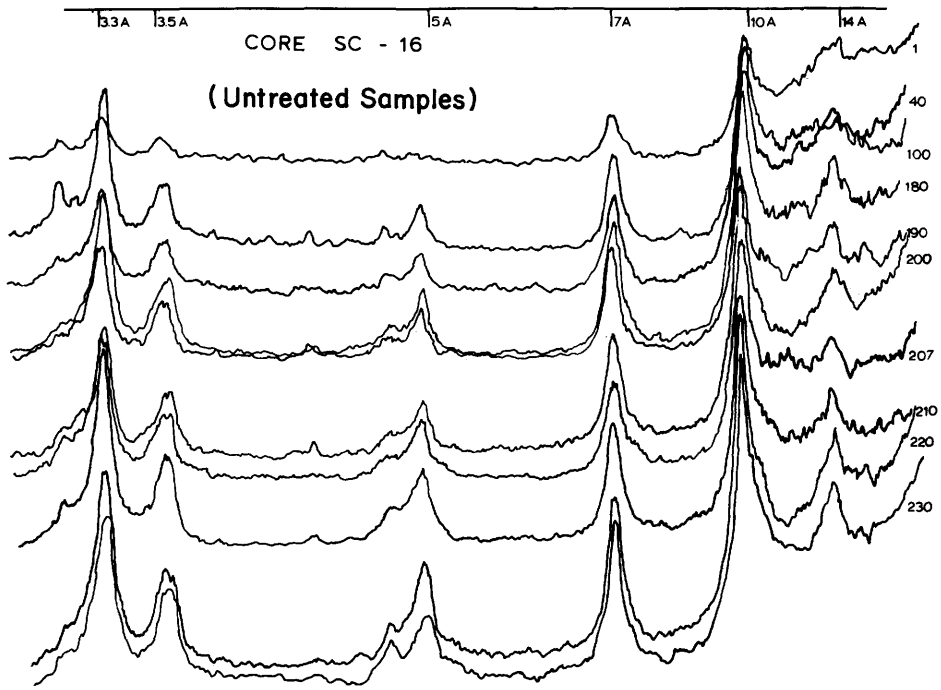



FIGURE 73.—Nova Scotian slope core Sc-16, diffractograms of less than 2 micron fraction. Numbers on right refer to depth (in cm) in core (see Figure 14).

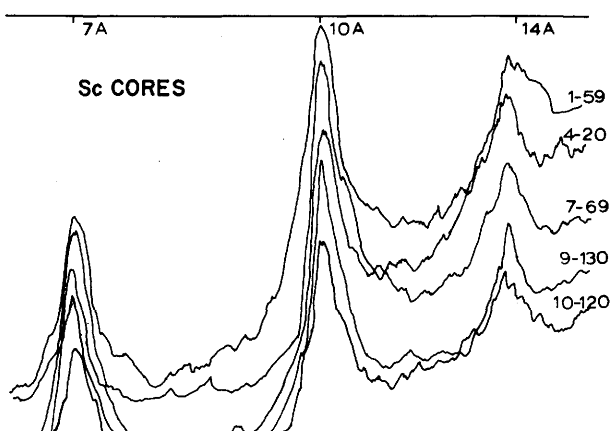



FIGURE 74.—Diffractograms of less than 2-micron fraction, slope core samples (Sc-1, -4, -7, -9, and -10) collected on the slope south of Sable Island Bank. Numbers following hyphen on right refer to depth (in cm) in core (see Figure 14).

peak areas assuming that the clay minerals account for 100 percent of the sample mineralogy. To retain consistency with Biscaye's methods the following weighting factors have been used: four times the illite 10Å peak, the area of the montmorillonite peak and twice the area of the 7Å peak which is divided proportionally between kaolin and chlorite [Biscaye (1965), following Johns, Grim, and Bradley (1954), and Weaver (1961)].

RESULTS.—The peak area ratios and the constructed mineral percentage are listed in Table 4 together with the mean clay mineral estimates of Sc core samples and values given by Biscaye for the surface sample of a Lamont-Doherty core taken closest to the samples collected for this study. Sample SAC-96 was obtained at a depth of 440 m on the upper slope (above core HUD 30-14). Although there is considerable variation in the physical properties of the sediment within a single core there is no significant consistent variation in the clay mineral content. The same suite of clay minerals characterizes each of the core samples analyzed by Biscaye (1965) and Conolly et al. (1967) from this geographic region. Conolly et al. (1967, page 145) note a decrease in the percentage of kaolinite with time (from brown Pleistocene to gray Holocene facies) in the Gulf of St.

TABLE 4.—*Predominant clay minerals measured in samples from the slope and rise south of Sable Island Bank. Percentages are only approximate. Results of Lamont-Doherty core sample (164-47/5) studied by Biscaye (1965) are listed for comparison. Location of sample SAC 96 is shown as station 96 in Figure 3*

| SAMPLE NUMBER | WEIGHTED PEAK AREA PERCENTAGE | | | | PEAK AREA RATIOS | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | WATER DEPTH (METERS) | KAOLIN | CHLORITE | MONTMORIL-LONITE | ILLITE | K/C 3.58Å/3.54Å | K/I 7Å/10Å | K/M 7Å/17Å | C/I 7Å/10Å |
| SAC 96 | 440 | 7 | 13 | 1 | 79 | 0.54 | 0.18 | 3.52 | 0.32 |
| HUD-30-14 TOP | 1326 | 7 | 14 | 7 | 73 | 0.49 | 0.18 | 0.49 | 0.37 |
| BASE | | 9 | 11 | 7 | 73 | 0.83 | 0.25 | 0.69 | 0.30 |
| HUD-30-13 TOP | 2222 | 5 | 23 | 2 | 71 | 0.17 | 0.13 | 1.37 | 0.42 |
| BASE | | 7 | 16 | 2 | 75 | 0.42 | 0.18 | 1.53 | 0.43 |
| HUD-30-11 TOP | 3795 | 10 | 17 | 5 | 69 | 0.58 | 0.28 | 0.95 | 0.48 |
| BASE | | 6 | 11 | 1 | 82 | 0.58 | 0.15 | 21.00 | 0.26 |
| HUD-30-9A TOP | 4938 | 13 | 17 | 3 | 68 | 0.77 | 0.38 | 2.00 | 0.48 |
| BASE | | 8 | 17 | 1 | 74 | 0.48 | 0.22 | 6.25 | 0.58 |
| (1965) BISCAYE SAMPLE A164-47/5 | 4720 | 12 | 17 | 8 | 63 | 0.67 | 0.37 | 0.76 | 0.52 |
| 41°43'N 59°W | | 10-14 | 15-19 | 9 | 50 | | | | |
| RANGE OF VALUES OF Sc-CORES (Silverberg, 1965) | (Depth Limits) 600-1200 | 2-11 | 2-5 | 3-7 | 80-88 | NO PEAK AREAS REPORTED | | | |

Lawrence region. Such a distinct change could not be recognized in the area south of Sable Island Bank.

The upper slope (Sc) cores treated in the previous section show a slightly different proportion of clay minerals. This slight difference of clay mineral assemblages can be attributed to differences in sample preparation, and particularly the method of discriminating chlorite from kaolinite by hydrochloric acid leaching techniques. Further, differences are also derived from a different set of weighting factors to calculate mineral percentage concentration. The composition of sample SAC 96 collected just seaward of the southern margin of Sable Island Bank is directly comparable to that of the upper slope (Sc) cores.

### *Clay Mineral Suite in the Source Area*

The similarity of the clay mineral suites in all deep-water samples in this area indicates a common provenance of the clay fraction for the olive gray and brown facies. The color difference reflects different oxidation states of iron, and not differences of clay mineral suites, in the two sediment types.

In an earlier section we indicated that Carboniferous, Triassic, and Pleistocene deposits in New Brunswick and Nova Scotia served as the predominant source of red material of late Quaternary age on the outer Nova Scotian margin. Red and gray Pleistocene and Triassic units along the northern shore of the Minas Basin in the vicinity of Five Islands, Nova Scotia, were sampled in the summer of 1968. The clay mineral suites in this area (Table 5) are similar to those on the slope and rise (Table 4). The similarity of the olive gray and brown facies clay mineral suite on the upper continental slope (Sc cores) and that of Triassic units on shore is particularly noteworthy.

## Foraminifera and Stratigraphy of Surficial Continental Margin Sediments

Foraminifera in 40 samples of Nova Scotia Slope cores (Sc) were examined (F. Medioli, Dalhousie University, personal communication). Twenty-two samples were obtained from slope (Sc) cores in which a total of 31 species are identified (Table 6). Foraminifera represented by only a few individuals are

TABLE 5.—*Clay mineral composition (weighted peak area percentage method after Biscaye 1965) of Pleistocene and Triassic samples collected near Five Islands, on the mainland of Nova Scotia*

| Pleistocene | Kaolin | Chlorite | Montmorillonite | Illite |
|---|---|---|---|---|
| Gray mud | 12 | 32 | 3 | 53 |
| Brown Sandy mud | 9 | 22 | 5 | 64 |
| Reddish-brown mud | 9 | 25 | 4 | 63 |
| Triassic | | | | |
| Red mudstone | 1 | 5 | 3 | 91 |
| Gray mudstone | 1 | 5 | 17 | 77 |
| Red siltstone | 3 | 8 | 7 | 82 |
| Gray siltstone | 1 | 5 | 13 | 81 |

not listed. All the species reported are living in the North Atlantic region at the present time.

Deep-sea Quaternary chronology is commonly reflected by variations in selected colder and warmer water foraminifers. Forms such a *Globigerina pachyderma, Elphidium arcticum,* and *Nonion laboradoricum* are indicative of a cold water environment. Attempts to base a chronology on the coiling directions of *Globigerina pachyderma* were without success.

Planktonic: benthonic ratios show several significant changes within a single core. The top and bottom of core Sc-16 have relatively high ratios, with maxima at 80 and 240 cm (Figure 75). High planktonic numbers can imply an actual increase in abundance of planktonic forms, such as might accompany a rise in sea level, or it can indicate a relative reduction in benthonic forms.

A study of the distribution of individual species provides useful stratigraphic information. In core Sc-16 a total of 29 species were observed (numbers 1-29 on Table 5). A change in the planktonic-bentonic ratio occurs at the boundary between the brown and olive gray facies at a depth of about 209 cm from the top of the core. It is noteworthy, however, that the major faunal assemblage change occurs at a depth of approximately 80 cm *within* the upper olive gray facies. Within a section about 70 cm thick,

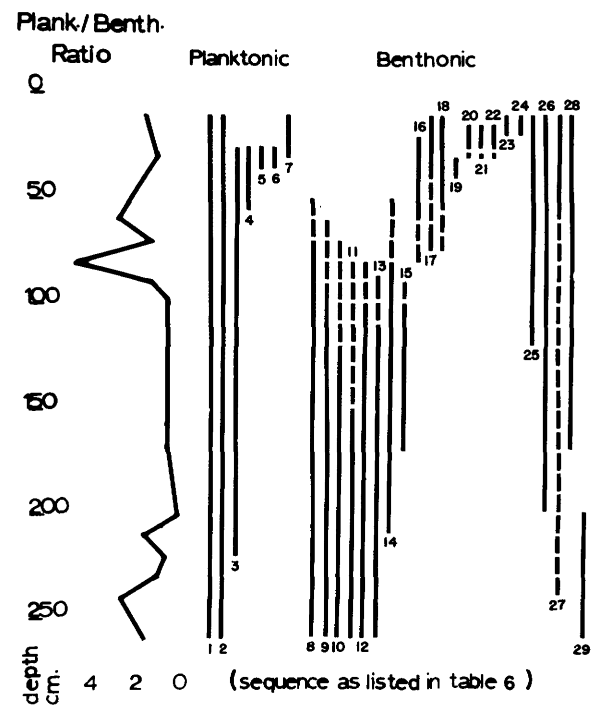



FIGURE 75.—Distribution of Foraminifera in core Sc-16 (see Table 6).

TABLE 6.—*Foraminifera in Nova Scotian Slope core Sc-16 (see Figure 75)*

PLANKTONIC FORMS

1. Globigerina pachyderma (Ehrenberg)
2. Globigerina bulloides d'Orb.
3. Globigerina inflata d'Orb.
4. Globorotalia menardii (d'Orb.)
5. Globorotalia truncatulinoides (d'Orb.)
6. Globigerinoides rubra (d'Orb.)

BENTHONIC FORMS

| | |
|---|---|
| 7. Sphaeroidina bulloides d'Orb. | 20. Epistomina elegans (d'Orb.) |
| 8. Nonion labradoricum (Dawson) | 21. Karreriella brady (Cush.) |
| 9. Cassidulina norcrossi Cush. | 22. Uvigerina sp. A - after Cush. |
| 10. Cibicides lobatulus (Walker & Jacob) | 23. Pullenia quinqueloba (Reuss) |
| 11. Virgulina complanata Egger | 24. Reophax atlantica (Cush.) |
| 12. Elphidium arcticum (Parker & Jones) | 25. Virgulina fusiformis (Williamson) |
| 13. Eponides umbonatus (Reuss) | 26. Buccella frigida (Cush.) |
| 14. Globobulimina auricolata (Bailey) | 27. Augulogerina augulosa (Williamson) |
| 15. Cassidulina subglobasa Brady | 28. Bulimina exilis Brady |
| 16. Bulimina marginata d'Orb. | 29. Cassidulina neocarinata Thalmann |
| 17. Bolivina subspinescens Cush. | 30. Elphidium incertum (Williamson) |
| 18. Bulimina aculeata d'Orb. | 31. Quinqueloculina seminulum Lin. |
| 19. Pullenia bulloides (d'Orb.) | |

8 forms disappear and 11 species first appear; 3 other species make their appearance within a slightly broader range (see Figure 75).

This faunal change corresponds with the position of the upper plantonic to benthonic maximum. It also corresponds with the position of the change from cold to warmer water conditions reported by Heezen and Drake (1964) in a similar core sequence (olive gray facies above brown facies) taken in the Laurentian Channel. Other cores collected on the continental rise off Nova Scotia show this faunal boundary at a depth of about 50 to 75 cm (Ericson et al. 1961); the faunal change is believed to coincide with the period of glacial retreat and rapid rise in sea level at the end of Wisconsin glaciation.

Conolly (1965) has reported a date of 24,000 B. P. for the upper part of the brown sediment (which in core Sc-16 occurs at a depth of 209 centimeters). The top of the brown layer may be as young as 15,000 years old (Conolly et al. 1967). Heezen and Drake (1964) do not indicate any evidence for a marked climatic change across the gray-brown contact. We thus believe that a position of the Holocene-Pleistocene boundary at a depth of approximately 80 cm (within the olive gray facies) on the slope of Nova Scotia is probably correct. The change in dominant species of planktonic Foraminifera has been noted in Atlantic and Caribbean cores and is estimated to have occurred about 11,000 years B.P. (Broecker et al. 1960, Ericson et al. 1964). If the faunal change in core Sc-16 corresponds to this climatic event, then a sedimentation rate of 7 to 8 cm per 1000 years can be postulated for the upper 80 cm Holocene section of olive gray sediments south of Sable Island Bank. This rate is somewhat lower than the average rate of 10 cm per 1000 years during Tertiary to Quaternary time calculated for the slope off eastern North American (Uchupi and Emery 1967).

A survey of Foraminifera in both olive gray slope (HUD 30–14) and brown upper rise (HUD 30–13 and 11) cores show a dominance of cold water forms. In contrast with these assemblages, the lower rise cores (HUD 30–9A and B) show an alternation of cold and warm water forms. This latter observation probably reflects the effect of meandering of warm Gulf Stream water masses transporting forms indigenous to the Sargasso Sea back and forth above the Nova Scotian rise (Cifelli and Smith 1970, and others).

## Interpreting Sedimentary Sequences and Stratigraphy

### *Slope and Upper Rise Facies*

Petrologic investigations detailed in the previous sections serve to define a trio of mappable sediment types that occur on the continental slope and upper rise south of Sable Island Bank. The distribution of these three facies, as determined by textural, mineralogical, and X-radiographic examinations of cored surficial and upper sediment sections, is patchy (Figure 18). The three dominant sediment types on the slope and upper rise are summarized below.

BROWN SEDIMENT TYPE.—This is an easily distinguishable brown pebble-sand-mud admixture (see cores HUD 30–13 and 11, Figure 15) whose provenance, as determined by the clay and coarse fraction minerolagy, is primarily Paleozoic and Triassic source areas in the Canadian Maritime Provinces of the north and northwest. The sand and coarser fraction in this facies is relatively important (as much as 50 percent pebbles) and is distinguished by an important "unstable terrigenous assemblage" consisting of red-stained quartz and feldspar; reddish and gray rock fragments and abundant heavy minerals (see logs of cores HUD 30–13 and 11, Figure. 76B). The coarse fraction also contains red sandstone and shale grains and occasional basalt fragments in the reddish brown mud (also noted by Marlowe 1964, and Conolly et al. 1967). It has been postulated on the basis of seismic evidence that a Triassic trough may once have been exposed on the Nova Scotian Shelf (Officer and Ewing 1954). It is more probable, however [as suggested by Marlowe (1964), Silverberg (1965), Conolly et al. (1967), James and Stanley (1968), and Stanley and Cok (1968)], that deposits of Carboniferous and Triassic age were eroded in the New Brunswick-Prince Edward Island-Nova Scotian area, and served as the predominant source of red sandstone and basalt fragments on the outer margin.

The angular and fissile nature of red shale fragments would suggest that this sediment was not transported very far. Evaluation of geological conditions in this region, however, indicate another conclusion: material, although angular, was in fact carried as much as several hundred kilometers from source areas. Transport by glacial and berg ice (ice-rafting) is a process which would best explain the angularity of the fragments.

The brown facies, the lowermost deposit penetrated in cores, is pre-Holocene in age. It crops out most commonly at or near intervalley highs and ridges, and floors much of the lower slope and rise. Faunal evidence indicates that the brown facies was being deposited during the height of the Wisconsin glaciation to perhaps as recently as 15,000 or even 13,000 years B.P. (Conolly et al. 1967). The Pleistocene-Holocene boundary at about 11,000 years B.P., also based on faunal evidence, is placed at 80 cm in Core Sc-16, suggesting an average sedimentation rate of about 7 to 10 cm per 1000 years during the Holocene. On the basis of this rate, the age of the top of the brown facies, lying at a depth of approximately 200 cm, may be as old as 20,000 years B.P. on the upper continental slope.

OLIVE GRAY SEDIMENT TYPE.—The olive gray facies covers upper reaches of The Gully Canyon, the Gully Trough, and valley axes on the upper to midcontinental slope. It does not cover the rise and mid and lower part of The Gully Canyon. Silt is the predominant textural fraction (see Core HUD 30–14, Figure 76A). Sand and pebble layers are proportionately less common than in the brown facies. The mineral components of fine- and coarse-grained fractions are almost identical with those of the older brown facies and their provenance is presumed to be the same. It is noteworth, however, that the proportion of "stable terrigenous assemblage" (clear and unstained quartz, feldspar, and glauconite) tends to be con-

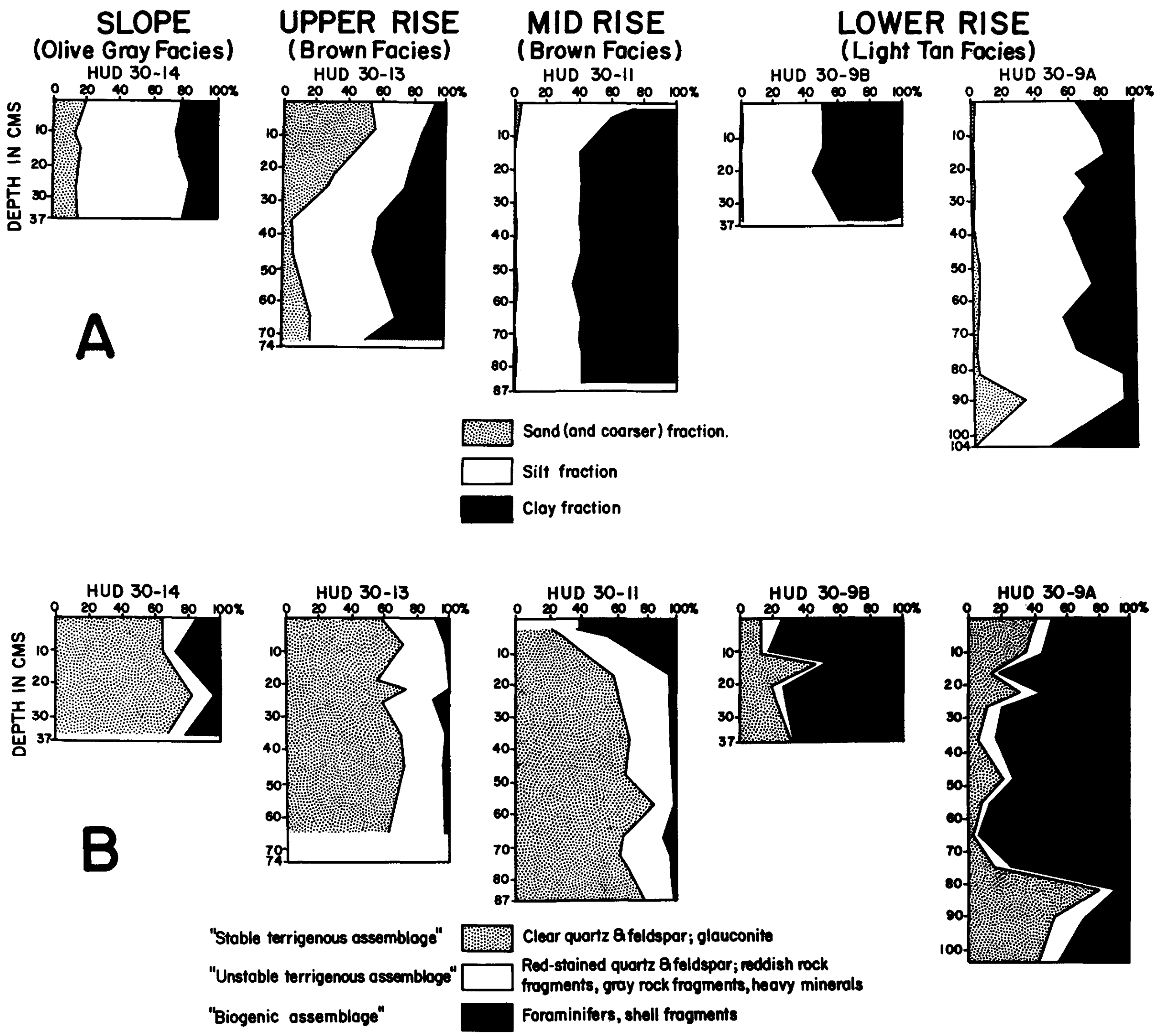



FIGURE 76.—A, Percent of sand, silt, and clay in slope and rise (HUD) cores. B, Percent of the coarse fraction suites (stable terrigenous, unstable terrigenous and biogenic assemblages) in the same cores.

siderably higher in the olive gray facies than in the brown facies (core HUD 30–14, Figure 76B). Bioturbate structures are also more common in this facies. The Pleistocene-Holocene boundary lies within the olive gray sediment type, and presumably sedimentation of the olive gray facies on the upper to mid slope has continued until recent time.

SURFICIAL SAND SEDIMENT TYPE.—The uppermost member of the trio, only locally present on the slope, is particularly common in depressions. It consists of thin sand laminae composed of light and heavy minerals similar to those of the underlying olive gray and brown facies. The composition is also similar to sand covering adjacent Sable Island Bank. Its position in cores clearly suggests that it is the youngest of the three slope facies and is recent (probably within historic time) in age.

*Lower Continental Rise Facies*

LIGHT TAN CONTINENTAL RISE SEDIMENT TYPE.—On the lower continental rise a fourth sediment type is apparent. A light tan, soft to stiff mud consists of silt and clay (cores HUD 30–9A and 9B, Figure 76A) and is equivalent in age to the olive gray facies on the upper and mid slope. It blankets most of the outer margin from the lower rise to the abyssal plain. This facies contains less sand than either the olive gray or brown facies (Figure 76A), and its composition is distinct: the coarser fraction is dominated by a "biogenic assemblage" consisting of Foraminifera and shell fragments, with subordinate amounts of the stable and unstable terrigenous assemblages described above (cores HUD 39–9B and –9A, Figure 76B; see also Figure 70). In addition to disseminated terrigenous constituents, occasional layers of terrigenous sand are noted in rise cores; these become more frequent below one meter from the top of the core. This terrigenous sand is, in fact, a fifth sediment type, but it is practical to consider it together with the light tan mud and biogenic sand. This sequence of biogenic with intercalated terrigenous strata is referred to as the *lower rise hemipelagic facies*. The coarse horizon observed at a depth of about 80 cm (core HUD 30–9A, Figure 76) may correspond to the brown-olive gray sediment boundary noted in some slope cores (see Sc-16 for instance at 210 cm, Figure 38). Coarser sediment below 80 cm on the lower rise may have been deposited at the time of the last maximum lowering of sea level at some period between 20,000 and 15,000 years B.P. A sedimentation rate of about 4 to 5 cm per 1000 years is estimated for deposition of fine-grained facies in this environment, or approximately half of the estimated sedimentation rate on the continental slope. A somewhat lower rate of 3.4 cm per 1000 years was calculated for lower rise cores to the southwest (Emery et al. 1970, page 95).

SAND AND SILT STRATA IN DEEP-SEA CORES.—Sand and silt strata referred to above as a fifth sediment type are frequently encountered in cores on the lower rise and the Sohm Abyssal Plain (Figure 17). These coarse units, accounting for as much as 50 percent of the core sections penetrated, are graded or laminated or both. Insufficient core coverage does not allow core-to-core correlation of these coarse layers. However, our preliminary survey suggests that sands grade into silts in a seaward direction. The composition of the sand-sized fraction is similar to that of outer shelf sand, and consists of both stable and unstable terrigenous assemblages. These coarse intrusions, some of them clearly turbidites, are believed to have accumulated much more rapidly than the clay- and silt-rich strata with which they are interbedded.

## Sediment Dispersal and *Spillover* on Shelf-Edge Banks

*Introduction*

The broad shallow banks sited along the outer shelf have played a unique role in the sediment dispersal system of the Nova Scotian continental margin. They have served as reservoirs for sediment received under one set of conditions (glacial, glaciofluvial, and glacio-aeolian) and subsequently released under a second set of conditions (marine littoral conditions, and deeper marine wave- and tide- agitated environments).

The varying role of the banks are reflected in the sedimentary record of the more distal depositional environments of this sediment dispersal system, as will be demonstrated in the following three sections.

*Sedimentation During Subaerial Exposure*

During the maximum low eustatic stand of the sea in Wisconsin time, sea level was believed to be 110 to 120 m lower [approximately 17,500 to 20,000 years B.P. according to Curray (1965), and closer to 15,000 years B.P. according to Milliman and Emery (1968)]. During this stage the coast coincided closely with the shelf-break, as determined by a study of terraces (Stanley et al. 1968, and others).

Pleistocene ice tongues approached Banquereau Bank and Sable Island Bank but apparently were unable to override them (Stanley and Cok 1968). Hence the bank surfaces received enormous volumes of outwash during periods of maximum glacial advances (see Figure 12). Some of this material accumulated as a thickening outwash plain which locally underwent aeolian modification (James and Stanley 1968, Medioli et al. 1967). Fluvial processes resulted in deposition of mud to pebble-size material on bank surfaces, and local pockets of gravel (Figure 29) encountered on Sable Island Bank are probably relict from this phase. Much of the material, however, must have been bypassed to the shoreline where it became available for deposition on the slope and beyond.

The coastal margin was dissected with deep bays formed by the heads of the large canyons (Sable Island Canyon and The Gully Canyon, for example) which indent the outer shelf. These embayments undoubtedly served as outlets for meltwater. In some cases they may have contained heavily stratified water bodies with well-developed estuarine circulation, capable of serving as hydraulic traps for accumulating fine sediment (Postma 1967). During peaks of outwash aggradation, the resulting estuarine clay deposits would be loaded by rapidly growing intra-estuary deltas of coarse sediment (Swift and Borns 1967). Transfer of all sediment-size grades from the bank tops onto the steep bank margins was probably accelerated during those phases when ice tongues migrated closest to the outer banks.

The seaward edge of Sable Island Bank, serving as the coast, received the brunt of erosion by surface waves, and if meltwater had sufficiently stratified coastal waters then possibly by breaking internal waves. The relatively steep slope (5° or more) of the outer bank margin meant that storm waves were not damped by a shallow shelf and that the coast was under intensive attack. Slumping of the heterogeneous coastal material would be expected and would provide a large volume of sediment for transfer downslope.

### *Sedimentation During and Subsequent to Inundation*

In late Pleistocene time sea level began to rise first slowly and then more rapidly (Emery 1968, his figure 15). The transgressing surf would have stripped sediment from the retreating shore face and would have released this material on the adjacent shelf floor for resedimentation by marine currents (Swift 1968). This resedimentation process has resulted in a second set of petrographic attributes being overprinted on the original textures. Most obviously, the finer fractions (silt and clay, have been winnowed out leaving a clean sand lag whose pebbly admixture reflects the original periglacial origin (see Figures 8, 9). Such hybrid sediments have been designated *palimpsest* (Swift et al. 1971). Processes resulting in the modification of texture have been more effective on the outer banks than in the deeper central shelf physiographic province.

After water deepened over the banks, the blanket of palimpsest sand continued to undergo textural modification and transport according to a new and well-defined system of sediment dispersal. This system has been best studied on Sable Island Bank where its elements include Sable Island, the emerged crest of the bank, and the surrounding submarine bank surface.

Sable Island consists of two parallel beach-dune ridges which, with the rise of sea level, have converged toward the crest of the bank until they are contiguous. This sediment reservoir exchanges material with the adjacent shallow sea floor according to a seasonal cycle whereby sediment is accreted to the island in summer by marine processes and is later deflated by strong winter winds (James and Stanley 1967).

The island was initiated by convergence of the dune ridges in late Pleistocene-early Holocene time (Medioli et al. 1967), but it is presently maintained as a dynamic system of water and sediment circulation. The island and surrounding bank would, in fact, appear to be a circulating sand cell of the type described by Van Veen (1936) from the floor of the southern bight of the North Sea. The distribution of large-scale sand waves indicates a clockwise circulation of residual tidal and wave-driven currents (James and Stanley 1968). Large sand waves are present between 10 and 70 m depth, both north and south of Sable Island and on the western part of the bank. Smaller sand waves, averaging 6 to 7 m in height (Figure 77) and having wave lengths from 300 to 1000 m, are most abundant south of Sable Island. Their asymmetry indicates a predominant wave migration from east to west, while north of the island, sand wave asymmetry indicates migration from west to east. A sequence of lines trending north-south across the submerged bar west of the island shows that sand waves in that sector are migrating northward (Figure 78). The east bar of Sable Island (Figure 77) has been likened to an asymmetric sand wave with a steeper northern face suggesting predominant movement of sand toward the north just east of the island (Figure 79).

Smaller scale structures, such as asymmetric ripple marks as observed on most bottom photographs of Sable Island Bank (Figure 80), show vectorial properties that are much more variable than those of sand waves. Regional pattern of these ripples conforms in

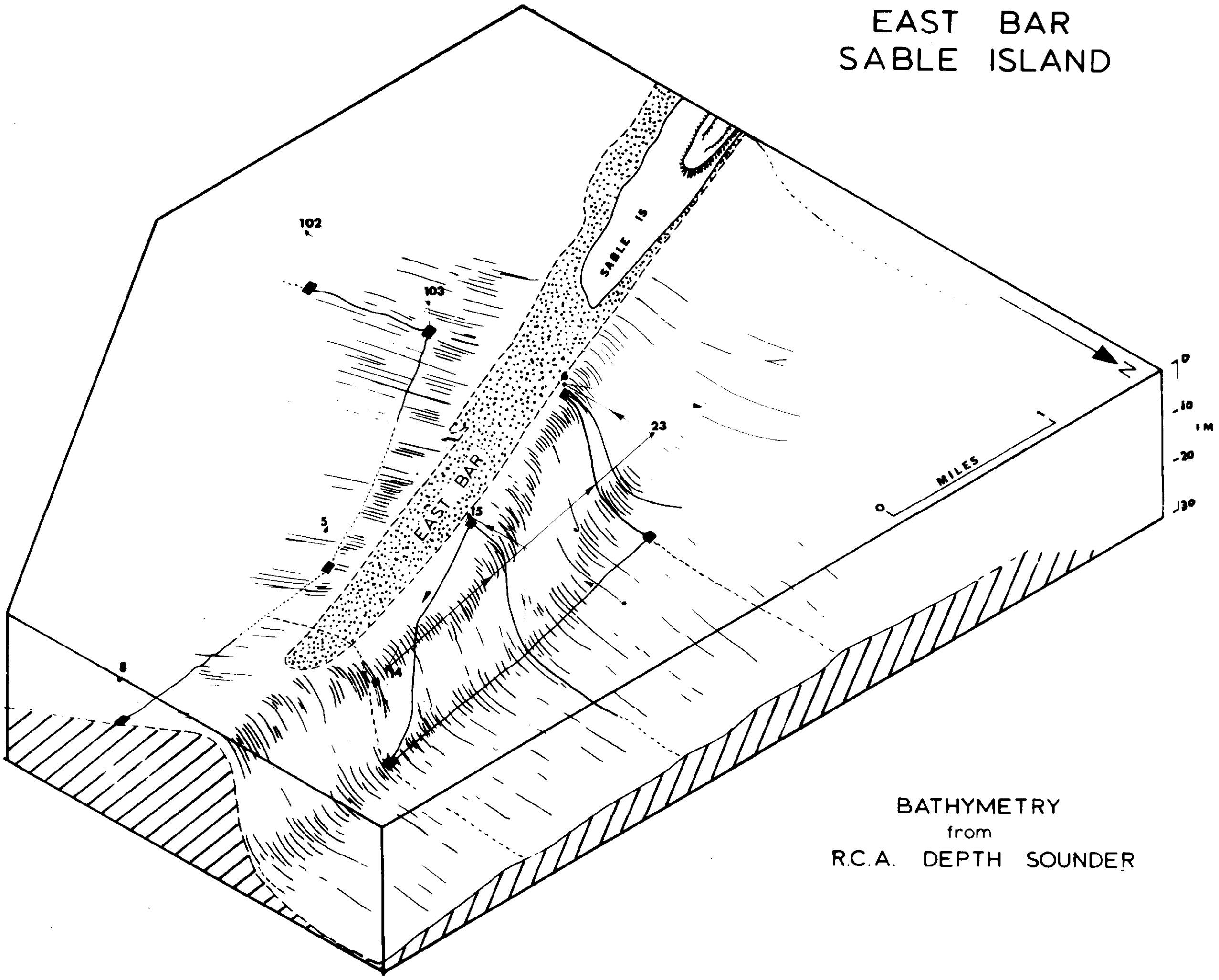



FIGURE 77.—Diagram showing submarine topography in the vicinity of the east terminal bar of Sable Island based on records obtained with an RCA depth sounder. The northern face is steeper than the more gently southern slope (based on data obtained in May 1965).

a general way to the sand-wave circulation pattern: ripples off the west end of the island indicate predominantly northward and eastward transport, and those off the east end show southward and westward flow; those on the northern part of the bank migrate west and north. One station (78) at the southern margin of the bank near the head of Sable Island Canyon shows a predominant southerly (or off-bank) transport.

*Radial Dispersal and Sediment Spill-Over*

While bed-forms indicate primarily a clockwise system of sediment transport, textural and mineralogical patterns on the bank surface (James and Stanley 1968) reflect a net long-term process of radial dispersal off the banks into the adjacent lows. Transport patterns are clearly marked as orthogonals to isopleths of mineralogy, mean grain size, sorting, and skewness. In general, on Sable Island Bank, sediment is being

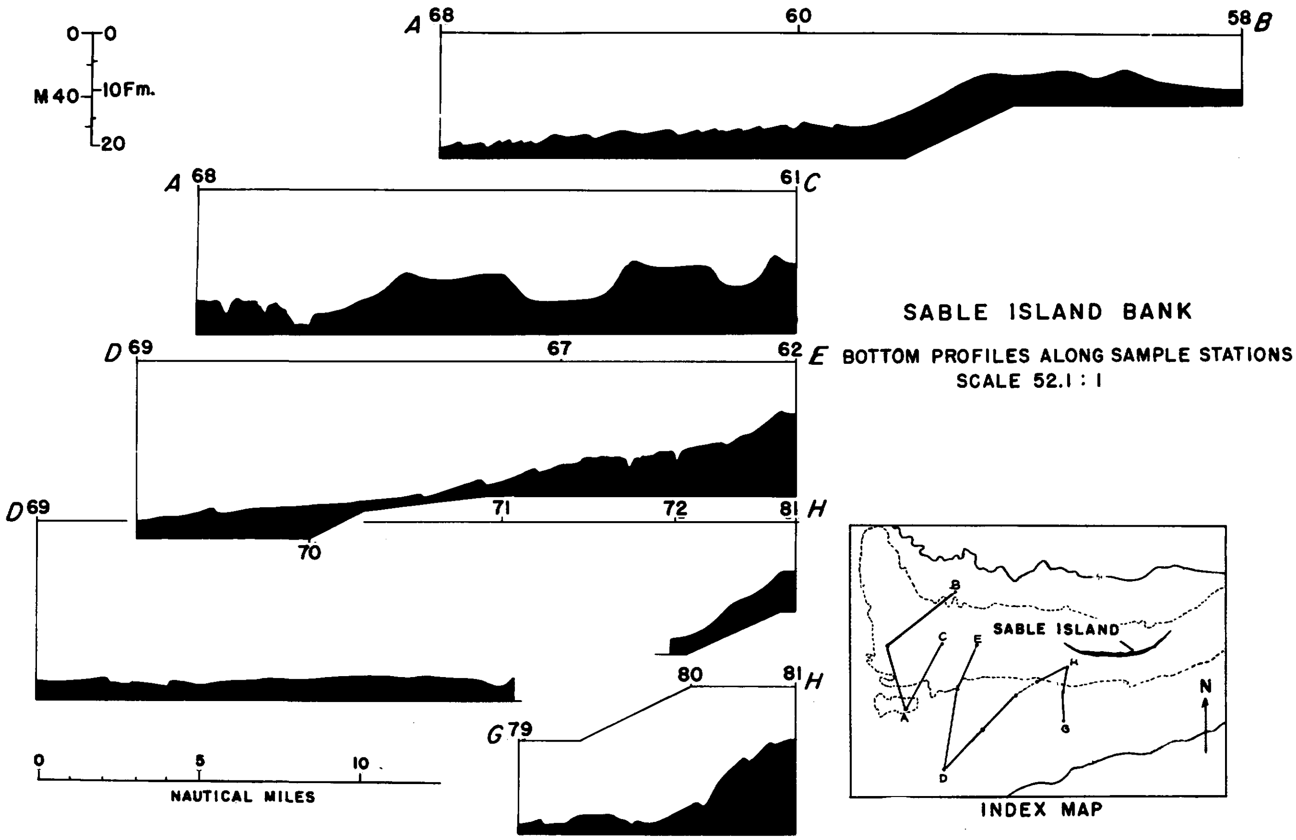



FIGURE 78.—Bathymetric profiles of the surface of Sable Island Bank plotted from PDR and RCA depth sounder records. Sand waves and related bed-forms are shown to depths of 70 m. Note the northward set of sand waves along selected portions of profiles.

transported from central areas of relatively coarse, coarse-skewed sand to marginal areas of relatively fine, fine-skewed sand. These marginal areas tend to be less sorted than the zones where unmixing and transport is most intensive. Sediment-yielding lag deposits are richer in the heavier, coarser, heavy minerals (opaques, garnet); sediment-receiving areas are richer in the lighter heavy minerals (hornblende, kyanite, and tourmaline). The intensity of iron-staining of relict quartz is assumed to be inversely proportioned to the intensity of abrasion during modern transport; areas of stain-free quartz are areas indicated by other criteria to be areas of active sediment unmixing and transport. A pattern of erosion, transport, and deposition on Sable Island Bank emerges upon integration of all data (Figure 81).

Thus, the present cyclical movement results in a net loss of sediment from the bank surface by transfer of sand-size material off Sable Island Bank. This transfer of silt and sand by bottom currents from the outermost shelf across the shelf-break and onto the upper slope and beyond is here designated as *spillover.*

There appears to be several large areas of sand spillover: south and southwest of Sable Island, from the outer shelf onto upper slope; north of the island, from the bank margin into the Gully Trough; and east of the bank, into The Gully Canyon. Details of sediment spillover into The Gully Canyon have been presented elsewhere (Stanley 1967). Relatively clean palimpsest sands are noted draping onto both east and west canyon walls (Stanley 1967, his figure 3B), presumably from the adjacent bank surfaces. Further evidence of spillover in the shelf-break area occurs south of the bank. Here, also, sand drapes from the outer shelf onto the upper slope (Figure 29), and cores in the area penetrate a surficial sand layer above older muds.

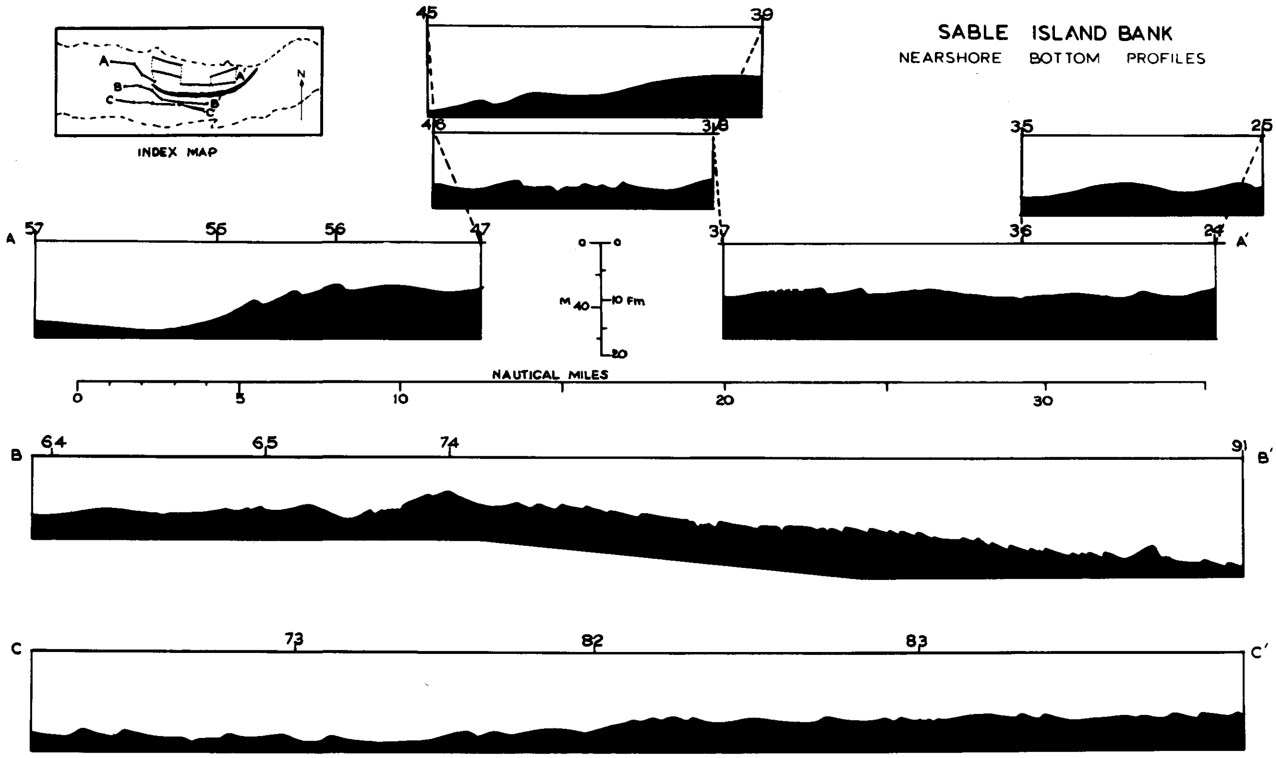



FIGURE 79.—Bathymetric profiles of the surface of Sable Island Bank. Profiles are oriented roughly parallel with Sable Island. Asymmetric sand waves appear to progress westward on southern side and eastward on northern side of island. Net movement north of the island is directed eastward, except between stations 38 and 46 which appears to be a zone of confluence.

## Quaternary Progradation on the Nova Scotian Outer Margin: A Summary

### *Introduction*

The shift in sediment dispersal processes and patterns on the Nova Scotian banks through late Quaternary time has resulted in a corresponding sequence of depositional events on the slope and rise. The consanguinous nature of these two sedimentary provinces is clearly indicated by the similarity of mineral suites noted repeatedly in preceding sections of this study.

Thus the late Quaternary history of the study area has been one of progradation: the seaward extension of the shelf edge, slope, and rise by sediment accumulation. Seismic study of the continental margin off Nova Scotia has led Uchupi and coworkers (Uchupi and Emery 1967, Uchupi 1969, Emery et al. 1970, Uchupi, 1970) to estimate 5 kilometers of progradation, although they do not clearly indicate the stratigraphic horizon from which this progradation was initiated. These workers can distinguish among such gross lithostructural units as seaward dipping strata, slumps and slides, turbidites, and pelagic deposits. On the other hand, our data based primarily on cores provides much higher resolution of the thinner uppermost section of Wisconsin to recent age. The time sequence of events which generated the progradation and the resulting stratigraphic sequences, illustrated in Figures 82 and 83, are evaluated below.

### *Brown Sediment Time*

During Pleistocene time, large volumes of fine to coarse reddish-brown, fluvioglacial material carried south to the coast was rapidly transferred to the adjacent slope below the strandline (Figure 82A). The high and rapidly varying rate of sediment input and short distance to the upper slope would have been capable of generating stratified sequences of muds, sands, and gravels, but would not have been capable

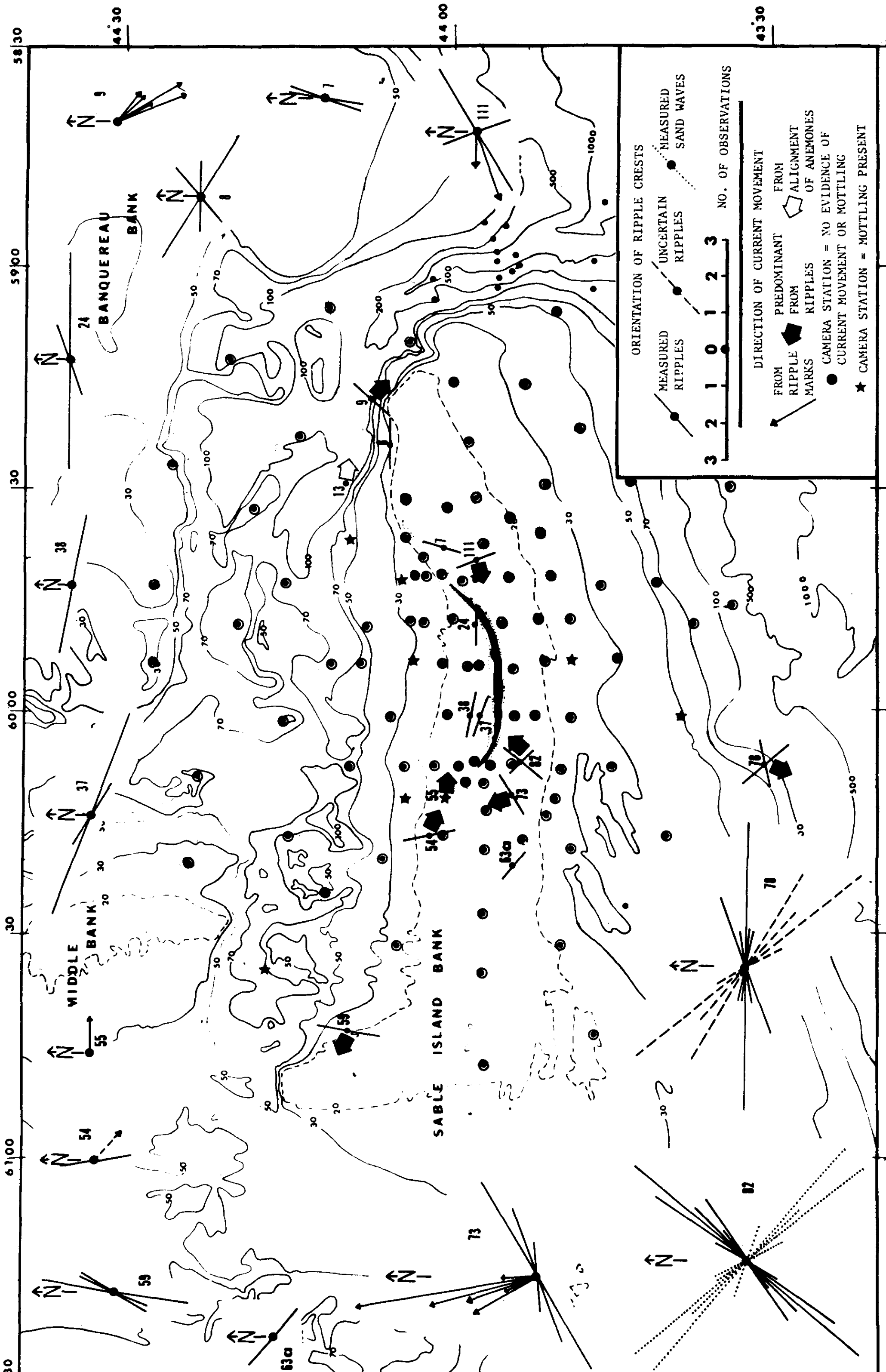



FIGURE 80.—Direction of current dispersal on Sable Island Bank based on features such as ripple marks observed on bottom photographs.

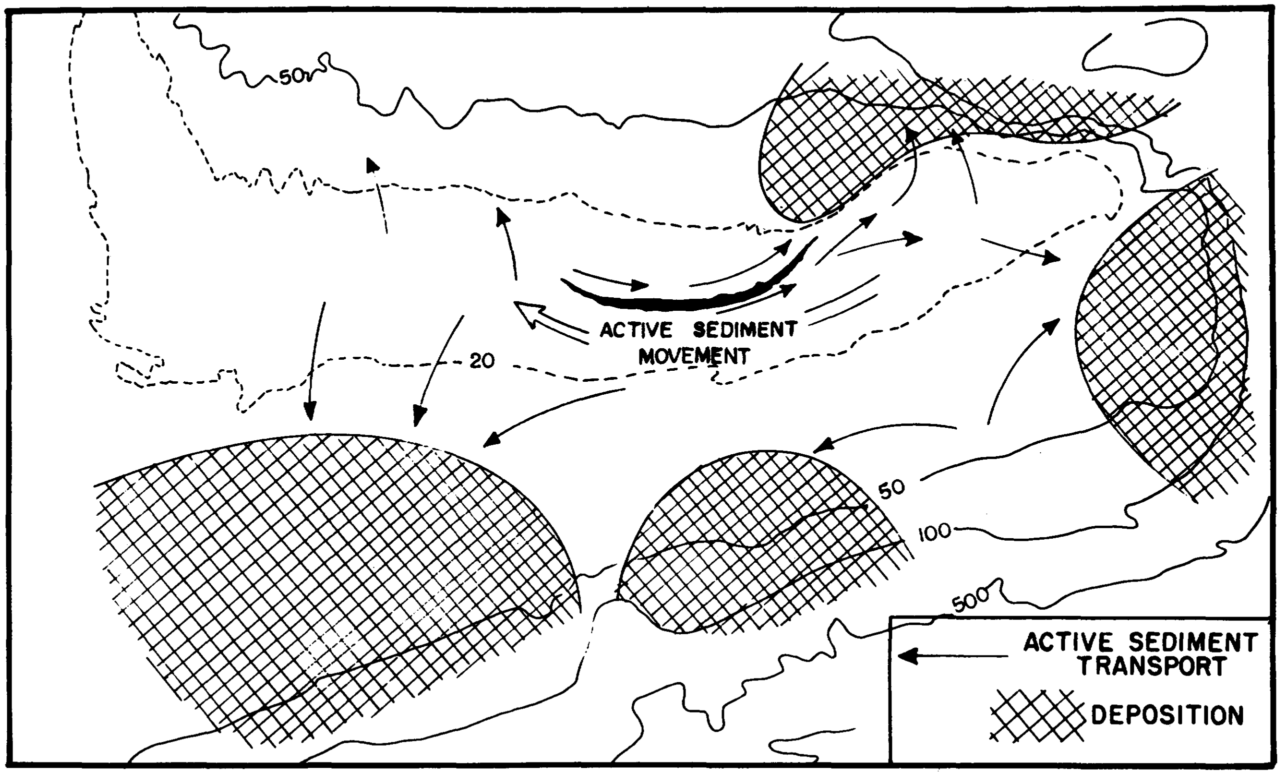



FIGURE 81—Interpretation of bottom circulation pattern on Sable Island Bank showing areas of dominant sediment transport and deposition (after James and Stanley 1968).

of effecting large-scale horizontal size fractionation on the slope. The resulting heterogeneous sediment pile, precariously poised on a relatively steep submarine slope, would have been prone to fail by slumping.

That mass-gravity processes have been in large part responsible for the scalloped topography of the region south of Sable Island Bank has been shown by bottom profiles (Pratt 1967) and subbottom profiles (Uchupi 1969, Emery et al. 1970) which reveal large slide blocks on the lower slope and rise. These studies indicate that most of the dissected topography presently observed is clearly of relict origin. When slumping actually began is not clearly established, but seismic studies show that gravitational sliding was effective during much of the Tertiary, and has certainly antedated the glacial stages. However, it is reasonable to suspect that in this region, as elsewhere, the rate and scale of slumping must have become considerably accelerated during the Pleistocene, especially during those periods when low sea-level stands resulted in the exposure of much of the shelf (Stanley and Silverberg 1969). The relatively nondissected slope south of Western Bank (Figure 6) may not have received as much sediment as in regions to the east (south of what is now Sable Island) and, consequently, may have been less prone to slumping.

During this time of heightened sedimentation, mass gravity processes were also intensified in canyon heads. The attack of open ocean storm waves on the unconsolidated emerging coastline would have released large volumes of sand and gravel to littoral drift systems intercepted by canyon heads. Periodic flushing of these depressions would have further contributed to slope and rise sedimentation as attested by the presence of sand layers in rise and abyssal plain cores. Turbidity currents or turbid-layer flows (Moore 1969) channelized by the canyon system would have had a higher probability of reaching base-of-slope environments. Such far-traveled material would indeed have the opportunity to undergo horizontal size sorting as indicated by the general decrease in grain size between

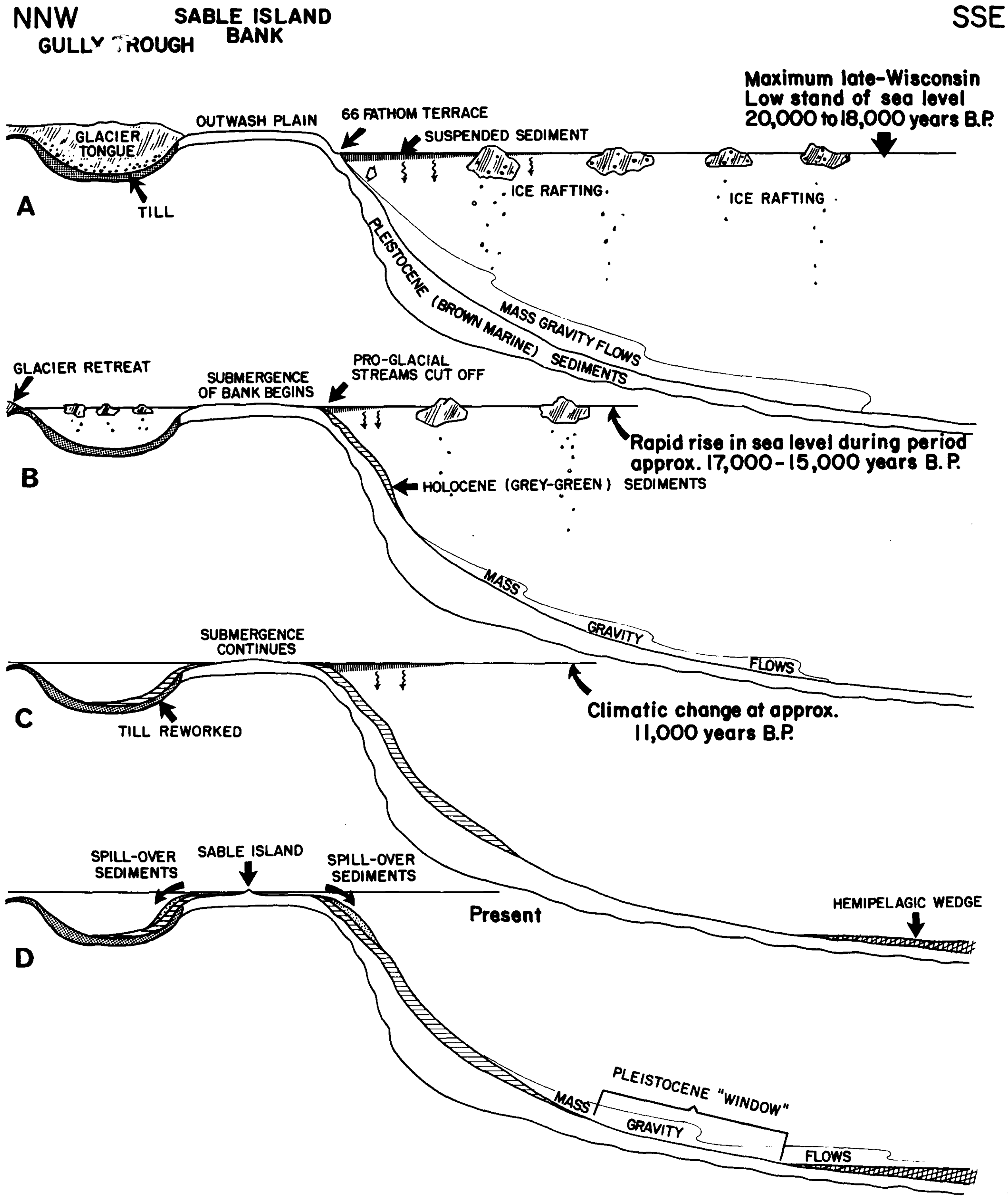



FIGURE 82.—Interpretation of late Quaternary to recent sedimentary progradation on the Nova Scotian continental margin south of Sable Island Bank (Stanley and Silverberg (1969).

cores HUD-13 and HUD-11, respectively, on the upper and lower rise.

In addition to mass gravity movement on the bottom, the seaward diffusion of fines (clay, silt, and possibly fine sand) would have been a second major process during this time of heightened periglacial sedimentation. The meltwater runoff was heavily loaded with fines, and received in addition material resuspended by wave attack on the coast. The intensified "estuarine" circulation of the coastal water mass would have carried turbid surficial water far out to sea so that the suspended fines would have rained out over the slope and rise, perhaps even over the Sohm Abyssal Plain. Such fine sediment fallout on the upper slope may have generated near-bottom, nepheloid, suspension-rich layers which, in turn, would have settled seaward across the rise.

In addition to the general seaward movement of suspended sediment entrained in surficial meltwater, masses of coarse material were carried seaward by floe ice and calving glacier ice. This is attested by the presence of pebble clusters within cores from the brown facies, and gravel patches seen in sea-floor photographs (Brundage et al. 1967).

### *Gray Sediment Time*

As the sea level rose over the banks and the bank sediment dispersal system shifted from a subaerial glacial regime to a regime of submarine reworking, the character of sediment accumulating on the slope and rise underwent a change (Figure 82B). The mineral suites of slope and rise sediments accumulating during this transition remained qualitatively constant, although the relative proportions shifted in some cases. An obvious difference, however, was the color of material accumulating during and subsequent to submergence of the banks. This study has shown that color change does not reflect a change in provenance, but simply a change in the rate of sedimentation, such that sediment passed through the sediment-water interface sufficiently slowly that it was reduced (Hinze and Meischner 1968). This slower rate of sediment accumulation is also demonstrated by the greater intensity of bioturbation and increase in benthonic Foraminifera as noted in cores of this facies.

Most processes of sediment dispersal discussed for brown sediment time continued, but at reduced rates. Contorted stratification in cores, and local exposure of Pleistocene strata normally under gray sediment, suggests that slumping continued as a dominant process on the slope in gray sediment time. The presence of interbedded, brecciated, reddish-brown Pleistocene and younger gray sediment in the upper sections of cores is evidence that slumping has, in fact, continued to the present time. Is the triggering mechanism tectonic or sedimentological in origin? This continental margin is generally considered to be a relatively stable one, although recent earthquake activity is known to have affected the outer continental margin east of Sable Island Bank, particularly off Newfoundland (Heezen and Drake 1964). Although earthquakes or other movements could thus effectively trigger the sudden downslope movement of sediment, the sediment regime in this environment is sufficient in itself to account for slumping. The rate of sedimentation on the upper and mid sectors of the slope, for instance, though reduced, has continued to be relatively high since the beginning of the post-Pleistocene rise in sea level. Estimated average rates, based on an evaluation of the total thickness of the olive gray facies (1 to over 5 m total thickness), range from 5 to 25 cm per 1000 years.

With the retreat of the ice, outwash was no longer supplied but littoral sands concentrated by coastal erosion were still available for redistribution. Initially, their volume does not appear to have been as great as during the preceding brown sediment period. These sands continued to be trapped in canyon heads and depressions on the upper slope and discharged from these lows as turbidity currents.

Suspended fines were no longer provided by meltwater, but surf and sea floor erosion of the outer banks provided an alternate source. In addition, far-traveled fines were now being bypassed from recently submerged portions of the central shelf landward of the outer banks (Curray 1965, his figure 3) and transported onto the slope. Ice-rafting would have progressively diminished throughout gray sediment time as the ice sheet withdrew from the Maritimes.

Because of the diminished input of sediment and also because of the reduction in freshwater runoff with concomitant reduction of "estuarine" circulation, suspended sediment settled primarily on the slope. Such material as has bypassed the slope by means of turbidity currents (Erickson et al. 1952 and 1961, Gorsline et al. 1968, Piper 1970), turbid layer flows (Moore 1969), and/or nepheloid layers (Stanley 1970) accumulated beyond the base of the slope. Biogenic materials primarily in the form of planktonic foraminiferal tests sedimented in parts from the overlying Gulf Stream formed a prominent admixture of this terrigenous influx. The resulting hemipelagic wedge appears to thicken seaward within the area of study. Its light tan color is more a consequence of slow transport and attendant oxidation as in the case of abyssal red clays, rather than an inherited pigment as in the case of the brown sediment type. The sands of this facies may be diverted into two populations on the basis of sedimentary structures and textural parameters. One group displaying graded bedding is distinguished as the "typical" turbidite unit, the other nongraded in origin may have been deposited by reworking of turbidite sediments by marine currents.

Between the thin gray sediment prism of the slope and seaward thickening wedge of tan hemipelagic sediments on the lower rise there is a window through which is exposed the older brown sediments. This sector may be a one of nondeposition as a consequence of the southwestward flowing Western Boundary Undercurrent (Heezen et al. 1966, Schneider et al. 1967). These authors have suggested that the red sediments of the rise are a modern rather than a relict facies; that they are eroded from the St. Lawrence region and swept south parallel to the contours. However, our cores (HUD-30-11 and 13) are anomalously coarse and contain pebbly horizons within the uppermost 10 cm. Since modern icebergs only rarely proceed south to Newfoundland, such pebbles were most probably transported by Pleistocene ice.

The change in microfauna noted within the olive gray facies, also noted by others in this region (Ericson et al. 1961), coincides with a change in climate at about 11,000 to 10,000 years B.P. as recorded elsewhere in the North Atlantic (Broeker et al. 1960, Ericson et al. 1964). See C, figure 82.

### *Surficial Sand Time*

As the banks continued to submerge and the development of the blanket of winnowed sand and sandy gravel approached completion, less and less fines were generated by littoral and sea floor erosion on the banks. Rates of fine sediment deposition on the adjacent slope decreased yet further, and spillover sands, emplaced during occasional storms, became a progressively more prominent part of the upper- to mid-slope section (Figure 82D.) A number of the slope (Sc) cores are capped by relatively clean sands of this type that may have been emplaced in historic times.

Shelf sands draped thus over gullies and depressions of the upper slope appear to be intermittently activated as turbidity currents, which may bypass the slope and appear as coarse horizons within the top of base-of-slope facies (see Lamont-Doherty cores, Figure 17, and hypothetical core d, Figure 83). Channelizing in canyons appears to be one important method of bypassing as attested by the presence of sand in The Gully Canyon axis (Stanley 1967) and levees bordering submarine valleys (Hurley 1964, Pratt 1968).

As early as 1952 Ericson and coworkers called attention to sands of shallow water origin on the ocean floor of the Western North Atlantic and attributed their presence to turbidity current action. More recent studies of the textures of Atlantic deep-sea sands (Hubert 1964) and of ocean floor current indicators (Heezen et al. 1966, Schneider et al. 1967) have suggested that ocean bottom currents may also be of primary importance in the transport of deep-sea sands. Although many of these deep-sea sand layers are, in fact, current laminated and display a low clay content, it is believed that most sands were nonetheless originally emplaced by turbidity currents (Kuenen 1967) and subsequently received their secondary structure and texture through reworking by bottom currents (Stanley 1970, his figure 12). Our study supports the contention of others (Hubert and Neal 1967, and others) that mineralogic dispersal patterns formed during Quaternary progradation of the western North Atlantic continental margin reflect predominantly a downslope movement of sediment normal to the continental margin with a minor contour-parallel component.

## Acknowledgments

This study, like most modern oceanographic investigations, is the result of a multi-author cooperative venture. We are indebted to a number of organizations for their generous backing, including financial aid, ship-time, materials, and facilities provided, which made this investigation possible: Bedford Institute of Oceanography, Dalhousie University (Institute of Oceanography), Lamont-Doherty Geological Observatory of Columbia University, and the Smithsonian Institution. Sampling was conducted on the CSS *Hudson*, CSS *Kapuskasing*, and CNAV *Sackville*: the

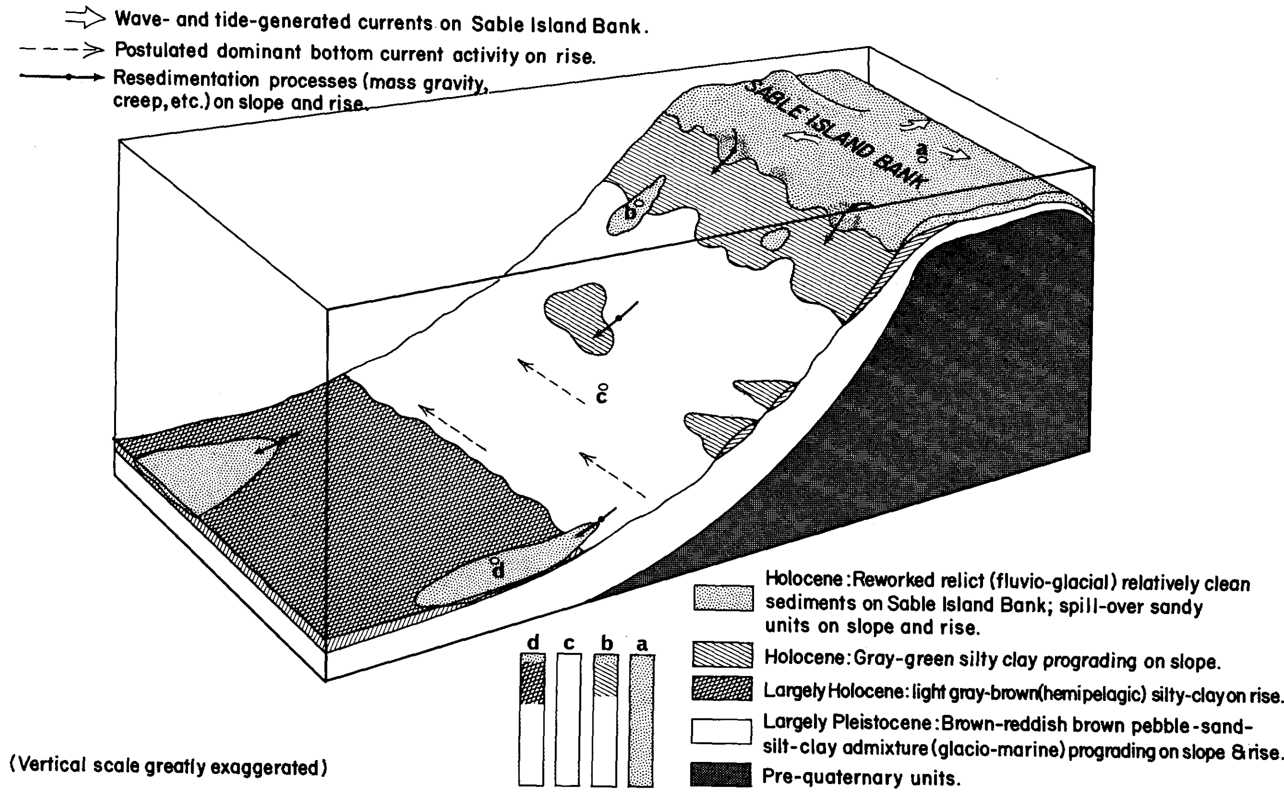



FIGURE 83.—Interpretation of late Quaternary sedimentary facies distribution on the Nova Scotian continental margin south of Sable Island Bank. This schema of the upper sediment sections on the slope and rise also shows postulated dispersal patterns and stratigraphy as based on observations made in this study.

Captains; officers, and men of these ships are thanked for support so efficiently given in the work at sea.

We acknowledge with gratitude the many persons with whom we have had an opportunity to discuss the various problems raised in this study and, in particular, our many colleagues who have made special contributions to this undertaking: Dr. A. E. Cok, Adelphi University, and Mr. G. Drapeau, Bedford Institute, with whom we shared pleasant and productive hours at sea and in the laboratory. Dr. Cok kindly identified heavy minerals from slope cores. We are also indebted to Dr. T. T. Davies, University of South Carolina, who kindly provided data on selected clay mineral suites in slope and rise cores, Dr. J. I. Marlowe, Miami Dade Junior College (formerly with Bedford Institute of Oceanography), for generously sharing his Gully Canyon cores with us, and Dr. F. Medioli, Dalhousie University, for identifying Foraminifera in selected slope and rise cores collected off Sable Island Bank. We thank Mrs. A. E. Cok and Mr. H. Sheng for help in processing core and rise samples, and Mr. L. Isham for drafting and modifying a number of figures. Drs. A. E. Cok and J. I. Marlowe critically read the manuscript.

Support for continued coordination of this project, including travel and preparation of the manuscript, has been provided to one of us (D.J.S.) by the Smithsonian Institution Research Foundation grants No. 235320 (FY 1970) and No. 436330 (FY 1971).

## Literature Cited

Berger, J., A. E. Cok, J. E. Blanchard, and M. J. Keen
1966. Morphological and Geophysical Studies on the

Eastern Seaboard of Canada: the Nova Scotian Shelf. In *Continental Drift* (G. D. Garland, editor). Pages 102–113. University of Toronto Press, Toronto.

Biscaye, P. E.
1965. Mineralogy and Sedimentation of Recent Deep-Sea Clay in the Atlantic Ocean and Adjacent Seas and Oceans. *Bulletin of the Geological Society of America,* 76:803–832.

Bouma, A. H.
1962. *Sedimentology of Some Flysch Deposits; A Graphic Approach to Facies Interpretation.* Elsevier Publishing Co., Amsterdam, 168 pages.
1964. Notes on X-ray Interpretation of Marine Sediments. *Marine Geology,* 2:278–309.

Broecker, W. S., M. Ewing, and B. C. Heezen
1960. Evidence for an Abrupt Change in Climate Close to 11,000 Years Ago. *American Journal of Science,* 258:429–448.

Brundage, W. L., Jr., C. L. Buchanan, and R. B. Patterson
1967. Search and Serendipity. In Deep-Sea Photography (J. B. Hersey, editor), *The John Hopkins Press Oceanographic Studies,* 3:75–87. Johns Hopkins Press, Baltimore.

Canada Department of Transport
1965. Sea Ice Observations, 1965. Eastern Canadian seaboard. *Meteorological Branch Report T 57-10/1964-1,* 94 pages.

Cifelli, R., and R. K. Smith
1970. Distribution of Planktonic Foraminifera in the Vicinity of the North Atlantic Current. *Smithsonian Contributions to Paleobiology,* 4:1–52.

Clarke, A. H., Jr., D. J. Stanley, J. C. Medcof, and R. E. Drinnan
1967. Ancient Oyster and Bay Scallop Shells from Sable Island. *Nature,* 215:1146–1148.

Cok, A. E.
1970. Morphology and Surficial Sediments of the Eastern Half of the Nova Scotian Shelf. Unpublished Ph.D. dissertation, Dalhousie University, Halifax, 261 pages.

Cok, A. E., G. Drapeau, D. Grant, N. James, F. Medioli, N. Silverberg, and D. J. Stanley
1965. Marine Geology Studies on the Scotian Shelf and Slope. *Maritime Sediments,* 1:2–11.

Conolly, J. R.
1965. Recent Sediment Studies. *Maritime Sediments,* 1:4.

Conolly, J. R., H. D. Needham, and B. C. Heezen
1967. Late Pleistocene and Holocene Sedimentation in the Laurentian Channel. *The Journal of Geology,* 75:131–147.

Curray, J. R.
1965. Late Quaternary History, Continental Shelves of the United States. In *The Quaternary of the United States* ( H. E. Wright and D. G. Frey, editors). Pages 723–735. Princeton University Press, Princeton.

Dall, W. H.
1925. Tertiary Fossils off the Northeastern Coast of North America. *American Journal of Science,* 10:213–218.

Dill, C. E., Jr.
1968. Formation and Distribution of Glauconite on the North Carolina Continental Margin and Slope. M.Sc. thesis, Duke University, Durham, N. C., 55 pages.

Donn, W. L., W. R. Farrand, and M. Ewing
1962. Pleistocene Ice Volumes and Sea-Level Lowering. *The Journal of Geology,* 70:206–214.

Doyle, L., W. Cleary, and O. Pilkey
1968. Mica: Its Use in Determining Shelf-Depositional Regimes. *Marine Geology,* 6:381–389.

Emery, K. O.
1952. Continental Shelf Sediments off Southern California. *The Geological Society of American Bulletin,* 63:1105–1108.
1965. Geology of the Continental Margin Off Eastern United States, 1-17. In *Submarine Geology and Geophysics* (W. F. Whittard, and R. Bradshaw, editors) London, Butterworths, 464 pages.
1968. Relict Sediments on Continental Shelves of the World. *The American Association of Petroleum Geologists Bulletin,* 52:445–464.

Emery, K. O., E. Uchupi, J. D. Phillips, C. O. Bowin, E. T. Bunce, and S. T. Knott
1970. Continental Rise off Eastern North America. *The American Association of Petroleum Geologists Bulletin,* 54:44–108.

Ericson, D. B., M. Ewing, and B. C. Heezen
1952. North Atlantic Turbidity Currents and Sediments. *The American Association of Petroleum Geologists Bulletin,* 36:489–511.

Ericson, D. B., M. Ewing, and G. Wollin
1964. The Pleistocene Epoch in Deep-Sea Sediments. *Science,* 146:723–732.

Ericson, D. B., M. Ewing, G. Wollin, and B. C. Heezen
1961. Atlantic Deep-Sea Sediment Cores. *The Geological Society of America Bulletin,* 72:193–286.

Ewing, J., M. Ewing, and C. Fray
1960. Buried Erosional Terrace on the Edge of the Continental Shelf East of New Jersey (abstract). *The Geological Society of American Bulletin,* 71:1860.

Ewing, M., W. L. Donn, and W. Farrand
1960. Revised Estimate of Pleistocene Ice Volume and Sea-Level Lowering (abstract). *The Geological Society of America Bulletin,* 71:1861.

Folk, R. L.
1954. The Distinction Between Grain Size and Mineralogical Composition in Sedimentary Rock Nomenclature. *The Journal of Geology,* 62:345–351.
1964. *Petrology of Sedimentary Rocks.* Austin, Texas, Hemphills, 154 pages.
1966. A Review of Grain-Size Parameters. *Sedimentology,* 6:73–95.

Folk, R. L., and W. C. Ward
1957. Brazos River Bar: A Study in the Significance of Grain-Size Parameters. *Journal of Sedimentary Petrology,* 27:3–27.

Freas, D. H.
1962. Occurrence, Mineralogy, and Origin of the Lower Golden Valley Kaolinitic Clay Deposits near Dickinson, N. D. *The Geological Society of America Bulletin,* 73:1341–1362.

Goldthwait, J. W.
1924. Physiography of Nova Scotia. *Memoir 140 Geological Survey of Canada,* 179 pages.

Gorsline, D. S., D. E. Drake, and P. W. Barnes
1968. Holocene Sedimentation in Tanner Basin, California Continental Borderland. *The Geological Society of America Bulletin,* 79:659–674.

Grant, D. R.
1963. Pebble Lithology of the Tills of Southeast Nova Scotia (unpublished M.Sc. thesis). Dalhousie University Halifax, Nova Scotia.

Heezen, B. C., and C. L. Drake
1964. Grand Banks Slump. *The American Association of Petroleum Geologists Bulletin,* 48:221–225.

Heezen, B. C., C. D. Hollister, and W. F. Ruddiman
1966. Shaping of the Continental Rise by Deep Geostrophic Contour Currents. *Science,* 152:502–508.

Heezen, B. C., M. Tharp, and M. Ewing
1959. The Floors of the Oceans, I. The North Atlantic. *The Geological Society of America Special Paper,* 65:1–122.

Hinze, C., and D. Meischner
1968. Gibt es Rezente rot-sedimente in des Adria? *Marine Geology,* 6:53–71.

Holtedahl, H.
1955. On the Norwegian Continental Terrace, Primarily Outside Møre-Romsdale; Its Geomorphology and Sediments with Contributions on the Quaternary Geology of the Adjacent Land and on the Bottom Deposits of the Norwegian Sea. Universit. I Bergen, *Naturvitenskapalig rekke,* 14:1–209.

Hubert, J. F.
1964. Textural Evidence for Deposition of Many Western North Atlantic Deep-Sea Sands by Ocean Bottom Currents Rather Than Turbidity Currents. *The Journal of Geology,* 72:757–785.

Hubert, J. F., and W. J. Neal
1967. Mineral Composition and Dispersal Patterns of Deep-Sea Sands in the Western North Atlantic Petrologic Province. *The Geological Society of American Bulletin,* 78:749–772.

Hurley, R. J.
1964. Bathymetric Data from the Search for USS "Thresher". *International Hydrographic Review,* XLI:43–52.

Jackson, M. L.
1956. *Soil Chemical Analysis—Advanced Course.* University of Wisconsin, Madison (published by the author). 991 pages.

James, N. P.
1966. Sediment Distribution and Dispersal Patterns on Sable Island and Sable Island Bank. M.Sc. thesis, Dalhousie University, Halifax, Nova Scotia, Canada. 254 pages.

James, N. P., and D. J. Stanley
1967. Sediment Transport on Sable Island, Nova Scotia. *Smithsonian Miscellaneous Collections,* 152(7): 1–33.
1968. Sable Island Bank Off Nova Scotia: Sediment Dispersal and Recent History. *The American Association of Petroleum Geologists Bulletin,* 52: 2208–2230.

Johns, W. D., R. E. Grim, and W. F. Bradley
1954. Quantitative Evaluation of Clay Minerals by Diffraction Methods. *Journal of Sedimentary Petrology,* 24:242–251.

Johnson, D. W.
1925. *New England-Acadian Shoreline.* John Wiley and Sons, New York. 608 pages.

Judd, J. B., W. C. Smith, and O. H. Pilkey
1969. The Environmental Significance of Iron-Stained Quartz Grains on the Southeastern United States Atlantic Shelf. *Marine Geology,* 8:355–362.

Keller, W. D.
1953. Illite and Montmorrillonite in Green Sedimentary Rocks. *Journal of Sedimentary Petrology,* 23: 3–9.

Keller, W. D., and C. P. Ting
1950. The Petrology of a Specimen of the Perry Farm Shale. *Journal of Sedimentary Petrology,* 20: 123–132.

King, L. H.
1965. Use of a Conventional Echo-Sounder and Textural Analyses in Delineating Sedimentary Facies—Scotian Shelf (unpublished manuscript). *Report of Bedford Institute of Oceanography,* 64(14): 1–27.
1967a. On the Sediments and Stratigraphy of the Scotian Shelf (unpublished manuscript). *Report of Bedford Institute of Oceanography,* 67(2):1–32.
1967b. Submarine End Moraines on the Scotian Shelf (abstract). *Program of Meeting of the Geological Society of America, Northeastern Section,* pages 37–38.
1969. Submarine End Moraines and Associated Deposits on the Scotian Shelf. *The Geological Society of America Bulletin,* 80:83–96.

King, L. H., B. MacLean, G. Bartlett, J. A. Jeletzky, and W. J. Hopkins, Jr.
1970. Cretaceous Strata on the Scotian Shelf. *Canadian Journal of Earth Sciences,* 7:145–155.

Kuenen, Ph. H.
1967. Emplacement of Flysch-Type Sand Beds. *Sedimentology,* 9:203–243.

Lyall, A. K., D. J. Stanley, H. N. Giles, and A. Fisher, Jr.
1971. Suspended Sediment and Transport at the Shelf-Break and on the Slope, Wilmington Canyon

Area, Eastern U.S.A. *Marine Technology Society Journal,* 5:15–27.

Marlowe, J. I.
1964. The Geology of Part of the Continental Slope near Sable Island, Nova Scotia (unpublished manuscript). *Report of Bedford Institute of Oceanography,* 64(17):44.
1965. Probable Tertiary Sediments from a Submarine Canyon off Nova Scotia. *Marine Geology,* 3: 263–269.
1967. The Geology of Part of the Continental Slope near Sable Island, Nova Scotia. *Geological Survey of Canada, Paper* 65-38:30.
1969. A Succession of Tertiary Strata off Nova Scotia, as Determined by Dredging. *Canadian Journal of Earth Sciences,* 6:1077–1094.

Medioli, F., D. J. Stanley, and N. P. James
1967. The Influence of a "paleosol" on the Morphology and Preservation of Sable Island off the Coast of Nova Scotia. In *Quaternary Soils, INQUA Symposium 9.* Pages 246–259. Nevada Desert Research Institute, Reno.

Milliman, J. D., and K. O. Emery
1968. Sea Levels During the Past 35,000 Years. *Science,* 162:1121–1123.

Moore, D. G.
1969. Reflection Profiling Studies of the California Continental Borderland: Structure and Quaternary Turbidite Basins. *The Geological Society of America Special Paper,* 107:1–142.

Moore, D. G., and P. C. Scruton
1957. Minor Internal Structures of Some Recent Unconsolidated Sediments. *The American Association of Petroleum Geologists Bulletin,* 41:2723–2751.

Nolan, F. J.
1963. Heavy Mineral Analysis of Beach Sands of Nova Scotia. Unpublished M.Sc. thesis, Dalhousie University, Halifax, Nova Scotia.

Norris, J. R.
1965. Change in Color of Sand Dunes with Time (abstract). Program of the International Association for Quaternary Research, Seventh International Congress.

Nota, D. J. G., and D. H. Loring
1964. Recent Depositional Conditions in the St. Lawrence River and Gulf.—A Reconnaissance Survey. *Marine Geology,* 2:198–235.

Officer, C. B., and M. Ewing
1954. Geo-physical Investigations, part VII, South of Nova Scotia. *The Geological Society of America Bulletin,* 65:653–670.

Piper, D. J. W.
1970. Transport and Deposition of Holocene Sediment on La Jolla Deep-Sea Fan, California. *Marine Geology,* 8:211–297.

Postma, H.
1967. Sediment Transport and Sedimentation in the Marine Environment. In *Estuaries* (G. H. Lauff, editor). Pages 158–180, American Association for the Advancement of Science, Washington, 757 pages.

Powers, M. C.
1953. A New Roundness Scale for Sedimentary Particles. *Journal of Sedimentary Petrology,* 23:117–119.

Pratt, R. M.
1967. The Seaward Extension of Submarine Canyons off the Northeast Coast of the United States. *Deep-Sea Research,* 14:409–420.
1968. Atlantic Continental Shelf and Slope of the United States—Physiography and Sediments of the Deep-Sea Basin. *U.S. Geological Survey Professional Paper,* 529-B:44 pages.

Prest, V. K., and D. R. Grant
1969. Retreat of the Last Ice Sheet from the Maritime Provinces—Gulf of St. Lawrence Region. *Gelogical Survey of Canada Paper 69-33,* 15 pages.

Rock Color Chart Committee
1963. *The Rock-Color Chart.* Geological Society of America, 16 pages.

Rvachev, V. D.
1965. Topographic Relief and Bottom Sediments of the Georges and Banquereau Banks. *Translation Defence Research Board Canada* T436R:7 pages.

Schlee, J.
1966a. A Modified Woods Hole Rapid Sediment Analyser. *Journal of Sedimentary Petrology,* 36:403–414.
1966b. Glacial History of the Gulf of Maine (abstract). *Program Annual Meeting of the American Association for the Advancement of Science,* Section E, page 32.

Schneider, E. D., P. J. Fox, C. D. Hollister, H. D. Needham, and B. C. Heezen
1967. Further Evidence of Contour Currents in the Western North Atlantic. *Earth and Planetary Science Letters,* 2:351–359.

Shepard, F. P.
1931. Glacial Troughs of the Continental Shelves. *The Journal of Geology,* 39:345–360.
1954. Nomenclature Based on Sand-Silt-Clay Ratios. *Journal of Sedimentary Petrology,* 24:151–158.
1963. *Submarine Geology* (second edition). New York, Harper and Row, 557 pages.

Shepard, F. P., and J. R. Curray
1967. Carbon-14 Determination of Sea Level Changes in Stable Areas. In *Progress in Oceanography* (B. C. Heezen, editor). Pages 283–291. Pergamon Press, Oxford.

Shepard, F. P., and R. F. Dill
1966. *Submarine Canyons and Other Sea Valleys.* Rand McNally and Company, Chicago. 381 pages.

Shepard, F. P., J. M. Trefethen, and G. V. Cohee
1934. Origin of Georges Bank. *The Geological Society of America Bulletin,* 45:281–302.

Silverberg, N.
1965. Reconnaissance of the Upper Continental Slope off Sable Island Bank, Nova Scotia. M.Sc. thesis, Dalhousie University, Halifax. 79 pages.

Stanley, D. J.
1967. Comparing Patterns of Sedimentation in Some Modern and Ancient Submarine Canyons. *Earth and Planetary Science Letters,* 3:371–380.
1968. Reworking of Glacial Sediments in the North West Arm, a Fjord-like Inlet on the Southeast Coast of Nova Scotia. *Journal of Sedimentary Petrology,* 38:1224–1241.
1970. Flyschoid Sedimentation on the Outer Atlantic Margin Off Northeast North America. In Flysch Sedimentology in North America (J. Lajoie, editor), *Geological Association of Canada Special Paper,* 7:179–210.

Stanley, D. J., and L. R. Blanchard
1967. Scanning of Long Unsplit Cores by X-radiography. *Deep-Sea Research,* 14:379–380.

Stanley, D. J., and A. E. Cok
1968. Sediment Transport by Ice on the Nova Scotian Shelf. *Ocean Sciences and Engineering of the Atlantic Shelf,* Philadelphia, Marine Technological Society, Delaware Valley Section, pages 109-125.

Stanley, D. J., G. Drapeau, and A. E. Cok
1968. Submerged Terraces on the Nova Scotian Shelf. *Zeitschrift für Geomorphologie,* Supplement, 7: 85–94.

Stanley, D. J., and N. Silverberg
1969. Recent Slumping on the Continental Slope off Sable Island Bank, Southeast Canada. *Earth and Planetary Science Letters,* 6:123–133.

Stephenson, L. W.
1936. Geology and Paleontology of the Georges Bank Canyons, Part 2, Upper Cretaceous Fossil from Georges Bank (Including Species from Banquereau, Nova Scotia). *The Geological Society of America Bulletin,* 47:367–410.

Sutton, R. G.
1964. Use of Sedimentary Parameters in the Differentiation of North Atlantic Shelf, Slope, and Abyssal Plain Sands (abstract). *Program 1964 Annual Meeting of the Geological Society of America,* page 202.

Swift, D. J. P.
1968. Coastal Erosion and Transgressive Stratigraphy. *The Journal of Geology,* 76:444–456.

Swift, D. J. P., and H. W. Borns, Jr.
1967. A Raised Fluviomarine Outwash Terrace, North Shore of the Minas Basin, Nova Scotia. *The Journal of Geology,* 75:693–710.

Swift, D. J. P., D. J. Stanley, and J. R. Curray
1971. Relict Sediments on Continental Shelves: A reconsideration. *The Journal of Geology,* 79:322–346.

Uchupi, E.
1968. Atlantic Continental Shelf and Slope of the United States—Physiography. *U. S. Geological Survey Professional Paper,* 529-C:30 pages.
1969. Marine Geology of the Continental Margin off Nova Scotia, Canada. *Transactions of the New York Academy of Sciences,* ser. II, 31:56–65.
1970. Atlantic Continental Shelf and Slope of the United States-Shallow Structure. *U. S. Geological Survey Professional Paper,* 529-I:44 pages.

Uchupi, E., and K. O. Emery
1967. Structure of Continental Margin off Atlantic Coast of United States. *The American Association of Petroleum Geologists Bulletin,* 51:223–234.

Upham, W.
1894. The Fishing Banks between Cape Cod and Newfoundland. *American Journal of Science,* 47: 123–129.

Van Houten, F. B.
1968. Iron Oxides in Red Beds. *Geological Society of America Bulletin,* 79:399–416.

Van Veen, J.
1936. *Onderzoekingen in de Hoofden.* Landsdrukkerij, Den Haag, 252 pages.

Weaver, C. E.
1961. Clay Minerals of the Ouachita Structural Belt and Adjacent Foreland. In The Ouachita System. Austin, *University of Texas Publication,* 6120:147–162.

Weller, J. M.
1960. *Stratigraphic Principles and Practice.* Harper and Row, New York, 725 pages.

# Appendix

**Description of Cores Collected South of the Nova Scotian Shelf by the Lamont-Doherty Geological Observatory of Columbia University (locality number refers to core locations shown in Figure 17)**

**Locality No. 1** Lat. 41° 20′ N
Lamont No. A164-46 Long. 59° 00′ W
Depth: 2610 fm (4773m) Core Length: 245 cm

| *Unit* | *Position (cm)* | *Description* |
|---|---|---|
| 1 | 0–9 | Gray lutite with silt laminae |
| 2 | 9–18 | Gray foram lutite grading down to pink lutite at base |
| 3 | 18–33 | Gray foram sand |
| 4 | 33–42 | Red silty lutite |
| 5 | 42–48 | Brown silt |
| 6 | 48–66 | Interbedded red lutite and brown silt |
| 7 | 66–95 | Grayish red lutite grading down to red lutite at base. Mottling 80-90 cm |
| 8 | 95–101 | Red lutite with gray mottling |
| 9 | 101–120 | Red lutite with silt laminae |
| 10 | 120–128 | Brownish gray lutite grading down to pale red lutite at base |
| 11 | 128–145 | Interbedded red lutite and brown silt |
| 12 | 145–170 | Brownish gray lutite grading down to mottled red lutite at base |
| 13 | 170–221 | Interbedded red lutite and laminated silts |
| 14 | 221–245 | Mottled gray silty lutite with gray silt at base |

**Locality No. 2** Lat. 49° 45′ N
Lamont No. A164-47 Long. 59° 00′ W
Depth: 2580 fm (4718m) Core Length: 70 cm

| *Unit* | *Position (cm)* | *Description* |
|---|---|---|
| 1 | 0–3 | Gray lutite |
| 2 | 3–4 | Brown silt |
| 3 | 4–19 | Gray lutite grading down to pale pink mottled lutite at base |
| 4 | 19–31 | Brown silt grading down to foram-rich sand |
| 5 | 31–37 | Gray foram-rich lutite grading down to red-gray laminated lutite |
| 6 | 37–43 | Brown silt |
| 7 | 43–48 | Red lutite |
| 8 | 48–49 | Gray, silty lutite |

**Locality No. 2**

| | | |
|---|---|---|
| 9 | 49–52 | Red lutite with 3 mm light gray lutite at base |
| 10 | 52–58 | Interbedded brown silt and red silty lutite |
| 11 | 58–70 | Interbedded silt and brownish gray silty lutite (flowage) |

**Locality No. 3** Lat. 41° 30′ N
Lamont No. A164-48 Long. 59° 50′ W
Depth: 2530 fm (4627m) Core Length: 490 cm

| *Unit* | *Position (cm)* | *Description* |
|---|---|---|
| 1 | 0–15 | Gray silty lutite grading down to red mottled silty lutite |
| 2 | 15–18 | Brown foram-rich silt, laminated at top |
| 3 | 18–40 | Gray silty lutite grading down to red mottled lutite. Forams abundant |
| 4 | 40–230 | Brown silt interbedded with red and gray lutites |
| 5 | 230–250 | Gray silty lutite grading down to red silty lutite with brown silt at base |
| 6 | 258–272 | Red lutite |
| 7 | 272–400 | Red lutite with brown silt laminae |
| 8 | 400–450 | Gray lutite grading down to red lutite with silt laminae |
| 9 | 450–490 | Red lutite (flowage) |

**Locality No. 4** Lat. 42° 50′ N
Lamont No. A164-49 Long. 61° 35′ W
Depth: 510 fm (933m) Core Length: 473 cm

| *Unit* | *Position (cm)* | *Description* |
|---|---|---|
| 1 | 0–146 | Brown silty lutite with forams. Faint mottling at 40 cm; sand at 60 cm and large burrows at 65–70 cm |
| 2 | 146–148 | Pale red silty lutite |
| 3 | 148–160 | Brown silty lutite with silt at 151-153 cm |
| 4 | 160–267 | Pale red silty lutite with sand 163-165 cm |
| 5 | 267–473 | Brown silty lutite with pebbles at 305 cm and 340 cm |

**Locality No. 5** Lat. 42° 05′ N
Lamont No. A164-54 Long. 63° 25′ W
Depth: 1230 fm (2250m) Core Length: 441 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–70 | Pale brown silty lutite |
| 2 | 70–170 | Brown silty lutite. Mottled 90–120 cm Burrows 130–170 cm |
| 3 | 170–441 | Pink silty lutite with pebbles throughout |

**Locality No. 6** Lat. 41° 45′ N
Lamont No. A164-55 Long. 63° 00′ W
Depth: 1820 fm (3329m) Core Length: 325 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–47 | Pale brown silty lutite with forams and burrows |
| 2 | 47–203 | Brown pebbly lutite |
| 3 | 203–325 | Pale brown lutite with a few silt laminae |

**Locality No. 7** Lat. 43° 40′ N
Lamont No. A173-8 Long. 58° 45′ W
Depth: 1490 fm (2725m) Core Length: 1025 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–60 | Gray, laminated, silty lutite |
| 2 | 60–510 | Grayish brown silty lutite interbedded with silt and fine-grained sand |
| 3 | 510–615 | Gray sand |
| 4 | 615–1025 | Interbedded gray sand and brownish gray laminated silty lutite |

**Locality No. 8** Lat. 43° 30′ N
Lamont No. A173-9 Long. 58° 30′ W
Depth: 1775 fm (3246m) Core Length: 374 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–12 | Reddish gray sandy silt |
| 2 | 12–16 | Reddish gray silty lutite |
| 3 | 16–315 | Interbedded gray sandy silt and brownish gray laminated silty lutite |
| 4 | 315–374 | Fine-grained bedded sand. No grading noted |

**Locality No. 9** Lat. 43° 15′ N
Lamont No. A173-10 Long. 60° 30′ W
Depth: 900 fm (1646m) Core Length: 440 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–90 | Brown silty lutite with beds of red pebbly lutite at 16–20 cm |

**Locality No. 9**

| | | |
|---|---|---|
| 2 | 90–440 | Pale red silty lutite with thin beds of dark gray silty lutite |

**Locality No. 10** Lat. 40° 00′ N
Lamont No. A173-11 Long. 60° 30′ W
Depth: 1426 fm (2608m) Core Length: 188 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–30 | Interbedded red and gray lutite |
| 2 | 30–34 | Gray clayey silt |
| 3 | 34–188 | Gray silty lutite |

**Locality No. 11** Lat. 42° 15′ N
Lamont No. A173-12 Long. 63° 30′ W
Depth: 1150 fm (2103m) Sore Lenth: 870 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–135 | Brown silty lutite with forams |
| 2 | 135–212 | Pale red silty lutite. Bright red blebs in upper 5 cm |
| 3 | 212–870 | Brown silty lutite with a few pebbles, granules and forams |

**Locality No. 12** Lat. 42° 15′ N
Lamont No. A173-13 Long. 63° 25′ W
Depth: 1600 fm (2926m) Core Length: 450 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–76 | Pale pinkish brown silty lutite with forams |
| 2 | 76–90 | Pink silty and sandy lutite with gray mottling |
| 3 | 90–128 | Brown silty lutite with forams, sand, and granules |
| 4 | 128–185 | Pink lutite |
| 5 | 185–450 | Brown silty lutite with scattered granules and pebbles |

**Locality No. 13** Lat. 41° 55′ N
Lamont No. A173-14 Long. 64° 35′ W
Depth: 1410 fm (2578m) Core Length: 370 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–22 | Brownish gray sandy lutite (some flowage) |
| 2 | 22–26 | Pale red silty lutite |
| 3 | 26–40 | Interlaminated brown and gray silty lutite |
| 4 | 40–65 | Pale red silty lutite |

**Locality No. 13**

| | | |
|---|---|---|
| 5 | 65–110 | Same as 26–40 cm |
| 6 | 110–123 | Same as 40–65 cm |
| 7 | 123–245 | Interlaminated red and gray silty lutite |
| 8 | 245–370 | Flowage |

**Locality No. 14** Lat. 43° 50′ N
Lamont No. C25-10 Long. 59° 00′ W
Depth: 910 fm (1664m) Core Length: 30 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–30 | Brown silty lutite. No bedding noted |

**Locality No. 15** Lat. 43° 10′ N
Lamont No. KM 1-2 Long. 60° 15′ W
Depth: 750 fm (1372m) Core Length: 475 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–475 | Brownish gray clayey and sandy silt. Forams rare; pelecypod valves in upper 10 cm. |

**Locality No. 16** Lat. 43° 35′ N
Lamont No. KM 1-5 Long. 59° 20′ W
Depth: 136 fm (249m) Core Length: 122 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–122 | Brown silty sand with fragments of red silt scattered throughout |

**Locality No. 17** Lat. 43° 35′ N
Lamont No. KM 1-6 Long. 59° 30′ W
Depth: 310 fm (567m) Core Length: 300 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–53 | Brown clayey silt with fragments of red lutite |
| 2 | 53–65 | Interbedded gray silt and laminated lutite |
| 3 | 65–123 | Interbedded pink and brownish gray, clayey, granular silt (some flowage) |
| 4 | 123–147 | Brown silt |
| 5 | 147–151 | Brown silt interbedded with gray and pink lutite |
| 6 | 151–158 | Brown silt |
| 7 | 158–164 | Same as 147–151 cm |
| 8 | 164–300 | Brown granular lutite grading down to a brown clayey, pebbly silt |

**Locality No. 18** Lat. 43° 35′ N
Lamont No. KM 1-7 Long. 60° 05′ W
Depth: 450 fm (823m) Core Length: 310 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–78 | Gray silty lutite. Pebbles and shells at 72 cm |
| 2 | 78–121 | Brown clayey silt with scattered shell fragments |
| 3 | 121–150 | Interbedded brownish gray silty lutite and silt |
| 4 | 150–250 | Gray silty lutite grading to brownish gray clayey silt at base |
| 5 | 250–310 | Reddish brown clayey silt |

**Locality No. 19** Lat. 43° 20′ N
Lamont No. SP 12-1 Long. 59° 55′ W
Depth: 700 fm (1280m) Core Length: 345 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–55 | Brownish gray silty lutite. Burrows 36–45 cm |
| 2 | 55–72 | Pink to brownish gray pebbly lutite (some flowage) |
| 3 | 72–126 | Interbedded pink and brown silty lutite with a few burrows and granules |
| 4 | 126–135 | Brownish gray silty lutite |
| 5 | 135–155 | Interbedded pink and brown silty lutite |
| 6 | 155–345 | Red pebbly lutite |

**Locality No. 20** Lat. 43° 20′ N
Lamont No. SP 12-2 Long. 60° 15′ W
Depth: 680 fm (1244m) Core Length: 240 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–95 | Gray silty lutite grading down to brownish red granular silt at bottom. Burrows abundant. |
| 2 | 95–240 | Pale red granular lutite. Bedding faint but distinct. Granules at 98–110 cm and 205–40 cm |

**Locality No. 21** Lat. 43° 05′ N
Lamont No. SP 12-3 Long. 59° 55′ W
Depth: 1300 fm (2377m) Core Length: 215 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–75 | Pale brownish gray silty lutite grading down to brownish red lutite at base. Burrows 15–60 cm |

**Locality No. 21**

| | | |
|---|---|---|
| 2 | 75–215 | Interbedded pale red and brown silty lutite |
| 3 | below 215 | Brown silty lutite (flowage) |

**Locality No. 22** Lat. 43° 10′ N
Lamont No. SP 12-4 Long. 59° 45′ W
Depth: 1310 fm (2395m) Core Length: 360 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–303 | Pale brown lutite grading down to reddish brown silty lutite at base. Burrows at 76 cm; pebbles at 85 cm; forams in upper 40 cms |
| 2 | 303–308 | Red clayey silt |
| 3 | 308–350 | Brown granular lutite with a few forams |
| 4 | 350–360 | Pale red silty lutite |

**Locality No. 23** Lat. 43° 15′ N
Lamont No. V 2-4 Long. 56° 00′ W
Depth: 2000 (?) fm (3658m) Core Length: 390 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–53 | Red silty lutite |
| 2 | 53–390 | Red lutite with widely spaced silt laminae. No flowage |

**Locality No. 24** Lat. 39° 30′ N
Lamont No. V7-38 Long. 64° 55′ W
Depth: 2508 fm (4587m) Core Length: 490 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–8 | Gray silty lutite with forams |
| 2 | 8–11 | Red lutite with fragments of gray silt |
| 3 | 11–40 | Gray silty lutite grading down to red silty lutite |
| 4 | 40–80 | Brown silty lutite |
| 5 | 80–84 | Gray silt |
| 6 | 84–130 | Two beds of gray lutite grading down to red lutite with silt at base of each |
| 7 | 130–140 | Gray lutite |
| 8 | 140–142 | Silt |
| 9 | 142–158 | Gray lutite grading down to pink lutite |
| 10 | 158–160 | Silt |
| 11 | 160–195 | Brownish gray lutite |
| 12 | 195–300 | Silt interbedded with gray silty lutites |
| 13 | 300–400 | Brown silty lutite |
| 14 | 400–415 | Red lutite with beds of granules |
| 15 | 415–435 | Light brown silty lutite |
| 16 | 435–447 | Foram sand |
| 17 | 447–490 | Silts interbedded with brown silty lutites |

**Locality No. 25** Lat. 43° 00′ N
Lamont No. V7-63 Long. 61° 55′ W
Depth: 220 fm (402m) Core Length: 210 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–78 | Brownish gray silty lutite grading to clayey silt at base |
| 2 | 78–172 | Brownish gray silty lutite (some flowage) |
| 3 | 172–182 | Gray fine-grained silt |
| 4 | 182–210 | Light brown silty clay (flowage) |

**Locality No. 26** Lat. 40° 45′ N
Lamont No. V7-68 Long. 64° 40′ W
Depth: 2143 fm (4102m) Core Length: 245 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–17 | Brown silty sand with forams |
| 2 | 17–54 | Pink mottled lutite with forams |
| 3 | 54–245 | Sand grading to granules at 60 cm, grading to pebbles with cobbles at base. Reversal of grading at 210 cm |

**Locality No. 27** Lat. 40° 55′ N
Lamont No. V7-69 Long. 65° 35′ W
Depth: 1600 fm (2926m) Core Length: 612 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–20 | Brownish gray clayey foram silt grading down to red silt at base. Mottling in lower part |
| 2 | 20–110 | Brownish gray clayey silt with sand and granules |
| 3 | 110–127 | Red lutite and brown silt (flowage) |
| 4 | 127–186 | Brownish gray clayey silt grading down to red silty clay. Isolated pebbles throughout |
| 5 | 186–210 | Brownish gray clayey silt |
| 6 | 210–260 | Red and brown clayey silt interbedded with silt laminae |
| 7 | 260–345 | Brownish gray clayey silt with granules |
| 8 | 345–450 | Same as 210–260 cm |
| 9 | 450–612 | Silt interbedded with brownish gray silty lutite |

**Locality No. 28** Lat. 41° 55′ N
Lamont No. V7-70 Long. 64° 30′ W
Depth: 700 fm (1280m) Core Length: 560 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–60 | Brown sandy and clayey silt with burrows |

**Locality No. 28**

| | | |
|---|---|---|
| 2 | 60–67 | Red sandy and clayey silt with foram laminae |
| 3 | 67–162 | Brown granular, clayey silt interbedded with layers of shells and granules |
| 4 | 162–167 | Red sandy silt |
| 5 | 167–190 | Brown sandy, clayey silt grading down to reddish brown silt at base |
| 6 | 190–194 | Laminated silt |
| 7 | 194–285 | Reddish brown granular, clayey silt with scattered small pebbles |
| 8 | 285–290 | Red sandy silt |
| 9 | 290–320 | Brown sandy, clayey silt |
| 10 | 320–330 | Sand laminae |
| 11 | 330–560 | Brown sandy, clayey silt with thin beds of sand and gravel |

**Locality No. 29** Lat. 41° 40′ N
Lamont No. V16-213 Long. 62° 55′ W
Depth: 2065 fm (3777m) Core Length: 980 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–40 | Light brown foram lutite |
| 2 | 40–280 | Lutite, pale red to red at base, with silt laminae |
| 3 | 280–409 | Light brown silty lutite interbedded with light brown silt |
| 4 | 409–870 | Interbedded red lutite, brownish gray lutite and silt |
| 5 | 870–980 | Flow-in |

**Locality No. 30** Lat. 40° 25′ N
Lamont No. V17-209 Long. 63° 15′ W
Depth: 2453 fm (4486m) Core Length: 415 cm

| *Unit* | *Position(cm)* | *Description* |
|---|---|---|
| 1 | 0–38 | Light brown silty foram lutite |
| 2 | 38–140 | Brown silty lutite with laminated silt beds |
| 3 | 140–209 | Graded bed with silt at top, sand throughout except for granular bed at base |
| 4 | 209–244 | Red lutite |
| 5 | 244–415 | Interbedded light brown lutite and laminated silt |

# Index

☆ U.S. GOVERNMENT PRINTING OFFICE: 1972—484–312/3