RECONNAISSANCE OF THE UPPER CONTINENTAL SLOPE OFF SABLE ISLAND BANK, NOVA SCOTIA

by

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Submitted in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

A bathymetric chart of the continental slope off Sable Island Bank was compiled from soundings released by the Canadian Hydrographic Service. The slope in this area is dissected by numerous valleys in the region directly adjacent to Sable Island Bank but changes abruptly to a featureless terrain in the region off the southwestern limit of the bank.

During cruises aboard the CSS KAPUSKASING and the CNAV SACKVILLE, a total of 21 piston cores were obtained. Analyses of the sediment cores included visual description, investigation of internal structure through X-radiography, textural analysis, petrographic examination of the coarse fraction, heavy minerals, and clay fraction, and investigation of the distribution of foraminifera.

This reconnaissance study has revealed three sediment types on the continental slope. The sediments are very similar mineralogically and are probably derived from material transported from northern Nova Scotia and the Gulf of St. Lawrence region by glacial processes.

Several periods of sedimentation are indicated on the continental slope. During the height of the Wisconsin lowering of sea level active erosion of the exposed shelf led to the rapid deposition of a sand and pebble rich, brown mud on the continental slope. Following the rapid rise in sea level, the shelf was submerged, and the abundant supply of sediment was cut off. Slow deposition of fine sand and mud subsequently formed a layer of grey sediment on the slope. Continued removal of fines from the shelf, and increasing bottom currents, produced a gradual increase in the proportion of sand being deposited on the slope. A thin layer of relatively clean sand, found at the surface in many parts of the slope, suggests the intensification of this process in Recent time.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Following page

Plates

Figures

Tables

INTRODUCTION

General Statement

This study is a sedimentary reconnaissance of the Nova Scotian Continental Slope. It provides an initial interpretation of the recent sedimentological history of this poorly known region. It is hoped that the study will provide a basis for a more detailed investigation.

The survey was carried out aboard the CSS KAPUSKASING and the CNAV SACKVILLE during May and September, 1964. A series of sounding runs and 21 piston core samples were obtained from various topographic regions of the slope. The sediment cores were described in the laboratory, and selected samples were examined in detail to provide data for sedimentological analysis. The data obtained from this reconnaissance survey has led to an interpretation of the geology of the region.

Figure 1. Inset map showing study area.

Area of Study

The region examined (Figure 1) is contained between 59°00' to 62°00' West Longitude and 42°30' to 43°40' North Latitude and is confined to the zone between the 100 and 1000 fathom contour lines. The area trends northeast-southwest and is approximately 125 miles long by 30 nautical miles wide. The slope considered is contiguous to the Sable Island Bank region of the Nova Scotian shelf. It is bounded on the northeast by the submarine canyon known as the Gully and is terminated on the southwest by the region adjacent to the edge of Sable Island Bank. The region is approximately 120 nautical miles offshore and can be reached from Halifax in about half a day's steaming.

Acknowledgements

I wish to express my gratitude to Dr. D.J.P. Swift for his supervision and guidance in determining laboratory procedures and the preparation and integration of data throughout the course of this investigation.

I would also like to thank those who provided assistance during the various phases of the study.

Dr. J.L. Marlowe, of the Bedford Institute of Oceanography, introduced the author to shipboard techniques and solved many difficulties experienced by a novice at sea.

The officers and crew of CSS KAPUSKASING and CNAV SACKVILLE were particularly cooperative in the carrying out of the sampling program.

Dr. J.S. Manchester of the Diagnostic Radiology Department of the Victoria General Hospital generously provided the use of x-ray equipment for the study of internal structures.

L. Blanchard prepared the negatives for the radiography study and provided valuable suggestions towards the procedural aspects of this study.

A.E. Cok provided the data on the heavy mineral assemblage of the slope sediments and ready advice on many procedural problems and general interpretation of regional geology.

Dr. T.T. Davies reviewed the discussion of the clay fraction and provided advice and encouragement on other aspects of the study. Together with F. Aumento, he provided valuable assistance in the use of the x-ray diffraction unit.

Dr. F. Medioli investigated the foraminifera in the slope sediments and provided valuable stratigraphic information.

Dr. D.J.S. Stanley and Dr. M.J. Keen offered assistance during various phases of the study.

The author is grateful to J. Connolly who typed the final manuscript with very short notice.

The author wishes to thank Dr. C.G.I. Friedlaender, Head of Department of Geology, and Dr. J.E. Blanchard, former Acting Head of the Dalhousie Institute of Oceanography, for the wonderful co-operation of these departments in providing ship time and equipment.

I wish to acknowledge the scholarship, provided by the Faculty of Graduate Studies, which permitted the author to undertake this investigation.

METHODS AND PROCEDURES

Shipboard

BATHYMETRY

Boat sheets made available by the Canadian Hydrographic Service were used to produce a contoured bathymetric chart of the upper continental slope. These sheets show spot soundings picked from depth sounding profiles obtained with the Kelvin Hughes apparatus aboard the CSS KAPUSKASING in 1960-61. Over the slope, profiles are spaced 1.5-2.0 miles apart and spot soundings are recorded every half mile. Soundings are recorded to depths of about 1200 fathoms but many profiles terminate at shallower depths. It was possible, using a 50 fathom contour interval, to contour to a depth of 1000 fathoms. In areas where soundings are rare, dashed lines have been drawn. The original boat sheets are at a scale of 1:75,000. The individual sheets were photographically reduced, cut to fit a mosaic, and reproduced by ozalid to form an integrated bottom chart at a scale of one inch to approximately five nautical miles. (Figure 2)

Positioning of spot soundings is considered to be fairly accurate as continuous Decca plotting and auxiliary vessels are used by the Hydrographic Office. The Kelvin Hughes depth sounder aboard the Kapuskasing can be accurately read to five fathoms, except in heavy seas when the position of the bottom is obscured by noise. Still, several factors limit the accuracy of the chart. The greatest error results from interpretation between sounding lines during contouring. Features as large as two miles in width may be undetected in these gaps. Because the sounding lines run slightly across the maximum inclination of the slope, most of the topographic features would be traversed during the survey and this error would be somewhat reduced.

Spot soundings were recorded along equal distances of most sounding profiles. Since it is not likely that particular attention was made to geological interpretation, features as wide as half a mile may have been unrecorded.

The use of preconceived concepts, such as the river analogy employed by Veatch and Smith (1939), was avoided as much as possible in the interest of objectivity. Some interpretation, however, was unavoidable as the dissected nature of the sea floor became apparent soon after contouring began.

The chart was found to be quite workable at sea in conjunction with the depth sounding equipment. It is felt that the chart is accurate with respect to features larger than two miles in width. The character of smaller features, if not their precise configura-

FIGURE 2

BATHYMETRIC CHART OF THE CONTINENTAL SLOPE

tion, can be inferred from the chart.

NAVIGATION

Chain 7 Decca Navigation, with Master at Chester Basin and slaves at Jordan Bay and Ecum Secum, was used in most of the region. In the northeast section of the area Decca was considered poor and Loran electronic navigation with occasional sun-shots were employed for positioning. Absolute accuracy in positioning is difficult to estimate as it is dependent upon distance from Master, time of day, noise level and operator error. One to two miles was the estimate of accuracy used at sea.

The bathymetric chart and dead reckoning over short distances were used to a greater extent than Decca when determining the course of sounding runs, and when manoeuvering the vessel over a station. This procedure enabled positioning to one half mile, relative to the bottom, and is considered to be more significant for the purpose of this study than the geographical co-ordinates obtained through electronic positioning. Other workers in areas relatively far from shore have used similar procedures, e.g. Marlowe (1964).

SAMPLING

A 125 pound Alpine Piston Corer, with 2½ inch plastic liners, was used to sample the unconsolidated sediments on the slope. The Dietz Lafond snapper grab, used as a trigger weight, provided additional material.

Plates 1 to 3 show some of the stages of preparation of the coring device. The stern hydraulic winch was used aboard the KAPUSKASING and the side electric winch was used on the SACKVILLE. Both employ 5/32 inch cable.

The corer was lowered slowly (1-1.5 m/s) to prevent premature tripping but was raised as quickly as possible after being eased from the bottom. The corer was dismantled on deck, and the liner recovered. The material caught in the core bit and catcher was placed in the bottom of the liner and the end sealed with a plastic cap. The liner was then righted and sawed short just above the top of the sediment column. After sealing and labelling, the liners were stored in an upright position.

No attempt was made to describe the cores at sea because an internal veneer of washed sediment almost always obscured the material within the liner.

Plate 1

a. Winch arrangement on KAPUSKASING.

b. Setting up of core liner.

Plate 2

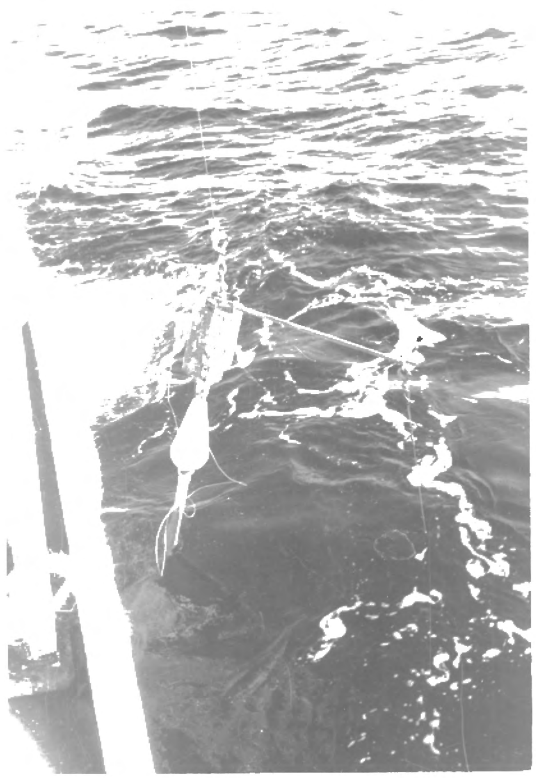
a. Assembled corer and trigger weight.

b. Manhandling corer over the side.

Plate 3

a. Laying out trigger weight.

b. Ready for lowering.



Laboratory Procedure

STORAGE AND SPLITTING

As recovered, the sediment was commonly very damp and subject to flowage. To prevent distortion, the upright cores were dried for several months until sufficient strength had been achieved to permit splitting. In some cases four months was insufficient and several holes were drilled into the liners to hasten drying.

A knife edge cutting device (See plate 4), constructed at the Dalhousie Physics Workshop, was used to split the core liner. A wide, thin-bladed kitchen knife was found to be most useful for slicing the sediment itself. After splitting, one half-core was used for subsequent analyses and the other was sealed in polyethylene sleeving to serve as a permanent reference.

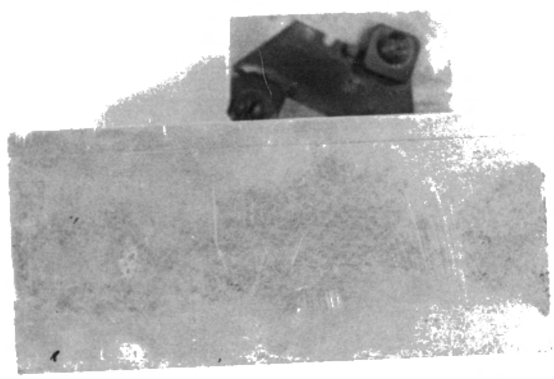
PRELIMINARY DESCRIPTION

The exposed cores were immediately examined. Colour, texture, structure, and unusual features such as large shells or pebbles, were noted. The Rock-Color Chart (1951) was used in describing sediment colours. Great care was taken in determining colour changes and nomenclature. As the author experiences a red-green visual deficiency, independent observers were asked to help perform this portion of the preliminary description.

Textures were estimated by the 'taste' method. These were considered only as a guide for more precise analysis.

Immediately after being logged, the cores were photographed

Plate 4



Device for splitting core liners.

to provide a permanent record of the fresh core.

To prevent rapid dessication the cores were then enclosed in polyethylene sleeving.

SAMPLING

On the basis of the preliminary description three cores were selected as representative and were sampled every 10 cm. in depth. The remaining samples were selected to sample the major horizons in the other cores and to serve for comparison in a reconnaissance survey of the sediments.

A spatula was used to extract samples approximately 1.5 cm. in depth, and 3 cm. in width. The surface of the samples were scraped to remove contamination due to washed sediment and knife smearing.

SAMPLE PREPARATION AND ANALYSIS

The weight of each sample was recorded after drying in a 40-50°C oven. The flow sheet (Figure 3) indicates the various operations performed during the analyses. Initial procedures were slightly different from the finally standardized method but were comparable to those used with the bulk of the samples.

Sand-Silt-Clay Determination

Dispersion was achieved using 0.01 N Sodium Oxalate and stirring for 15-20 minutes with an electric mixmaster. The dispersed sediment was transferred into 200 ml. centrifuge bottles, brought to the 10 cm. level, and centrifuged at 300

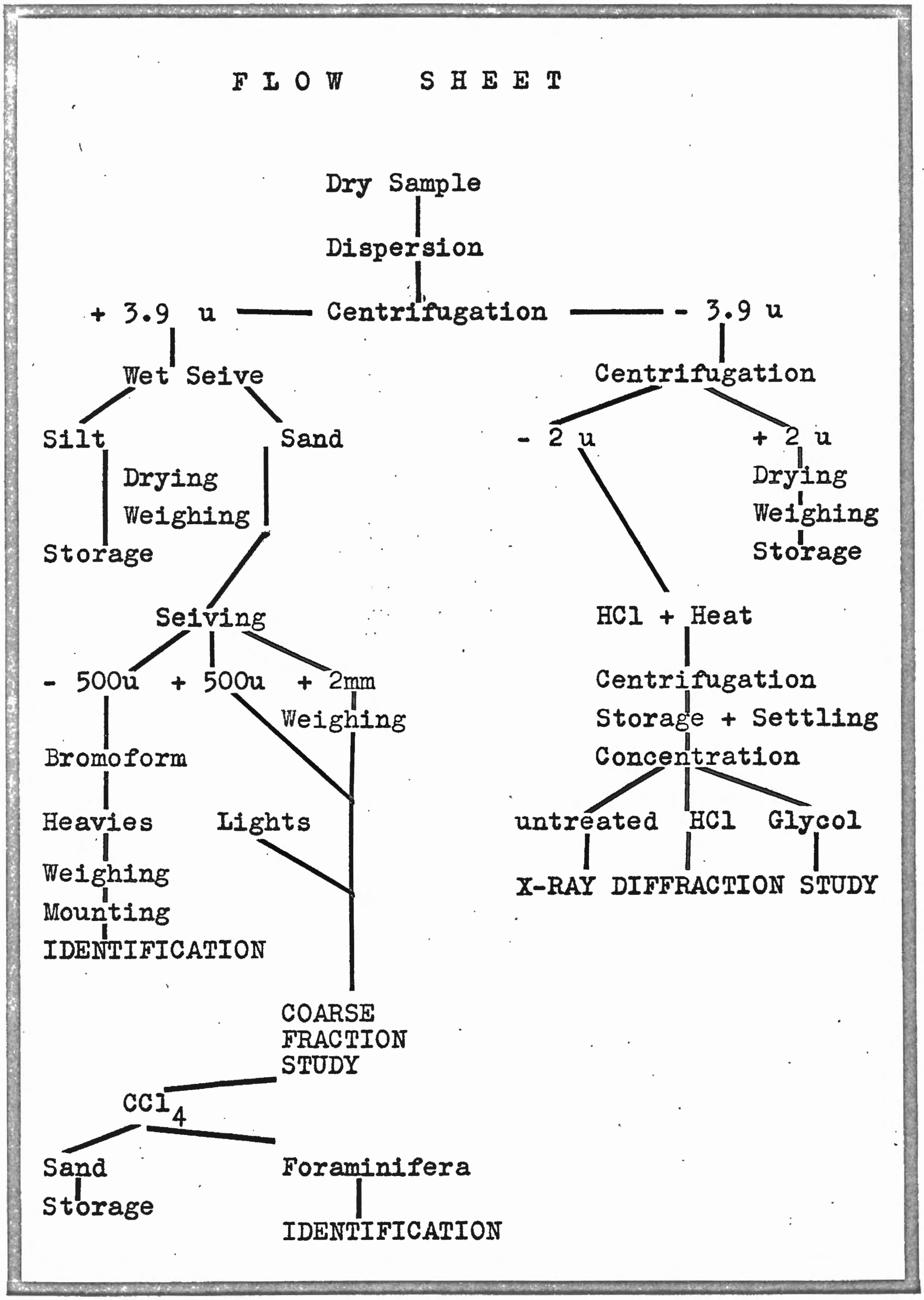


Figure 3. Flow sheet of laboratory procedure.

R.P.M. for 6.9 minutes (the time calculated for a 3.9 micron particle to settle 10 cm. with the centrifuge arrangement available). The supernatant clay suspension was decanted and the bottle refilled with distilled water, remixed, and recentrifuged. This procedure was continued until the supernatant was relatively clear, indicating that almost all the clay sized material had been removed.

The sedimented fraction was then washed through a 63 micron screen. The collected suspension was again centrifuged and the supernatant was added to the accumulated clay suspension.

The silt fraction (3.9-63 microns) and the sand fraction (greater than 63 microns) were then dried and weighed. Where material coarser than 2 mm. was present it was sieved off and the weight of the pebble fraction recorded separately. Sand-silt-clay percentages were then calculated directly.

Initially, in core Sc-9, weight was recorded to the nearest 0.1 grams, resulting in a limited accuracy of ± 1%. Subsequent determinations were made at 0.01 grams and the percentage figures recorded to the nearest unit are without significant error. Errors due to loss of material are negligible in consideration of sand-silt-clay percentages.

Coarse Fraction Study

The sand material finer than 500 microns was removed by sieving and weighed to 0.0001 grams. The heavy fraction was separated using bromoform (S.G. 2.89) as the heavy liquid, in steep-walled funnels. The heavies were recovered by means of a stopcock at the base of the funnel. After drying, the heavies were weighed and their contribution determined as parts per thousand of the fine sand fraction.

A number of samples were prepared in Caedex mounted slides. In most samples the total material recovered was used in preparing the slides.

The percentage of opaques to non-opaques was first determined, after which 100 non-opaque grains were counted. Identification was performed by A.E. Cok.

The light fraction was then studied using a modification of the technique described by Shepard (1958). An initial series of samples was split into the following sieve sizes. ... greater than 500 microns, 300-500, 150-300, 105-150, 62-105 microns. On the basis of these analyses it was decided that all subsequent samples be examined in two fractions; greater than 300 microns and 62-300 microns.

Each fraction was examined with the binocular microscope. The coarser fractions contained very few grains and the fractions were generally counted in total. The finer fractions were found to be dominantly composed of quartz grains. To avoid large errors in the remaining components the following counting procedure was used. Two hundred were examined for the percentage of quartz grains. Two hundred non-quartz were then counted to give the distribution of the remaining components.

Foraminiferal Study

The foraminifera in the sand fraction were concentrated by flotation on carbon tetrachloride. Because many individuals were fragmented, or sediment or pyrite filled, only a portion of the foraminifera were recovered. A check was made of the individuals remaining unconcentrated. It was found that no species were selectively concentrated in the procedure (F. Medioli, Personal Communication, 1965).

Clay Fraction Study

i) Sample Preparation

Techniques for the preparation of clay samples depend to a large extent on the type of material being studied, the purpose of the study, and available equipment. The procedure outlined below was developed to deal with the small quantities of sediment available from piston cores.

The total clay material of each sample remained in suspension after the determination of sand-silt-clay percentages. Coarse clay commonly contains a large percentage of non-clay minerals (Brindley, 1961). All the material coarser than 2 microns was separated using the centrifuge at 500 R.P.M. for 9.9 minutes. The material was centrifuged only once and some material just under 2 microns in size was removed along with the coarse clay. If this error were to be removed the initial suspension would have to be recentrifuged repeatedly. As the initial suspension consisted of one liter it was felt that further dilution, through recentrifuging, would make the clay fraction very difficult to extract.

With the coarse clay removed, the suspension was brought to a pH of 3.5 by the addition of 1 N HCl (Bromphenol Blue was used as an indicator), after which it was heated in a 100°C oven for 2 hours to induce flocculation (Jackson, 1956). This technique produced no apparent visible change in the suspension. However, upon centrifugation at 2000 R.P.M. for 25-35 minutes, it was found that the supernatant liquid appeared relatively clear, indicating that floccules greater than 0.5 microns had formed. It was assumed that the material then remaining in suspension was quantitatively insignificant.

The sedimented clay was then washed into a graduate and the volume of the thick suspension was noted before it was transferred to storage jars.

In preparing oriented slides for X-ray diffraction, a density of at least 15 mg./sq. in. is required (Brindley, 1961). The glass plates used with the available X-ray unit had a surface area of 2.25 sq. in. and so a minimum of 40 mg. of clay was required in preparing each slide. Because the weight of clay remaining at this stage was not known directly, but was calculated after determining the weight of all the coarser material, the value was known to be low because of experimental error. To avoid light slides the clay slurry was permitted to settle for several days, after which enough water was carefully pipetted off to bring the suspension to a calculated concentration of at least 20 mg./ml.

After concentration, three 3 ml. aliquots were removed using a wide-bore pipette. Two aliquots were placed on 1/8 inch thick glass plates, cut to 1.5 X 1.5 inches, and were allowed to settle and dry in a 40-50° C oven. The third was placed in a beaker, 50 ml. of 6 NHCl added, and heated for 2 hours on a steam bath. After the large floccules had settled, most of the supernatant was removed and the material was placed on a third glass plate to dry. The drying procedure required about four hours to complete.

After drying, one of the original slides was placed in a closed container several centimeters above a pool of ethylene glycol and heated at 60°C for two hours. The sample was cooled for 24 hours to establish an equilibrium before irradiation. The glycolated samples were maintained in the closed containers except during the actual analysis. This technique, described by Kunze (1955), was developed to prevent the incomplete glycolization of montmorillonite.

ii) X-ray Procedure

A Seimens Counter Tube Diffractometer, coupled to an electronic potentiometer recorder "Kompensograph", was used for this study.

Preliminary examination of the untreated samples was carried out using a concave quartz crystal monochromator and a scintillation counter in conjunction with Copper radiation. The monochromator allowed examination of the low angle reflections by reducing low angle scattering and it effectively removed the K-Beta radiation.

Because of procedural difficulties, an attachment was constructed to permit the use of the more compact flow counter. Reproduceability was found to be inadequate and because the monochromator attachment, particularly the crystal block mechanism, was too sensitive to the normal vibrations and drag of the diffractometer, the arrangement was eventually discarded in favour of a simpler knife edge attachment.

Reduction of background was achieved by adjustment of the gold-plated knife edge and through the use of discrimination of the scintillation counter response. The knife edge is mounted at right angles to the sample and effectively reduces low angle scattering by limiting the width of the x-ray beam. Final runs were made using the arrangement listed below.

Ni filtered Cu radiation

40 KV

12 mA

inlet aperture 1°

detector slit 0.1 mm.

Full scale 4000 cps.

Statistical error 2%

Pulse height 39 volts

Channel width 10 volts

Recording speed $\frac{1}{2}^{\circ}$ 2θ/min.

Range 3 - $30^{\circ}2\theta$

The three slides for each sample were run consecutively in order to minimize variations due to the recording apparatus.

To provide additional information, several samples were prepared in 0.5 mm. capillaries and were examined with the 114.6 mm. powder camera. Mn filtered Fe radiation at 35 KV and 10 mA were employed for 23 hour exposures.

Radiography Study

X-ray photography is a simple and valuable technique which has only recently been exploited in sedimentary geology. Hamblin (1962, 1965) was the first to use this technique in the study of apparently homogeneous sedimentary rocks. Modifications of his procedure were used by Calvert and Veevers, (1962), and Bouma (1964) in the study of unconsolidated sediments.

The method involves placing the sample in contact with x-ray film and exposing it to radiation. High density materials in the sample absorb more radiation than do lower density materials and the x-ray film is less exposed under these portions of the sample. Alignments and associations of heavy mineral grains in the sample can thus reveal internal structures that are not otherwise apparent.

To avoid superposition of structures, which make interpretation difficult, relatively thin slices of sediment are used in preparing radiographs. Prior to selecting zones where such slices would be removed, the author found it useful to examine the total lengths of core. The half cores, still in the liner and covered with polyethelene sleeving, were x-rayed in sections as long as 4 feet. Film cassettes as wide as 2 feet are available and several cores could be exposed together. A Picker X-Ray Unit, Model KM-300 was used for this part of the study. The pertinent exposure information is listed below.

Tungsten radiation

2.5 mm. Al filter

Rotating Anode

Full Wave Rectification

Film focal distance: 60 inches

60 KV

100 mA

3/20 sec.

Kodak Blue Brand Medical X-Ray Film and standard speed screen cassettes were used in obtaining all radiographs. Experimentation with industrial films did not indicate that superior definition could be attained.

All the cores were photographed using the above settings. Because the cores were in varying states of dessication, some cores appear darker than others and local regions within individual cores show the same relation to moisture content. Even so, with sufficient lighting available, all radiographs could be easily read. The quality of the radiographs of these half cores, and of those obtained in experimentation with complete core sections, was very good. It is suggested that this technique can offer valuable information to the investigator even before the cores are opened for visual examination.

On the basis of the structures revealed in the half cores, short sections of core were selected for slicing. A taut piano wire positioned above a sliding block was used to cut 5 mm thick slices of sediment from the core sections. The slices were photographed and wrapped in Saran Wrap before they were x-rayed. A General Electric, Model KX-19-8, x-ray unit, with similar anode and radiation features as the Picker unit, was used with these slices. Exposure factors were as follows...

Film focal distance 40 inches

52 KV

100 mA

1/20 sec.

The radiographs of the thin slices were printed using Cykora GL-2 paper. This paper has good tonal quality but unfortunately does not equal the x-ray film. Some of the features detectable on the negatives are obscured on the paper prints. Velox paper gave results which were more distinct but these had poorer tonal qualities. Intensity variations among the negatives led to problems in determining optimum exposures for the prints. Printing is a costly procedure and experimentation was kept at a minimum. Because of the printing difficulties interpretation of the radiographs have been based primarily upon examination of the negatives. If such problems are to be avoided it is wise to examine sample slices in their original conditions, or to maintain all samples under controlled humidity.

GENERAL GEOLOGY

Regional Setting

The continental margin of this region includes a variety of physiographic provinces, (See Figure 1). To the north and south, respectively, are the large epicontinental embayments of the Gulf of St. Lawrence and the Gulf of Maine. The Laurentian Channel, a straight-walled shallow trough, separates the Nova Scotian area from the great eastward trend of the continental margin towards the Grand Banks of Newfoundland. The Scotian shelf is a complex region, with areas of high local relief, large basins, and smooth, shallow, banks. A unique feature of the Scotian Shelf is Sable Island, a 25 mile long ridge of sand occurring over 100 miles from the mainland. The upper continental slope contains a system of incised valleys. Seaward of the study area lie the smoother lower reaches of the continental slope and rise which extend to the flat ocean bottom of the Sohm Abyssal Plain. The study of this large area is still in the preliminary stage.

PHYSICAL OCEANOGRAPHY

Oceanographic conditions in the region are also complex. The Labrador Current, the Gulf Stream, coastal water, and slope water all occur in close proximity. The area sampled is overlain by the slope water, a water type characterized by a temperature and salinity intermediate between the coastal waters and the Gulf Stream. It is thought to be formed of a mixture of surface coastal and Gulf Stream waters, Labrador current waters and upwelling deep Atlantic waters. (McLellan et al., 1953) A recent study by Foote et al. (1965, in press), shows that a core of cold coastal water extends several miles over the shelf edge. Below this layer, between 200 and 1000 meters, is a mass of water of low salinity, which lies against the continental slope. The main zone of mixed water occurs next to these two types and extends southwards to the Gulf Stream.

The current pattern in the region is poorly known. Electrokinetograph measurements and geostrophic current calculations, indicate that weak and irregular currents occur parallel to the slope in an east-north-easterly direction, between 300 and 800 meters (Foote et al., 1965). Strong surface currents occur at the eastern end of Sable Island and in the Gully. Marlowe, (1964), reported southerly drifts of five knots in the Gully, and compared them with southward ebb-tide flows reported in the Nova Scotian Pilot.

Drift bottle studies have revealed the gross surface current patterns on the continental shelf. Trites (1958) describes a counterclockwise circulation on the Scotian shelf which is roughly centered around Sable Island. Average drift speeds were between 0.11 and 0.15 knots. Confirmatory evidence is contained in a study of the coastal waters between Newfoundland and Florida published by the American Geographical Society (Bumpus and Lauzier, 1965). Seasonal variations are reported on the Scotian shelf. During Spring, a well-developed southeast movement occurs along the coast. This flow becomes discontinuous during the winter. Off Cape Sable the flow reverses and continues in a northeast direction along the outer shelf. The general motion carries the surface water off the shelf and is probably responsible for the core of cold coastal water observed by Foote. If these surface currents effect sediment dispersal, a mixture of Gulf of St. Lawrence, coastal Nova Scotian, and outer shelf sediment could reach the continental slope. These drifts are weak however, and may not reflect bottom conditions so that only fine sediment would probably be carried in this manner.

Gulf of St. Lawrence Region

The sediments of this large basin have been studied by Nota and Loring (1964). The deep basinal deposits were found to be predominantly pelitic while coarse-grained deposits were observed nearshore. The sediments, which are derived from the Canadian

Shield, are immature mineralogically, and are thought to be a consequence of present sub-arctic climactic conditions and the Pleistocene glaciations of the St. Lawrence basin.

Nova Scotian Continental Shelf

Sand and gravel form the principal sediments in the region with pelitic material occurring only in the basins.

Several topographic regions are described by Pizzetta (1962) on the southern portion of the Scotian shelf. The western area is irregular with many knolls and valleys. Two large basins occur off Halifax, extending below 100 fathoms in depth. A deep water channel separates these nearshore features from the flat bank region on the outer shelf.

A study of the northern portion of the shelf is being completed by A.E. Cok of the Dalhousie Institute of Oceanography. A nearshore region, a northeast region, and a banks region are apparent from this study. The nearshore region is finely irregular in topography and is thought to reflect the submarine extension of local Nova Scotian bedrock. The sediments here are very similar to those found in coastal till and beach deposits. The northeast section is characterized by an irregular network of steep valleys incised below a relatively flat surface. The deposits in this area are related to the Cape Breton and Gulf of St. Lawrence areas. The banks are featureless, shallow zones on the outer portion of the shelf and are separated from the remainder of the shelf by a deeper zone of low relief. The petrology of the bank sediments is different from the other regions of the shelf and may represent reworked Tertiary or older material. (A.E. Cok, Personal Communication, 1965)

Detailed studies of Sable Island and the southern portion of the Scotian Shelf are now in progress.

Nova Scotian Continental Slope

The continental slope is the least studied portion of this region. In a general study of sedimentary parameters Sutton (1964) states that mean size, sorting, kurtosis, quartz roundness, and heavy mineral percentage decrease seaward in sands obtained from the Nova Scotian continental margin. Ericson et al. (1961) report on five cores taken in the vicinity. These are muddy sediments with thin bands of sand and silt. On the basis of a microfaunal study the Recent : Pleistocene boundary was found to occur at a depth of approximately 50 centimeters in the cores. Calculated sedimentation rates ranged from 2.7 cm./1000 yrs. in Post-Pleistocene material to 9.0 for the Pleistocene deposits.

The Gully region, which forms the northeast boundary of the present study area, has been extensively sampled and a preliminary report has been completed by J.I. Marlowe, of the Bedford Institute of Oceanography (Marlowe, 1964). The sediments are primarily muds with varying amounts of gravel, sand, silt, and clay. Thin layers of clean sand, and occasionally gravel, are also noted, several of which are graded. The muddy sediments are various shades of grey and reddish brown. The grey generally overlies the brown but exceptions to this are noted. The contacts between the two sediments can be sharp or gradational. Interbedded grey and brown sediments are reported in some cores. Red sandstone and shale grains in association with basalt grains were noted in the reddish brown mud, and the association was compared with sediments of the Triassic fault basins in the Bay of Fundy and along the margin of the Atlantic Coastal Plain to the South. The angular and fissile nature of the red shale fragments indicates that the sediment was not transported very far. Seismic evidence suggests a Triassic trough, which may have represented the source, to landward of the region (Officer and Ewing, 1954). No textural changes were noted between the brown and grey sediments and it was considered that both types of sediment were deposited by the same process.

Compact sediment, which may be as old as Miocene, was recovered in dredge hauls and core bits from the west wall and bottom of the Gully. These were compared with similar sediments described by Stetson (1949) from the canyons of Georges Bank.

Present Study Area

BATHYMETRY

The continental slope in the study area is dominated by a system of valleys and intervening ridges and knolls. Although some of the valley heads extend several miles into the shelf margin, none are large enough to be called submarine canyons, a term which would describe the Gully which forms the northeast boundary of the study area. The valleys may be broad and fan out down slope as secondary valleys merge, or they may remain relatively narrow throughout as in area A, (See Figure 2). Few of the valleys have straight courses and most show a slight sinuousity. Cross sections of some of the regions on the slope (Figure 4) show that they are slightly rounded rather than V-shaped. These cross-sections were constructed from the bathymetric chart (Figure 2) and reflect an interpretation between sounding positions. Few complete profiles were obtained with the depth sounding equipment so that resolution of valley profiles remains a subjective matter. The author does not wish to encourage an analogy of V-shaped river valleys, which is commonly based upon depth soundings with very high vertical exaggerations.

The shapes and positions of the ridges are determined by the proximity of the bounding valleys. The gradients of the tops of the ridges are approximately 1:20, the same as that of the undissected region in the southwest portion of the area. The

FIGURE 2

BATHYMETRIC CHART OF THE CONTINENTAL SLOPE

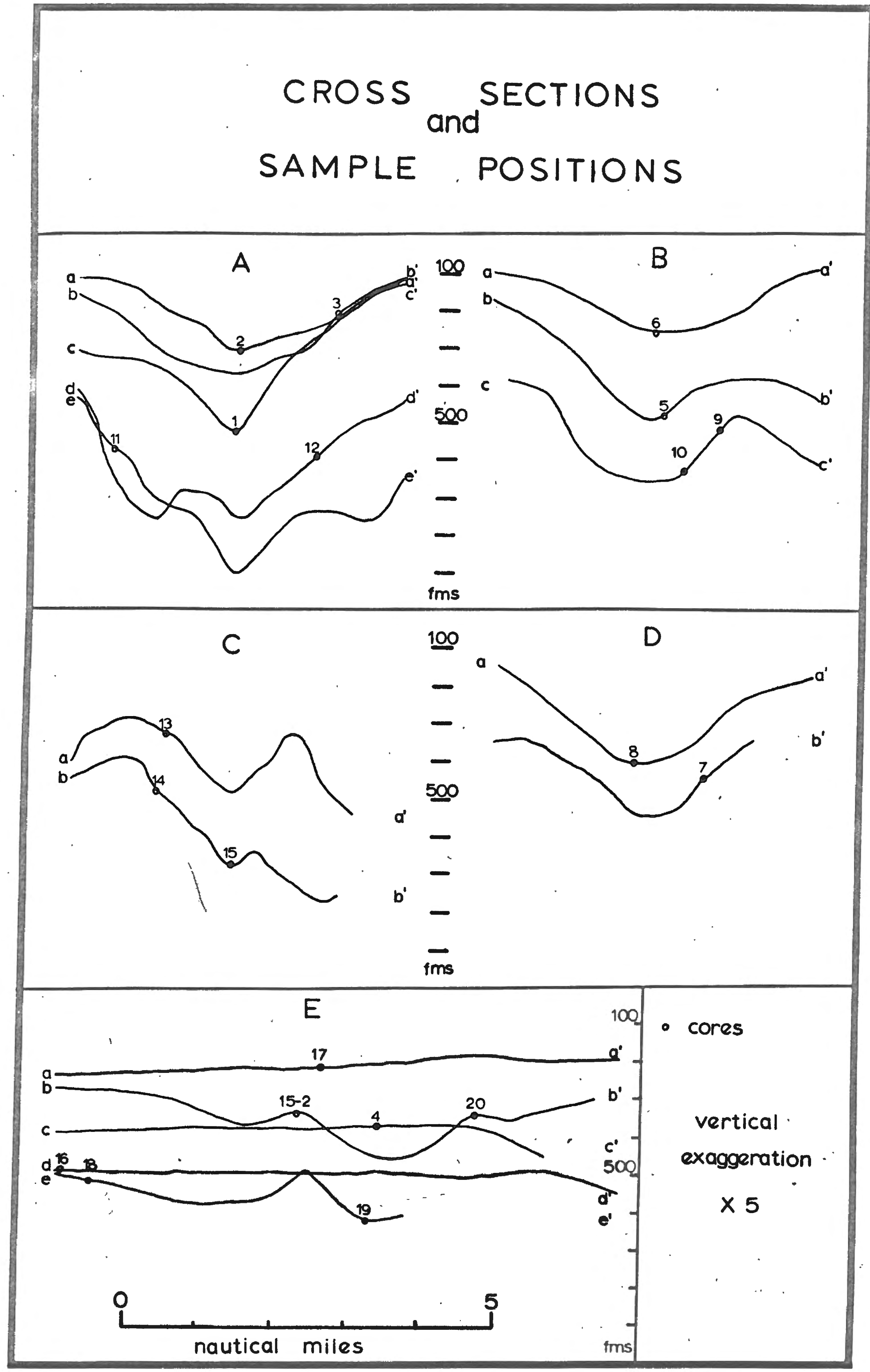


Figure 4. Cross sections and sample positions.

gradients of the valley axes are commonly about 1:12.

The flat, almost featureless region in the southwest is in sharp contrast to the remainder of the study area. The change from rugged to smooth topography occurs within less than 10 miles along a zone bounding Longitude 61°30'. This position corresponds closely to the edge of Sable Island Bank on the continental shelf. This correspondance of bank areas on the shelf with zones of active erosion on the slope indicates an interaction of these environments. The banks might possibly act as a sediment barrier and so prevent the filling of valleys forming on the slope or, conversely, they may act as ready sources of sediment to the slope and so induce overloading and slumping. This last concept of submarine valley formation, with individual modifications, has been suggested by several authors. Seismic profiling techniques, used on the continental slope off Georges Bank, have revealed large, relatively undisturbed, slump blocks (Emery, Personal Communication, 1964) and similar occurrences are probable off Sable Island Bank.

GENERAL CHARACTER OF THE SLOPE SEDIMENTS

Inspection of the core logs (See Appendix) indicated that the three sediment types occur in this area. They are very similar to the sediments reported from the Gully. A greenish grey mud covers much of the slope. This is underlain by, and sometimes interbanded with, a reddish brown sediment. Occasional thin partings of sand occur and sections are thick, between 50 and 200 centimeters, and show few partings. Relatively clean sand occurs in thin bands, between 2-15 centimeters, at the surface of several cores and is considered a third sediment type.

Figure 2 shows the sediment distribution on the slope. The grey sediment is quite extensive while the brown sediment appears to be irregularly scattered across the slope. This scattering is actually a function of the penetration of the coring device and topographic variation in thickness of the grey sediment. Figure 5 shows the relationship of the sediments with topography. It is noted that the brown sediment was penetrated only near the tops of the ridges and in the flat section of the slope. This indicates that deposition is more intense in the valleys and/or that erosion is occurring on topographic highs. It is possible that core Sc-16 represents a base upon which to compare the thickness of the grey sediment as it was taken on the undissected slope. Core Sc-4, however, is in the same region and no grey sediment is represented. This last sample lies close to the transition region and may represent different conditions.

The surface sand layers are also most common on topographic highs. This also suggests erosion, through winnowing, of the intervening ridges.

The occurrence of thinly laminated core sections, sand partings, and interbanded grey and brown sediment indicates that sedimentation has varied considerably within the study area. This reconnaissance study can only serve as a general indicator of this complex environment.

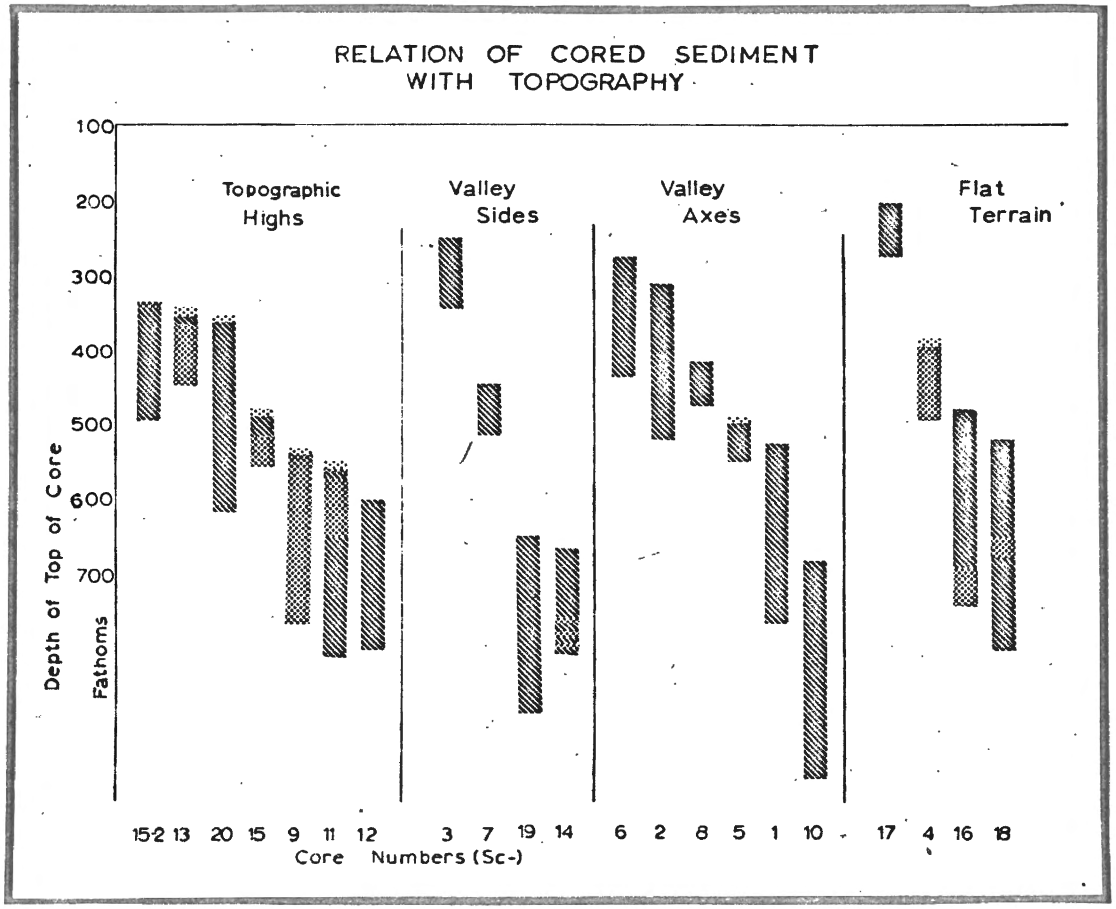


Figure 5. Relation of cored sediment with topography

RADIOGRAPHY AND INTERNAL STRUCTURES

General Statement

During the preliminary logging of the sediment cores, few internal structures were apparent. The sediments appeared massive except for a few cores were laminations ~~were~~ noted, and occasional colour mottles and thin partings. Colour differences were the main criteria used in determining sediment types. All the structures visible in the sliced cores are included in the Appendix.

Radiography has revealed many internal features not apparent to the naked eye and has permitted an interpretation of the depositional environments of the sediments.

The portion of the radiographic study involving thin sediment slices was somewhat disappointing. It was found that while sharp features, such as distinct mottles, are well defined in the radiographs of the 5 mm slices, the occurrence of fine layering and indistinct mottles was often undetectable. The reason for this is that many of the structural units possess only subtle density contrasts and cannot be delineated through thin slices. The half-cores present a one inch path length to the x-ray beam and fine density variations are more readily distinguished. Thus, the radiographs of the half-cores, though originally intended to provide cursory information only, have proved to be the most useful for this study. The prints of the thin-slice radiographs are included in Plates 5 to 12 to indicate the nature of the structures found in the slope sediments. Plates 1-a and 13, are of sections of half-cores and indicate the detail possible with the thicker slices. A diagrammatic description of the internal structures of all the half-cores is presented in Figure 6. The zoning, indicated by the gradational contacts, is based on changes in associations of internal features.

Types of Structures Observed

A classification of internal sedimentary structures, as revealed through radiography, has not yet been developed. In a recent paper, Hamblin (1965) suggests a grouping of structures which he found convenient for the discussion of consolidated sediments. Unconsolidated sediments do not show the clear-cut features observed by Hamblin, and less precise groupings are desirable. Calvert and Veevers (1962) and Bouma (1964) have used general descriptions and have not offered any preferred classification.

Plate 5

REGULAR LAYERING

a) Sc-18, 50-68 cm. Fine and coarse distinct layering, top is homogeneous with a few large indistinct mottles. This is a radiograph of a half-core section.

b) Sc-15, 23-33 cm. Fine distinct regular layering with scattered fine distinct mottles.

c) Sc-4, 55-63 cm. Indistinct regular layering, distinct irregular layering, and scattered fine distinct mottles.

d) Sc-4, 20-28 cm. Fine distinct regular layers and indistinct regular and irregular layers, and fine distinct mottles.

REGULAR LAYERING

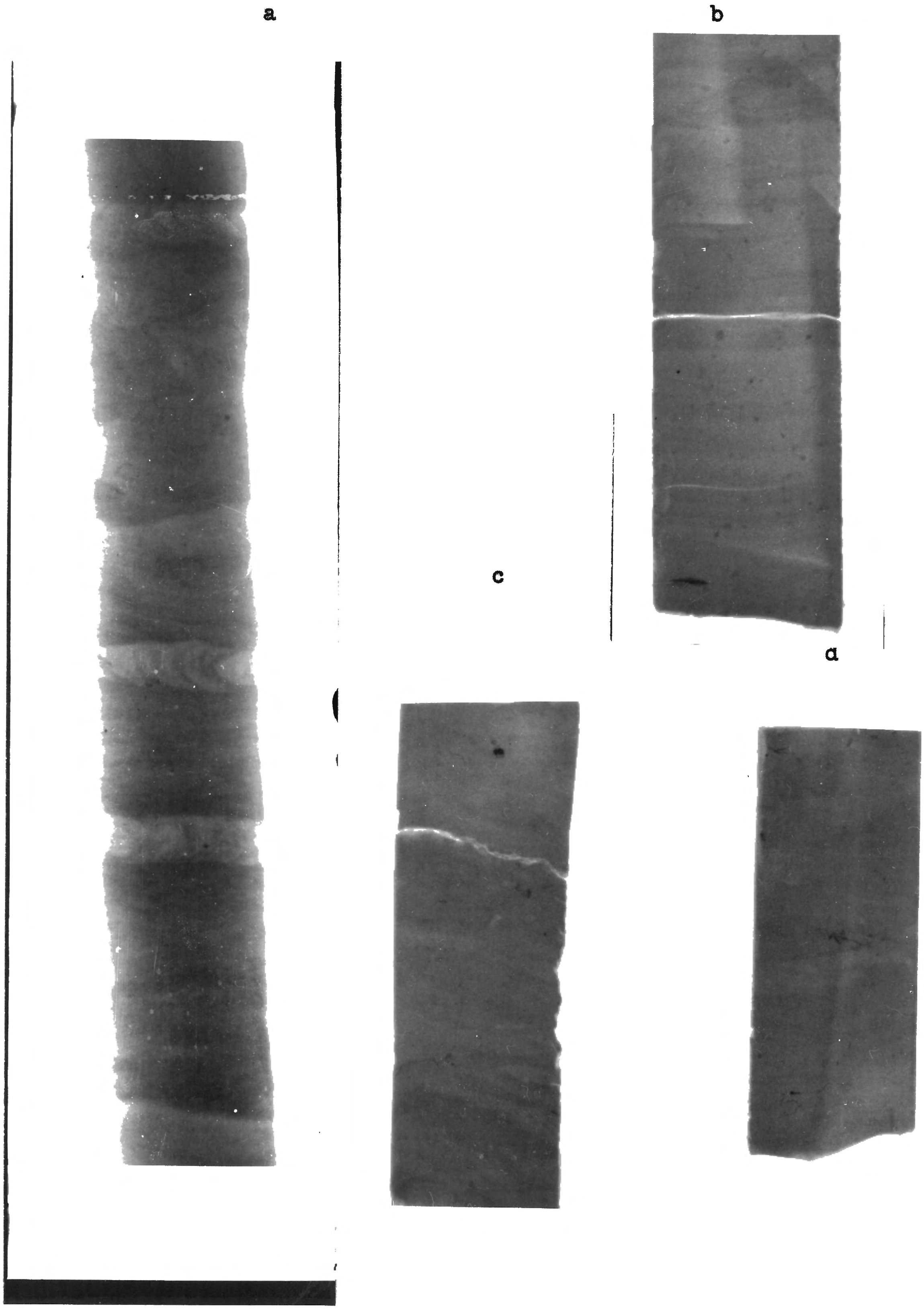


Plate 5

Plate 6

REGULAR LAYERING

a) Sc-6, 61-69 cm. Fine distinct layering with some cross-laminae, coarse distinct mottles and fine mottles.

b) Sc-8, 35-45 cm. Fine distinct layering with some cross-laminae and coarse indistinct mottles.

c) Sc-10, 34-42 cm. Several distinct layers near top. The rest is homogeneous with perhaps some very indistinct irregular layers.

d) Sc-12, 30-37 cm. Homogeneous except for thin distinct layer, some fine indistinct mottles.

REGULAR LAYERING

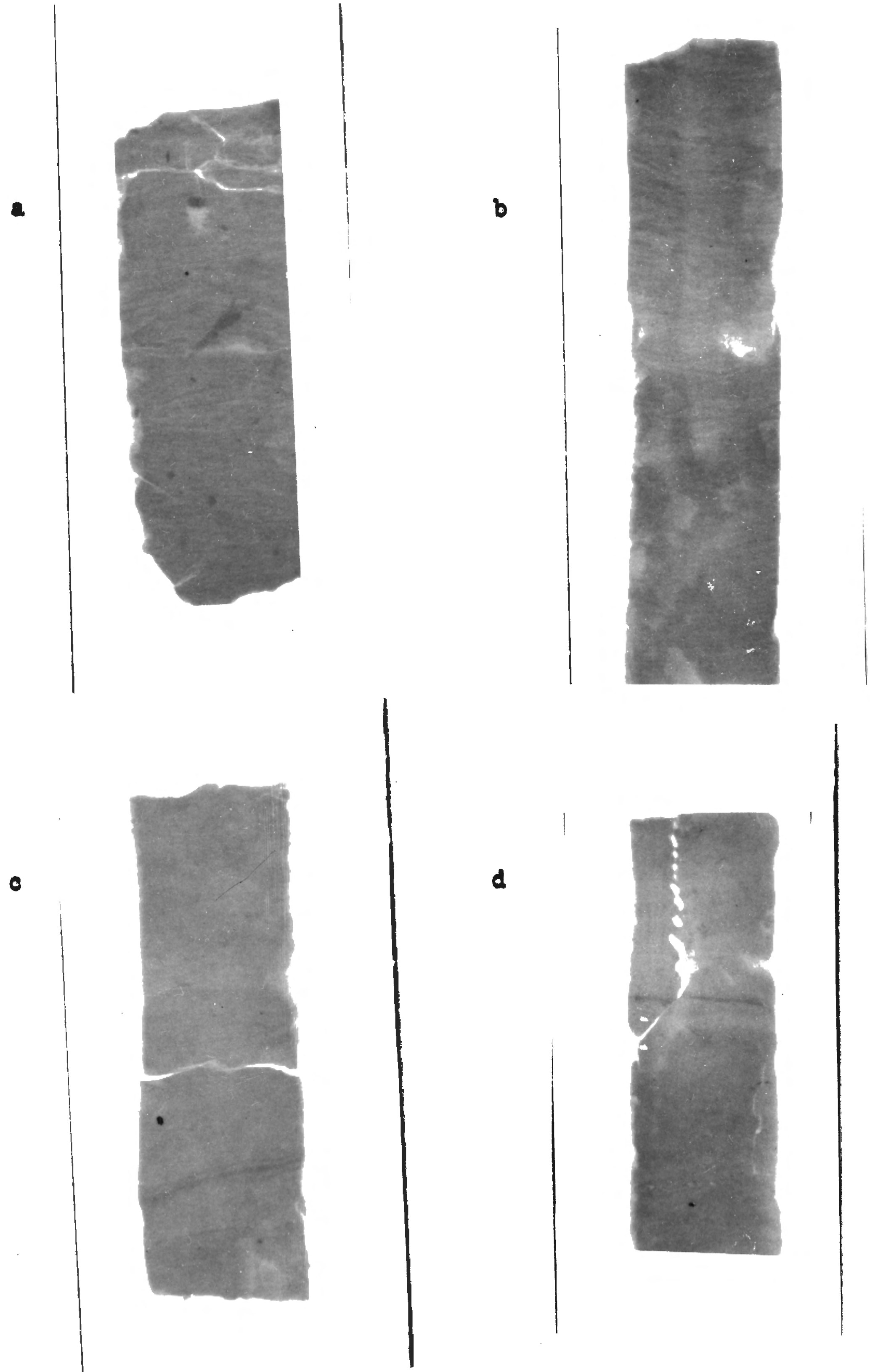


Plate 6

Plate 7

INDISTINCT LAYERING

a) Sc-19, 68-74 cm. Fine regular layers with suggestion of vague fine regular layers.

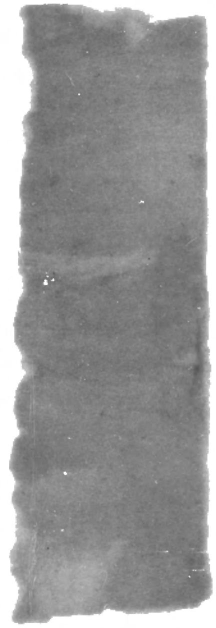
b) Sc-10, 55-63 cm. Large distinct irregular band and suggestion of fine regular layering.

c) Sc-9, 31-39 cm. Several indistinct coarse layers and suggestion of fine irregular layers.

INDISTINCT LAYERING

a

b



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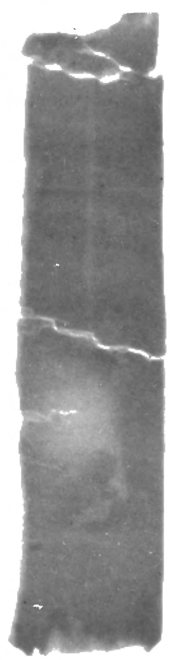


Plate 7

Plate 8

IRREGULAR LAYERING

a) Sc-5, 15-22 cm. Several coarse distinct irregular layers, and alignment of fine mottles.

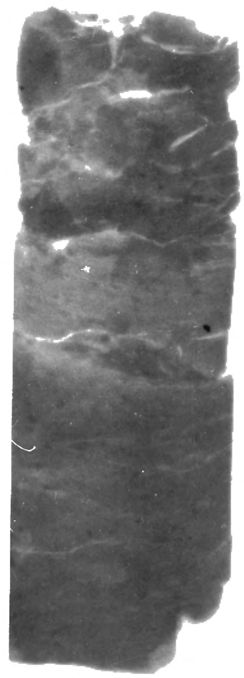
b) Sc-9, 71-80 cm. Alignment of mottles near center. Coarse distinct and indistinct mottles.

c) Sc-2, 152-155 cm. Alignment of coarse indistinct mottles.

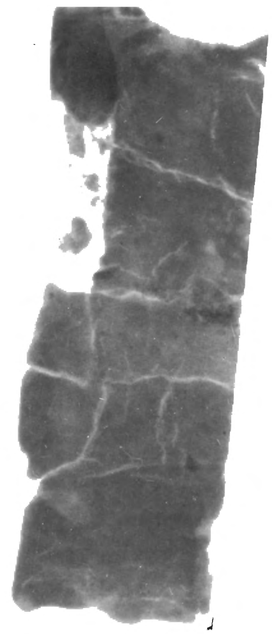
d) Sc-17, 17-27 cm. Indistinct fine regular layering and alignment of fine distinct mottles.

IRREGULAR LAYERING

a



b



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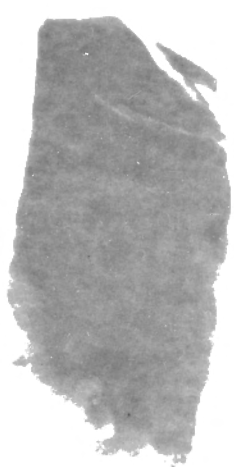

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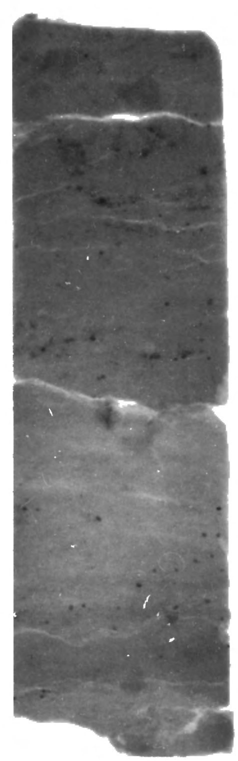


Plate 8

The author has adopted a modified form of the classification proposed by Moore and Scruton (1957). These authors did not employ radiographic techniques and based their terminology primarily on textural variations. Because radiographs reveal density variations, rather than textural variations, these have been employed in distinguishing internal structures.

The term regular layering is used to describe alternating light and dark (dense and less dense) bands on the negatives, which are continuous across the core section. Irregular layering refers to discontinuous, often lens-shaped, bands. Indistinct layering refers to bands which are only faintly distinguishable or which show gradational contacts.

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

An interesting structure revealed by this study is flow-in. This describes an undulating or contorted, vertically oriented pattern found near the bottoms of some cores. It defines the zone of sediment which is drawn into the core liner as the coring device is raised from the bottom in instances where the core barrel did not completely enter the sediment. This zone generally cannot be detected until the cored sediment has almost completely dried out. As this occurs after selected sampling

Plate 9

SAND AND PEBBLES

a) Sc-2, 80-85 cm. Scattered medium grained distinct mottles, and occasional indistinct mottles.

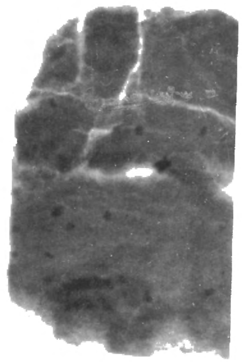
b) Sc-16, 210-219 cm. Scattered fine and coarse distinct mottles.

c) Sc-9, 121-125 cm. Thick layer of sand and pebbles, possibly graded, and undulating fine distinct layer against homogeneous background.

d) Sc-13, 60-64 cm. Thin layer of sand and pebbles and scattered distinct rounded pebbles.

SAND AND PEBBLES

a



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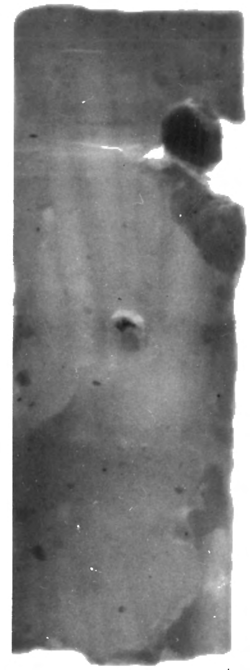

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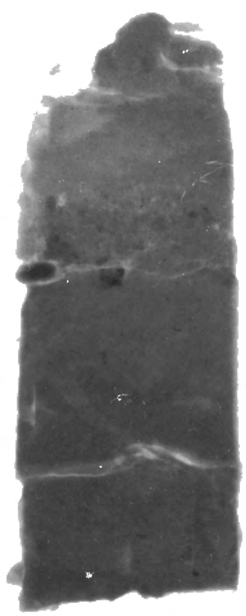

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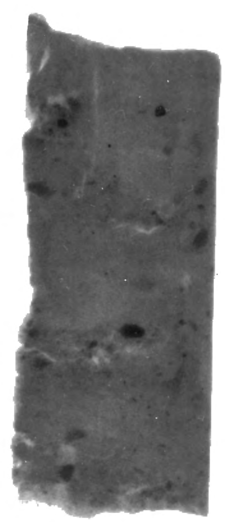


Plate 9

Plate 10

MOTTLING

a) Sc-9, 169-177 cm. Fine distinct and indistinct mottling against homogeneous background.

b) Sc-20, 11-17 cm. A few oblong indistinct mottles.

c) Sc-15, 5-10 cm. Indistinct fine and coarse mottles. Horizontal lines are due to slicing.

d) Sc-18, 63-73 cm. Coarse indistinct mottles with several distinct mottles. Washout is due to variable dampness. Compare with half-core radiograph of same section in Plate 5-a.

MOTTLING

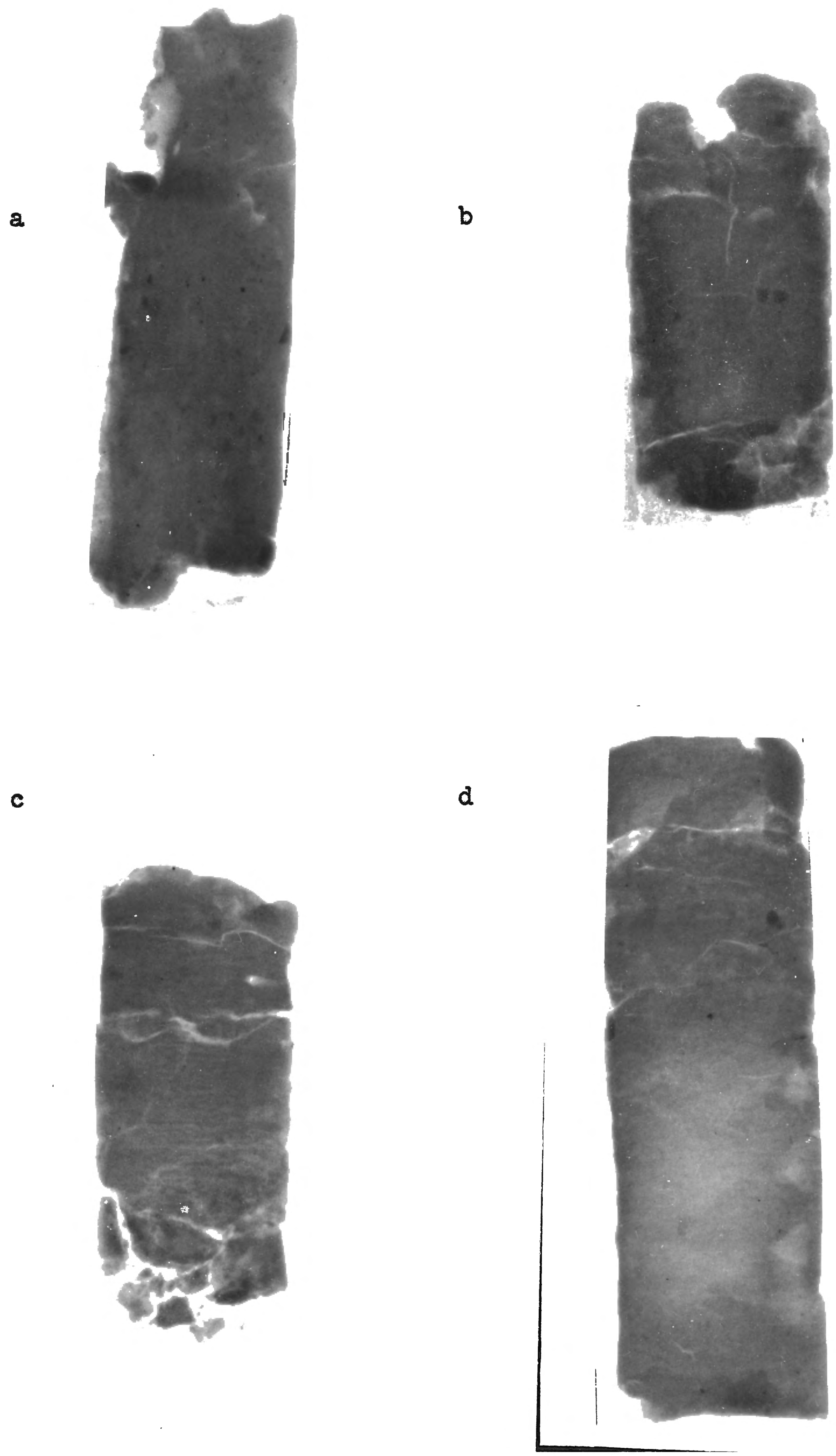


Plate 10

Plate 11

HOMOGENEOUS SEDIMENT

a) Sc-16, 200-207 cm.

b) Sc-10, 181-190 cm. A few fine mottles

c) Sc-2, 85-94 cm. Some irregular fine mottles

d) Sc-2, 132-138 cm.

HOMOGENEOUS SEDIMENT

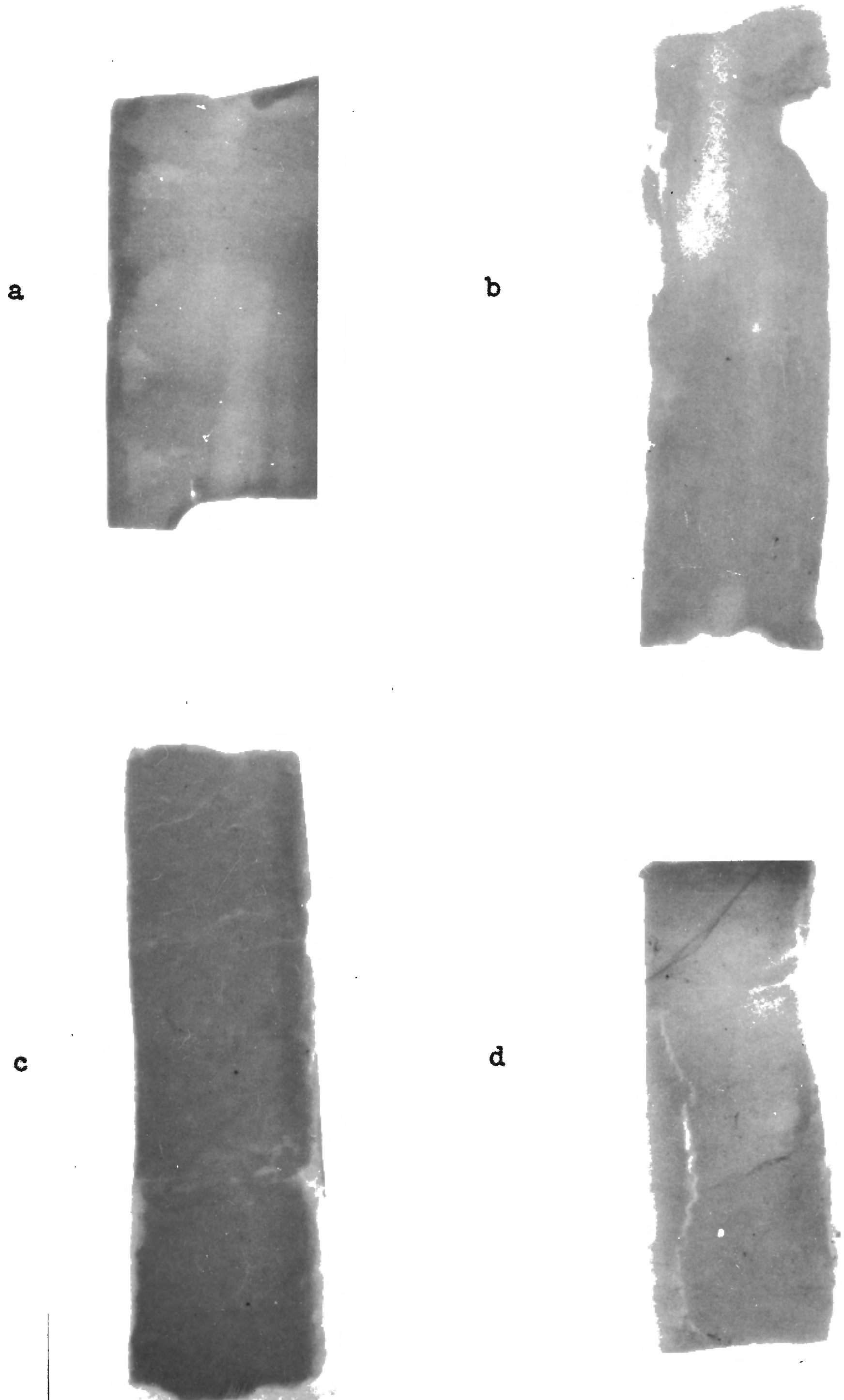


Plate 11

Plate 12

MISCELLANEOUS

a) Sc-15-2, 13-21 cm. Washout pattern due to damp section of core, white layer is typical of cracks in slice.

b) Sc-10, 191-200 cm. Flow-in structure.

c) Sc-6, 144-147 cm. Fine layered structure due to the formation of low ridges when slicing. Fine and coarse distinct mottles and washout structure.

d) Sc-8, 8-16 cm. Another example of ridge structure, in homogeneous sediment.

MISCELLANEOUS

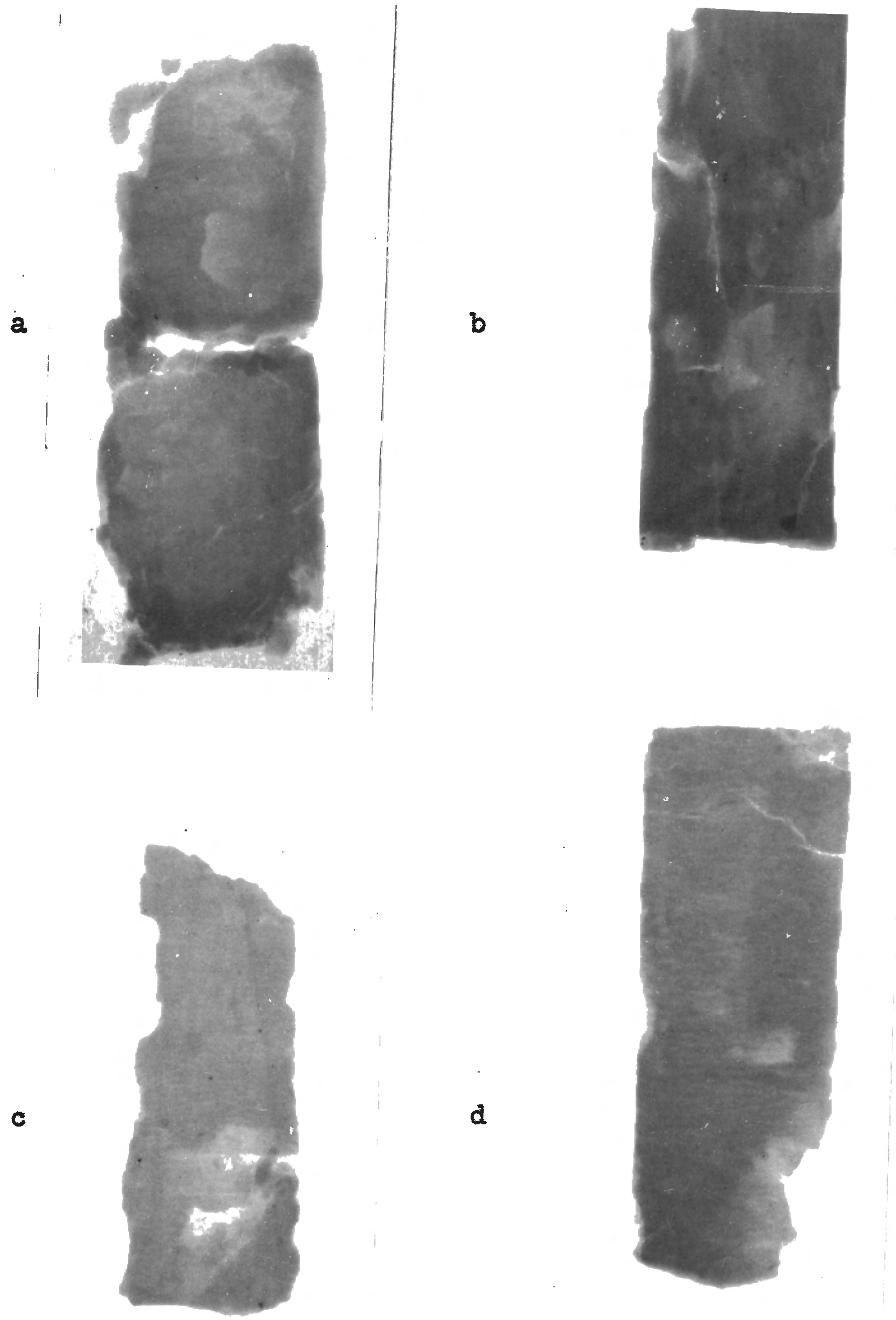


Plate 12

and analysis have already been performed, it is apparent that the use of radiography to detect this artificial structure, can prevent serious misinterpretation of cored sediment.

Other miscellaneous artificial structures are shown in Plate 12.

Internal Structures of the Slope Sediments

It is apparent from Figure 6 that no single internal structure is characteristic of a given sediment. For this reason, primary structure suites were used in distinguishing the sediment types.

The surface sand layer was most easily characterized. These contain bands of closely spaced fine mottles with scattered distinct coarse mottles. This pattern, although slightly less closely spaced, is found in some cores where the surface sand was not noted in the preliminary logs. The sandy nature of these zones, however, was discovered during textural analysis. The strong correlation of distinct mottling of this type with sand and pebble grains has led to identification of this sediment type in other parts of the cores where these structures occur.

The grey sediment is characterized by a general scarcity of internal structures. Some cores do show sections of regular and irregular layering (e.g. Sc-5, Sc-8, and Sc-15) but for the most part, the grey sediment consists of long sections of homogeneous sediment with widely scattered, indistinct, large and

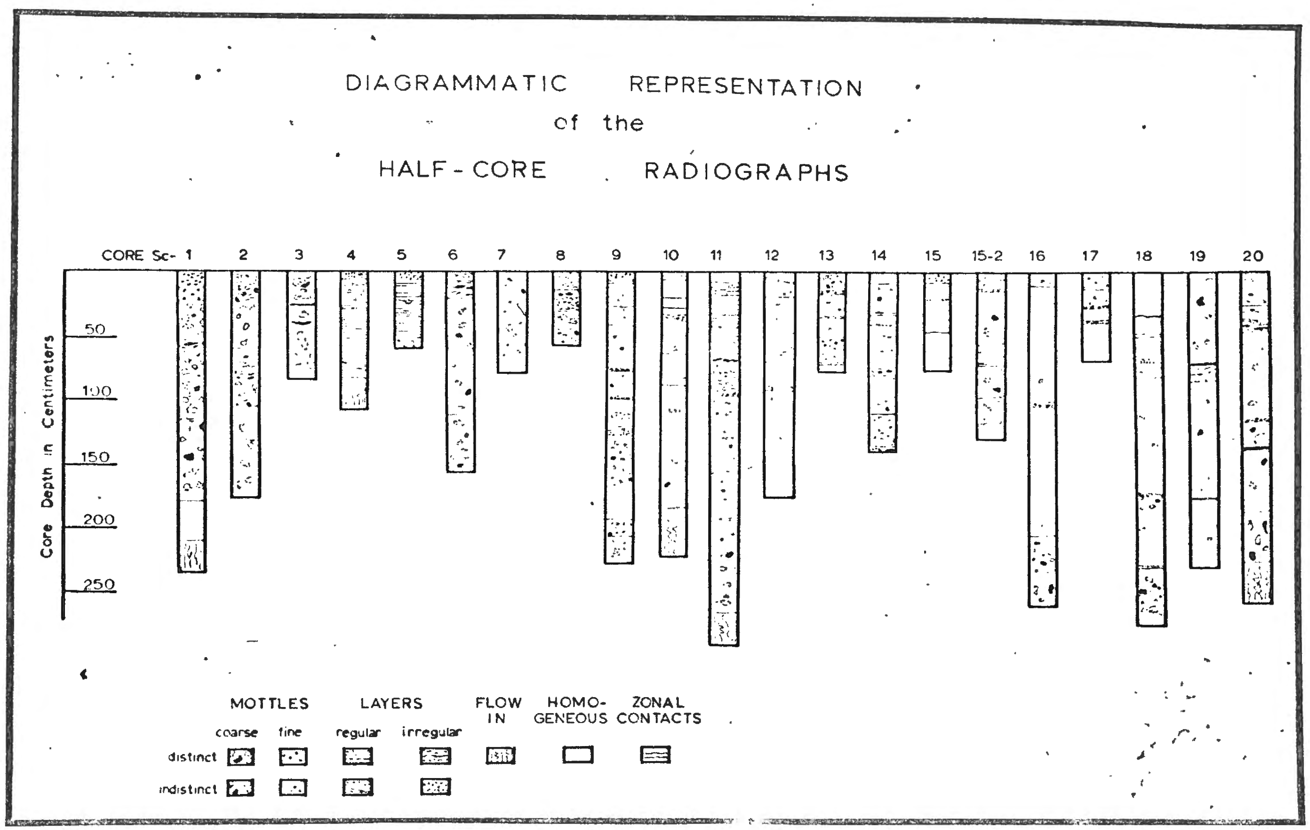


Figure 6. Diagrammatic representation of the half-core radiographs.

small, mottles and rare irregular layers (e.g. Sc-1, 2, 3, 7, and 10).

The major distinctions of the brown sediment are the widespread occurrence of distinct mottles, and the rapid changes in internal structure suites which break up the sediment column into numerous, thin zones. Regular layering is most extensive in core Sc-4 and distinct mottling at the base of core Sc-16. Core Sc-9 represents the longest section of brown sediment obtained and shows the rapid character changes.

Discussion

A study of the interaction between bottom dwelling organisms and rate of sedimentation has been made by Moore and Scruton (1957). They showed that in muddy sediments, the benthic fauna can seriously disrupt regular sedimentary laminae by shifting and reworking the sediment. Depending upon the rate of sedimentation and intensity of faunal activity, a complete gradation through regular and irregular layering, distinct and indistinct mottling, to homogeneous sediment, can be developed. A reverse process, the layering of originally structureless sediment by faunal activity can also occur. The preservation of internal structures is generally found only in areas where sedimentation is rapid or where mud-feeding organisms are rare.

Interpretation of the slope sediments in the light of these processes indicates that the grey sediment was deposited rather

Plate 13

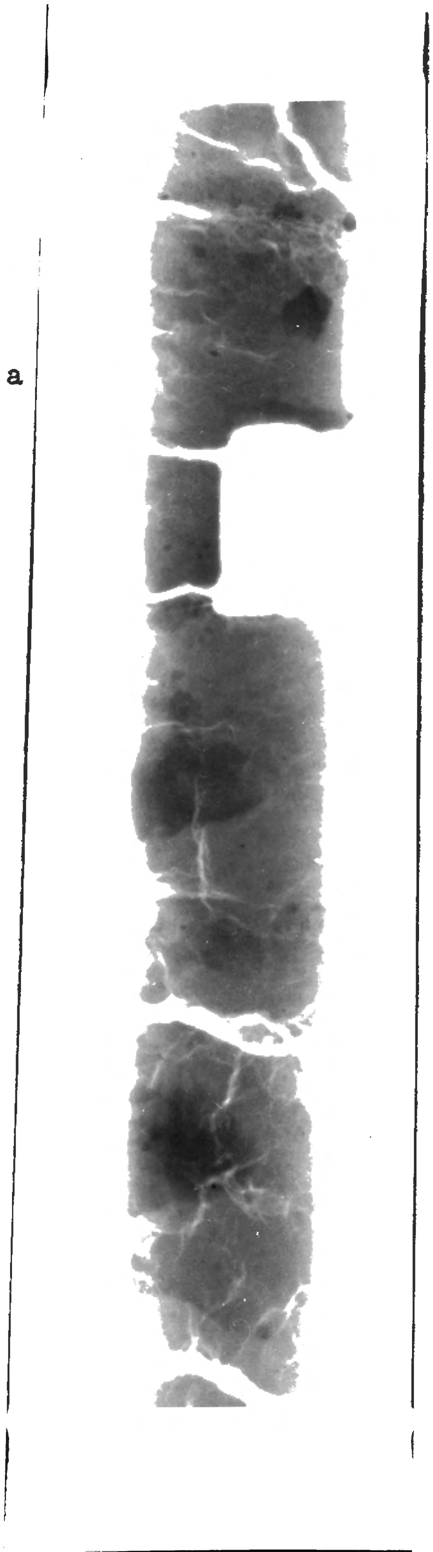
BROWN VERSUS GREY

a) Sc-18, 172-189 cm. Note layer of coarse distinct mottles at top, marking the beginning of the brown layer. Very large indistinct mottles with scattered fine distinct mottles. Short sections above and below are homogeneous and correspond to the grey sediment.

b) Sc-16, 200-220 cm. Top section is homogeneous with scattered very fine mottles. Contact with underlying brown occurs between the two sampling gaps. Note the coarse distinct mottles and numerous medium grained distinct mottles in the brown sediment.

BROWN VERSUS GREY

a



b

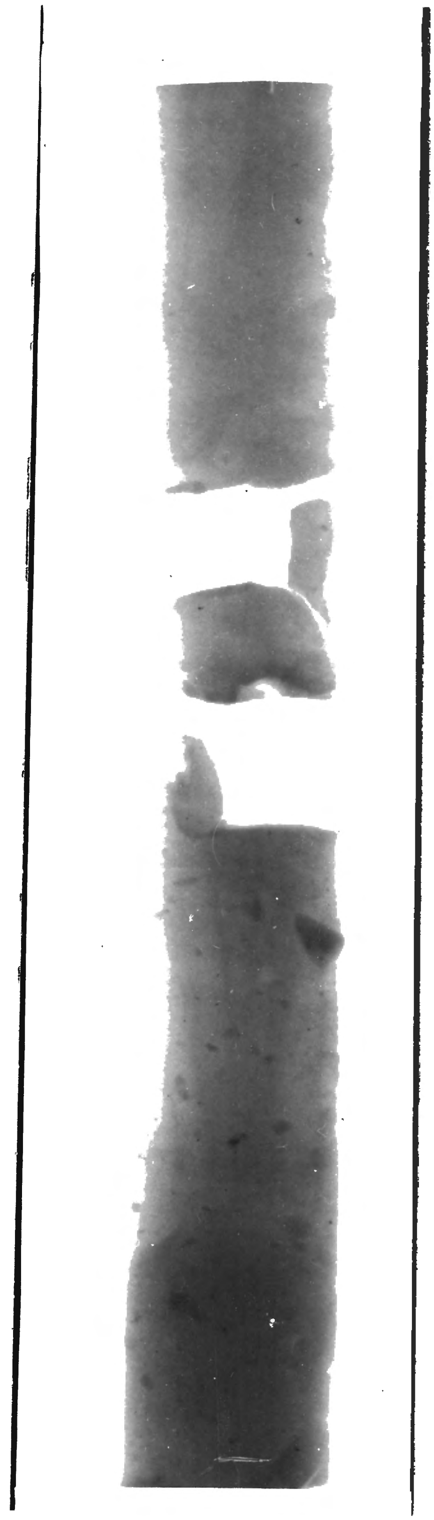


Plate 13

slowly. The occurrence of indistinct large mottles indicates that the process of homogenization did not go to completion. Because of the fine nature of the regular layering found in some sections, it is felt that the absence of mud feeders, rather than an increased rate of sedimentation, is responsible for their preservation.

The disruption of layering is also apparent in the brown sediment, but the preservation of many different zones indicates that the benthic fauna could not cope with the higher rate of sedimentation. The variable character of the preserved zones, which include sandy layers, irregular and regular layering, and indistinct mottling, indicates that the rate of deposition of the brown sediment was not constant, but apparently fluctuated randomly. The occurrence of sand and pebbles in the brown sediment, as indicated by the numerous distinct mottles, is another significant difference between the two types of sediment. This has been confirmed during the textural study (following chapter) which also indicated the variable nature of the brown sediment.

TEXTURAL ANALYSES

Size Analysis

The core samples provided very little material and so were not amenable to detailed size analysis. Visual estimates were made of the amount of material in the various sieve sizes used for part of the coarse fraction study and these provide some information. The surface sediment recovered with the Dietz-Lafond snapper did provide sufficient material and detailed analysis was performed on the coarse fraction.

SNAPPER SAMPLES

The size frequency distribution of the surface sediments are shown as histograms in Figure 7. Two groups of sediment are noted. Samples Sc-5 and Sc-13 are from the relatively clean surface sand layer. They are relatively coarse grained and show a small secondary mode in the coarse sand and fine pebble range. Sorting is poor. The other group of sediments show only traces

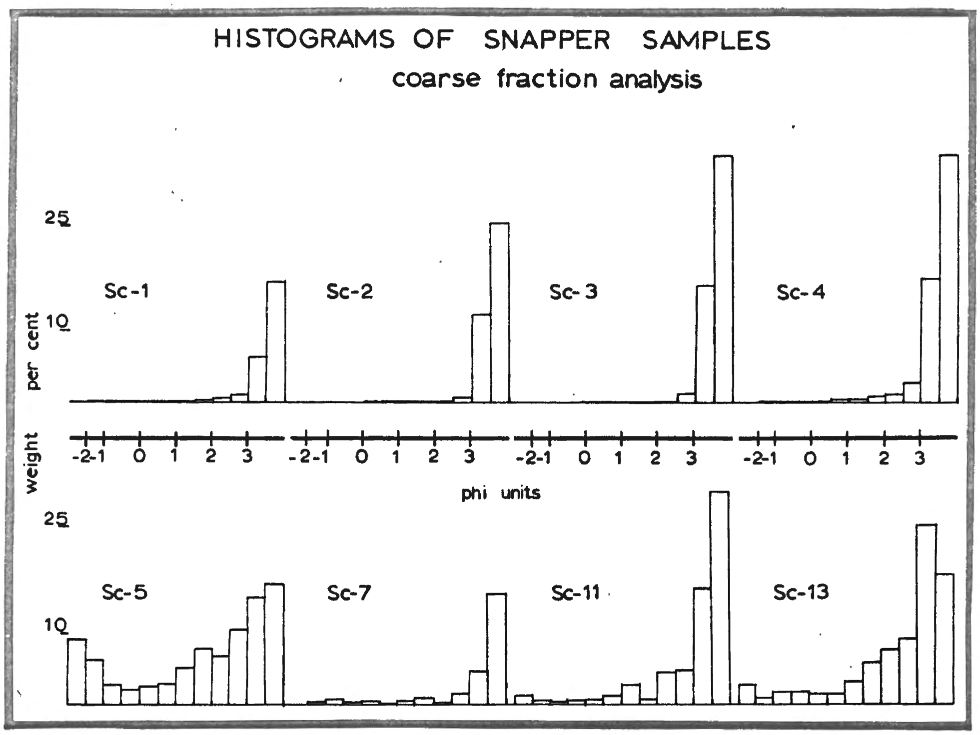


Figure 8. Cumulative curves of snapper samples.

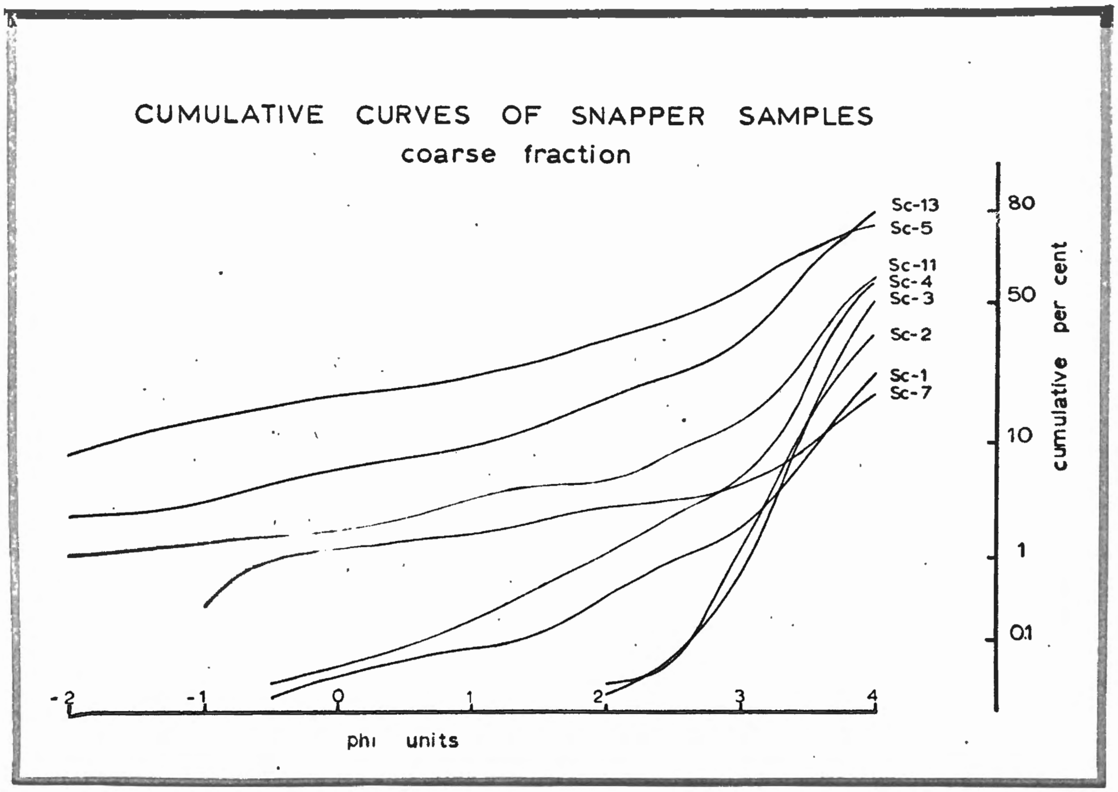


Figure 7. Histograms of snapper samples.

of coarse sand and are predominantly very fine sand. Cumulative frequency curves, plotted on a probability scale (Figure 8), show the spread of the size classes and indicate the poor sorting of the material. Samples Sc-2 and Sc-3 are somewhat better sorted but contain less sand. The modes for these samples lie in the silt range, which was not examined in this study. In general, the coarser grained sediments are more poorly sorted than those which are finer grained.

COARSE FRACTION STUDY SAMPLES

Since visual estimates tend to be subjective, these results are not accurate. They do indicate, however, a difference between the brown and grey sediments. Figures 21 to 25 show that the grey sediment contains mainly very fine sand, between 105 and 63 microns, and that the distribution is consistent from sample to sample.

The brown sediment sand fraction is also fine-grained but shows a measurable amount of coarse sand. Variations between samples is also apparent. The surface sand is only represented by one sample. The size distribution is similar to that found in most of the brown samples.

Although these estimates are not detailed, the binocular study promoted a familiarity with the sediments which is not possible during mechanical analyses. It was noted that the size distribution was continuous. The pebble sized material was mostly in the granule range and no apparent break was noted between these grains and the coarse sands. This indicates that the sediments are not bimodal. Because the silt and clay fractions were not studied, any sudden breaks in these ranges could not be determined. The evidence supplied in the snapper sample analyses however suggests that the distribution would remain continuous.

Sand-Silt-Clay Ratios

The results of this study of 117 samples are shown in the form of a triangular diagram (Figure 9). For convenience, the pebble fraction has been included with the sand component.

This diagram differentiates among the surface sand layer, the brown sediment, and the grey sediment. On the basis of Shepard's classification (Shepard, 1954), the surface sands can be described as sand and silty sand; the brown sediment mainly as sand-silt-clay, sandy silt, and silty sand; and the grey sediment as silt and clayey or sandy silt.

The brown sediment shows a broader textural distribution, considering the number of samples analysed, than does the grey. Some brown sediments appear to be anomalous. Sc-18-175, and Sc-4-100 (circled on the diagram) are markedly less sandy than the remainder. The former is taken from a brown layer within a core of grey sediment and the latter from a core showing fine laminations. These are both unusual brown occurrences and the anomalous textures suggest that they may represent different sediment types than the main brown sediment.

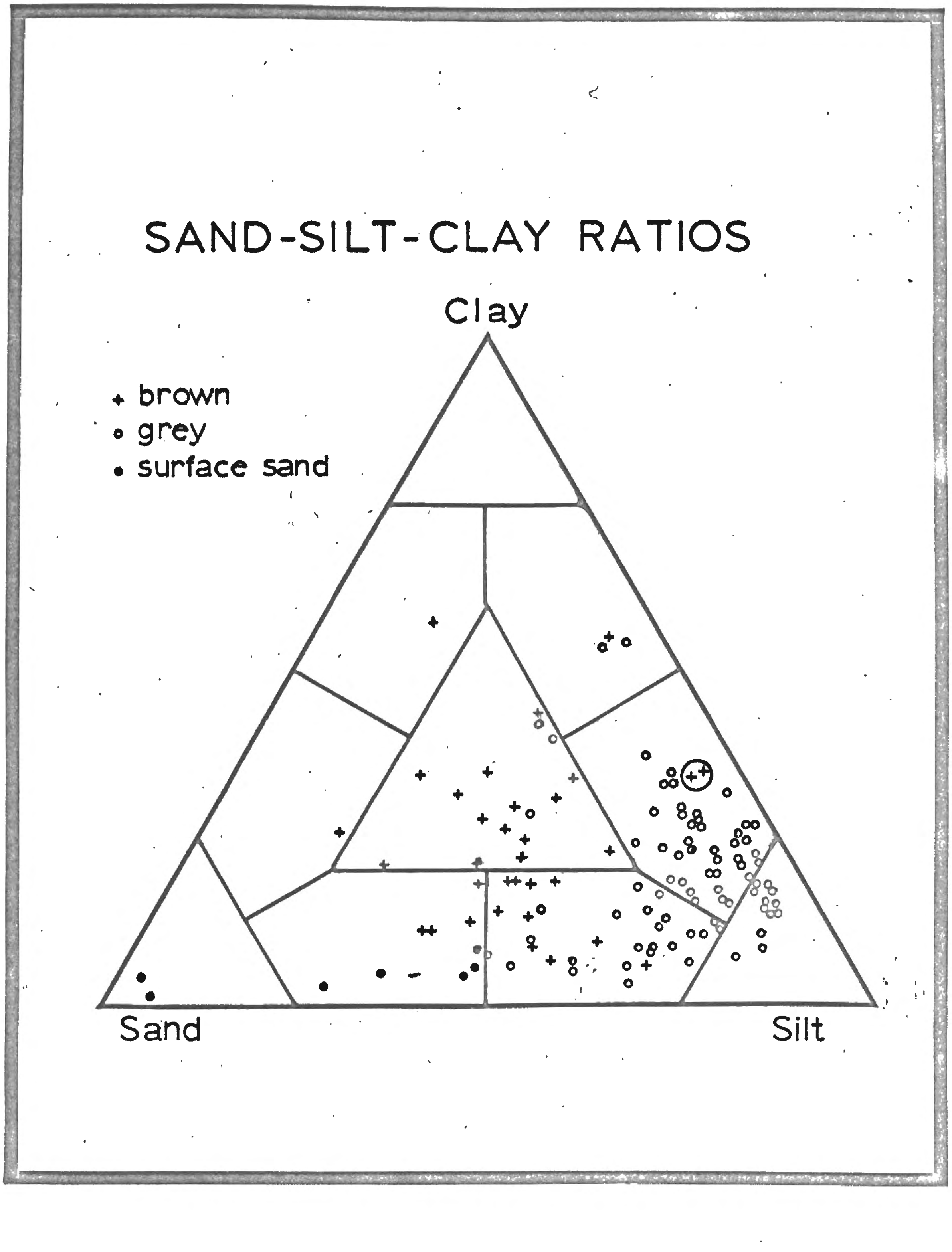


Figure 9. Sand-silt-clay ratios.

The grey samples are strongly grouped about the silt apex but show a continuous scattering toward the sand apex. The surface sand layers are also grey and may be the product of winnowing.

Textural variations with depth are plotted in Figures 10 to 20. There is a tendency for the surface of the sediment to be more sandy than the lower portions. This is well shown in core Sc-10, which has been sampled in detail. In other grey cores this tendency is reversed towards the bottom of the core.

In general the brown sediment is more sandy but the sediment may sometimes not be as sandy as the uppermost grey zones. Core Sc-16 shows the very abrupt change in texture between the grey and brown layers. The variability in texture, particularly of the sand component, is much greater within the brown sediment. A comparison of cores Sc-9 and Sc-10 points out this difference quite well.

These diagrams include the pebble fraction contributions and show that these coarse particles are common in the brown sediment and rare in the grey.

Discussion

Textural analysis has revealed striking differences in the slope sediments. Two major periods of sedimentation, and the beginning of a third, can be inferred from textural relationships.

The first period involved the deposition of the brown sediment. This sediment is poorly sorted, relatively coarse grained,

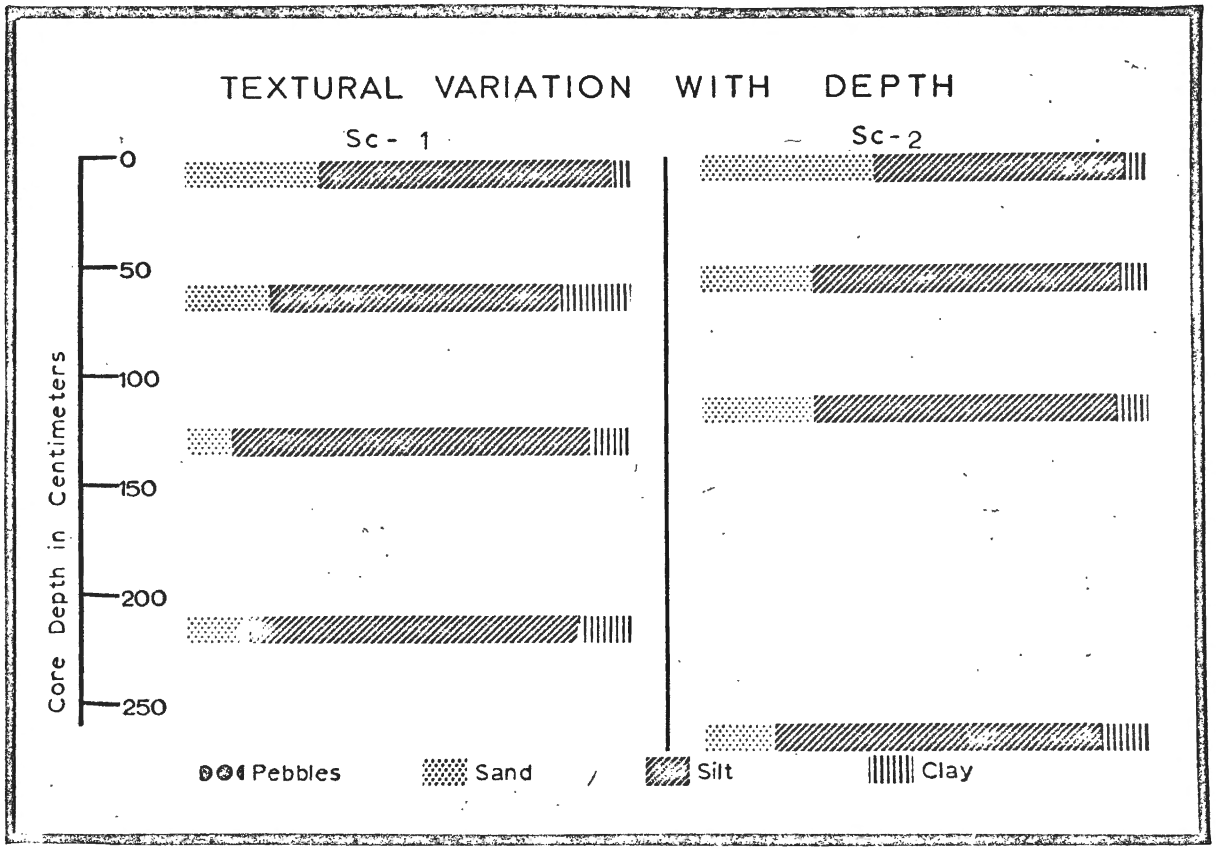


Figure 10. Textural variation with depth.

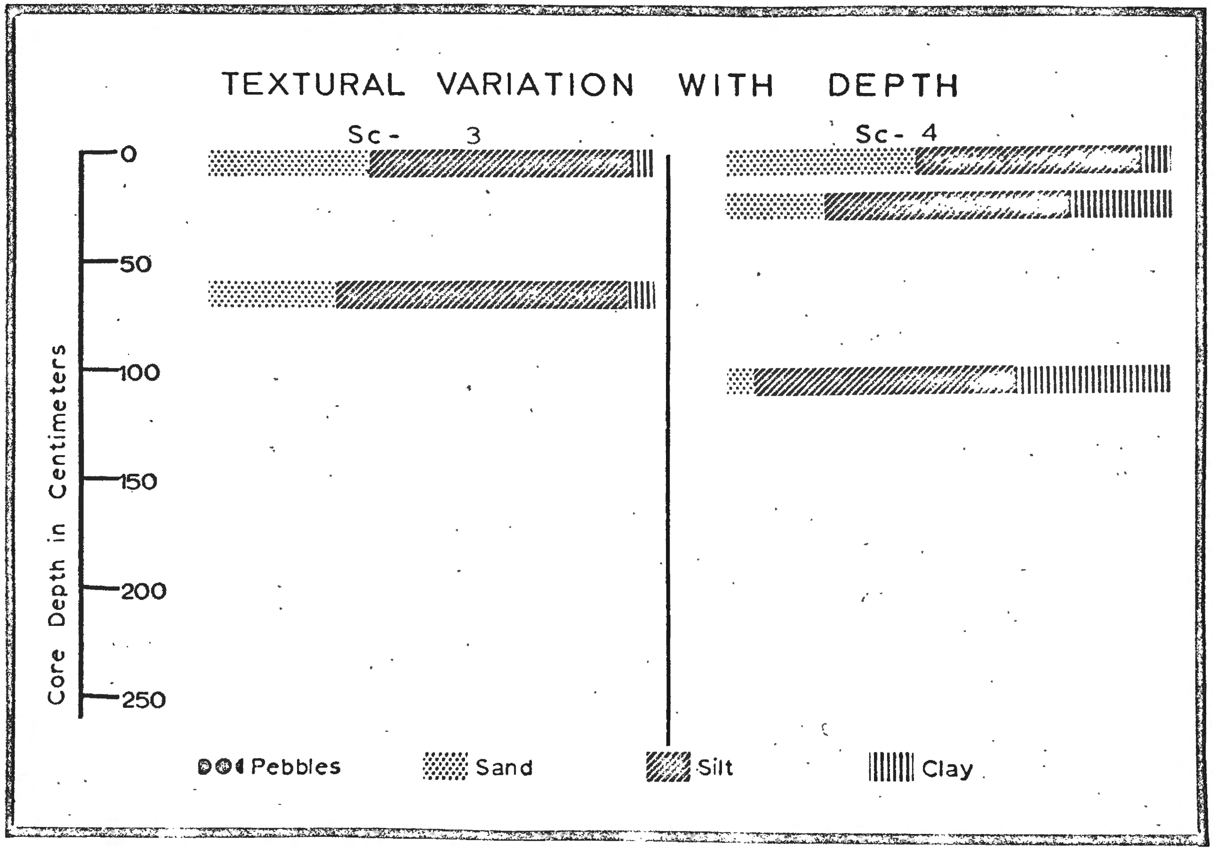


Figure 11. Textural variation with depth.

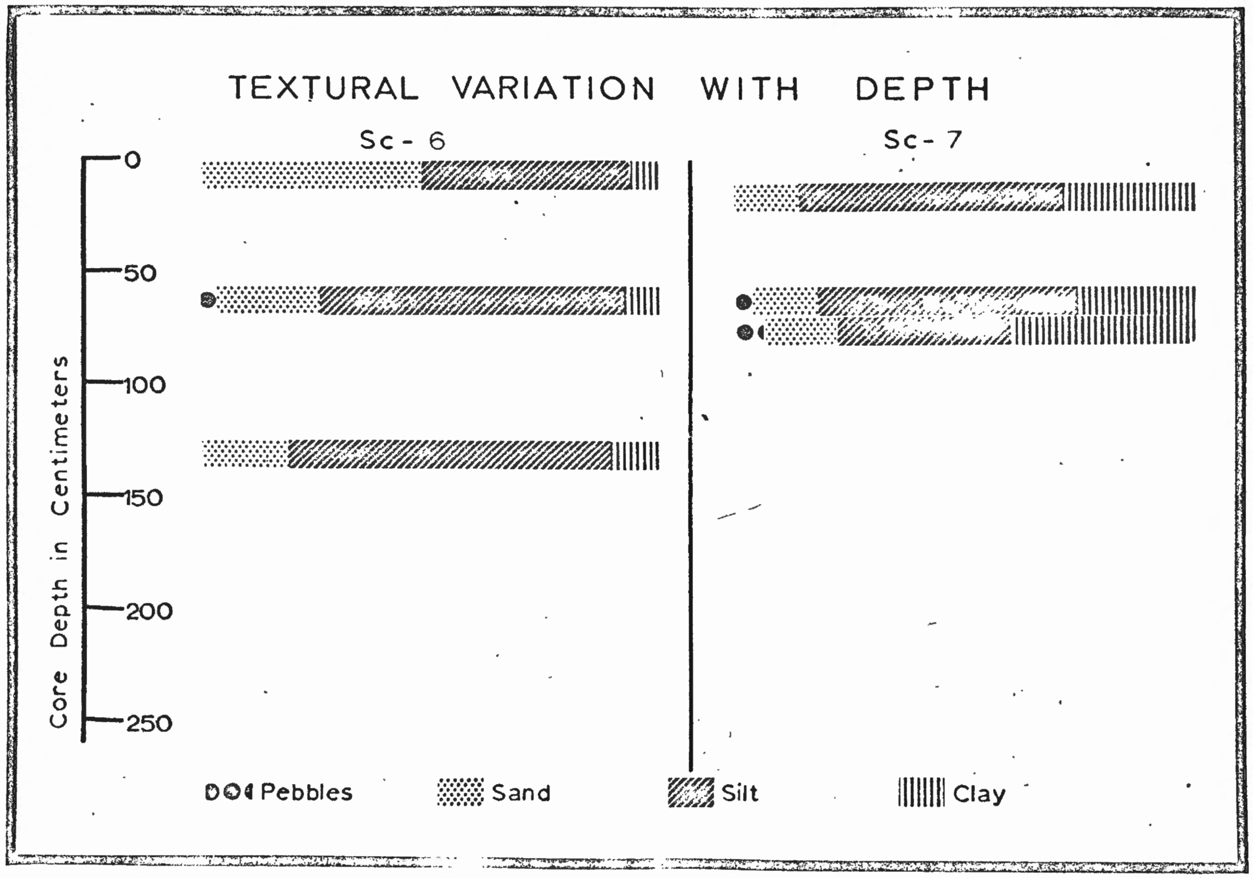


Figure 12. Textural variation with depth.

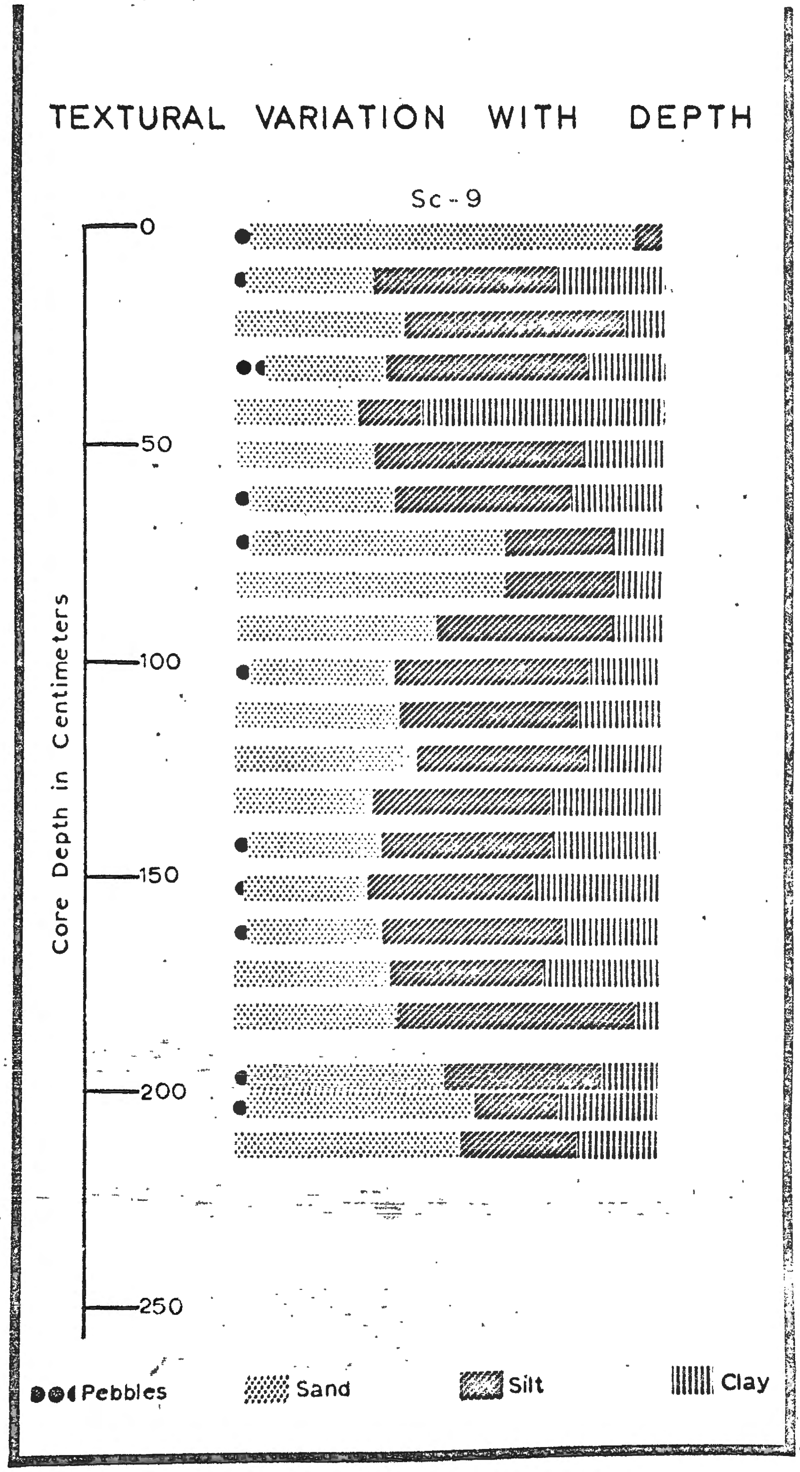


Figure 13. Textural variation with depth.

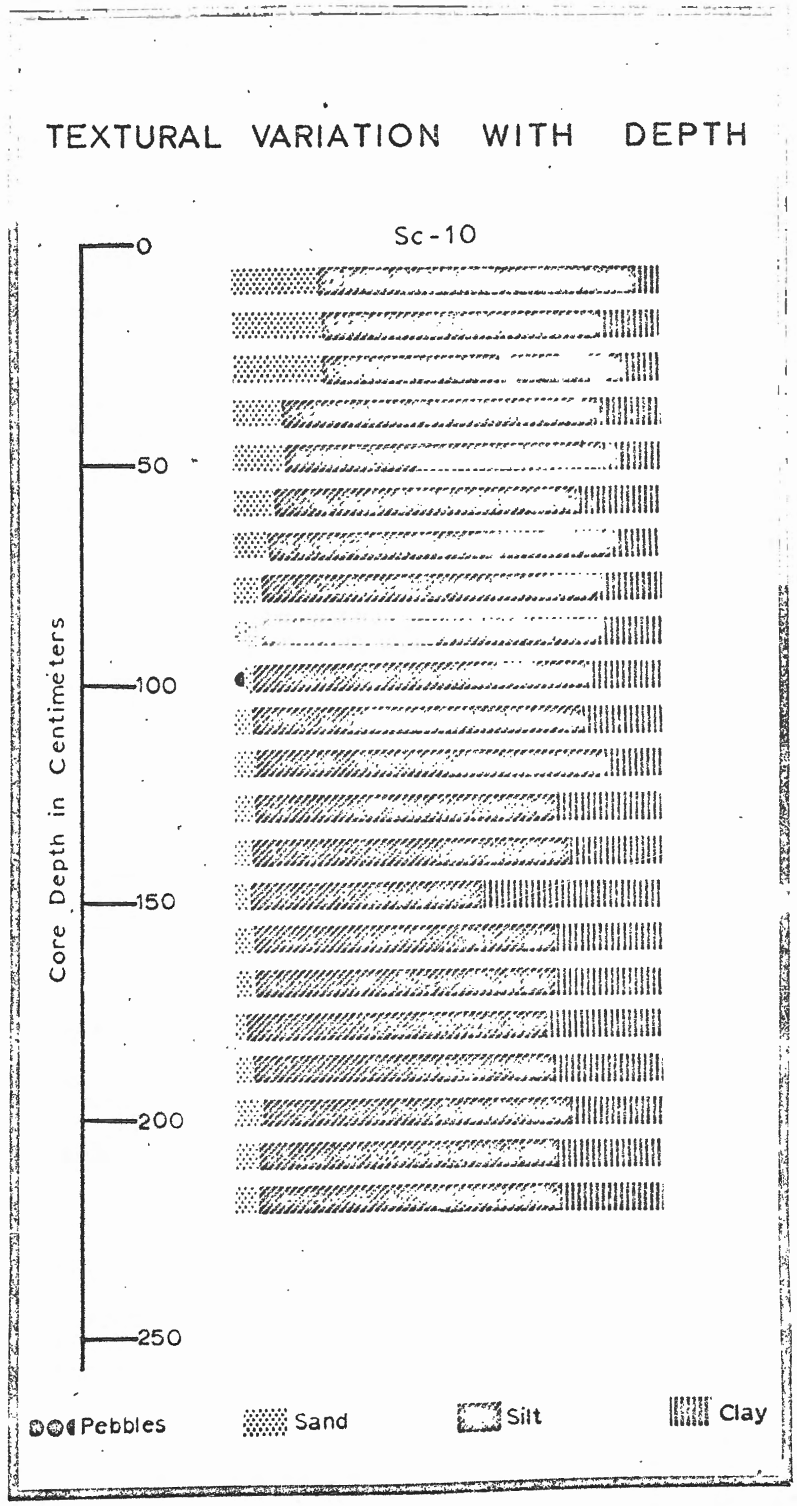


Figure 14. Textural variation with depth.

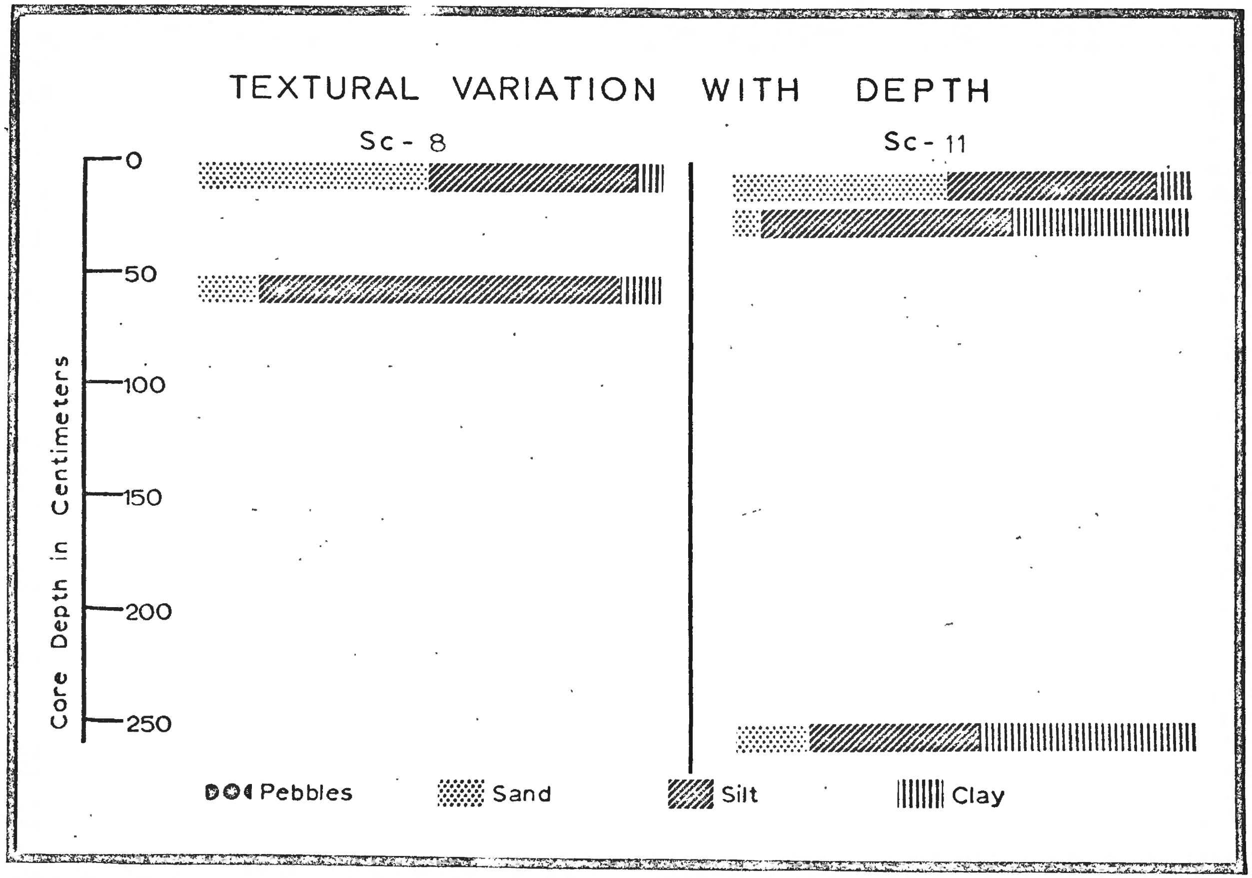


Figure 15. Textural variation with depth.

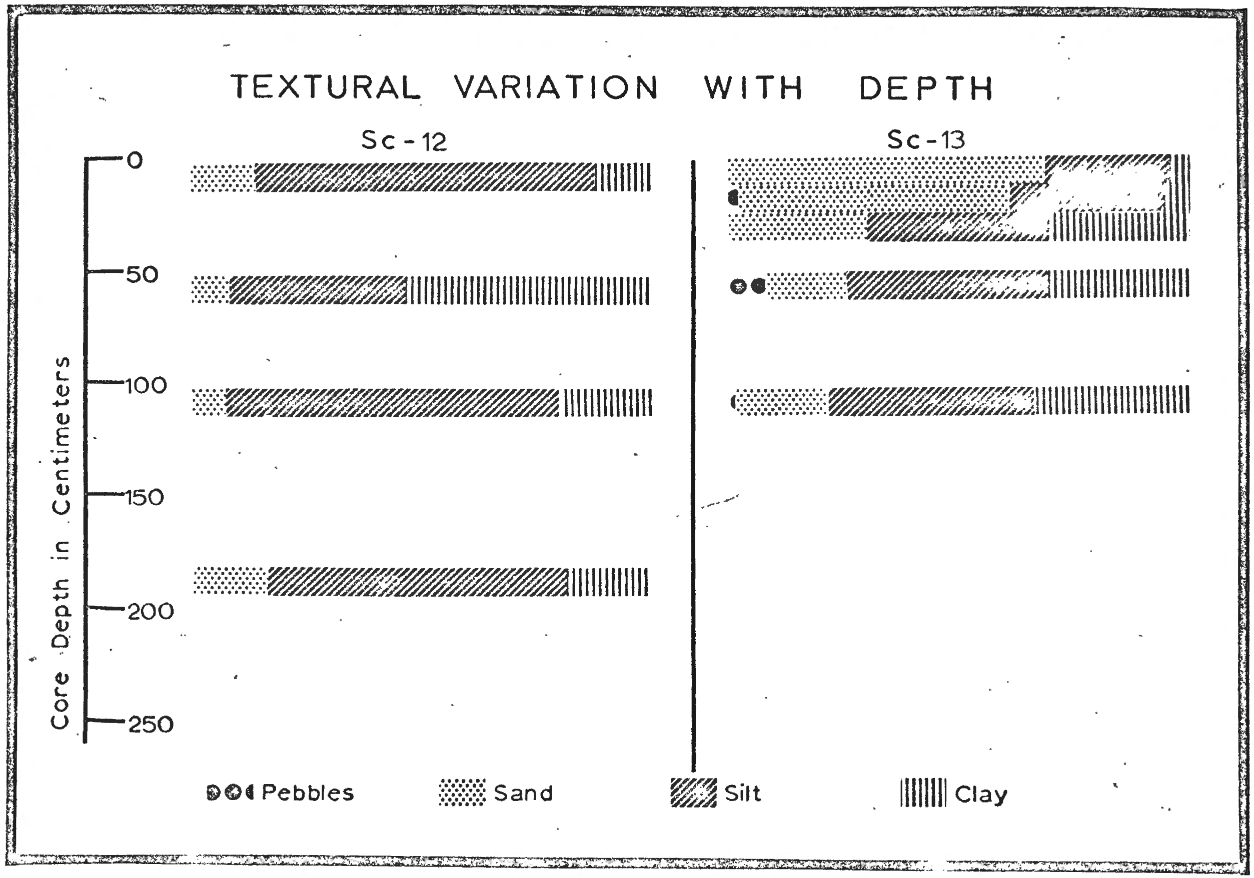


Figure 16. Textural variation with depth.

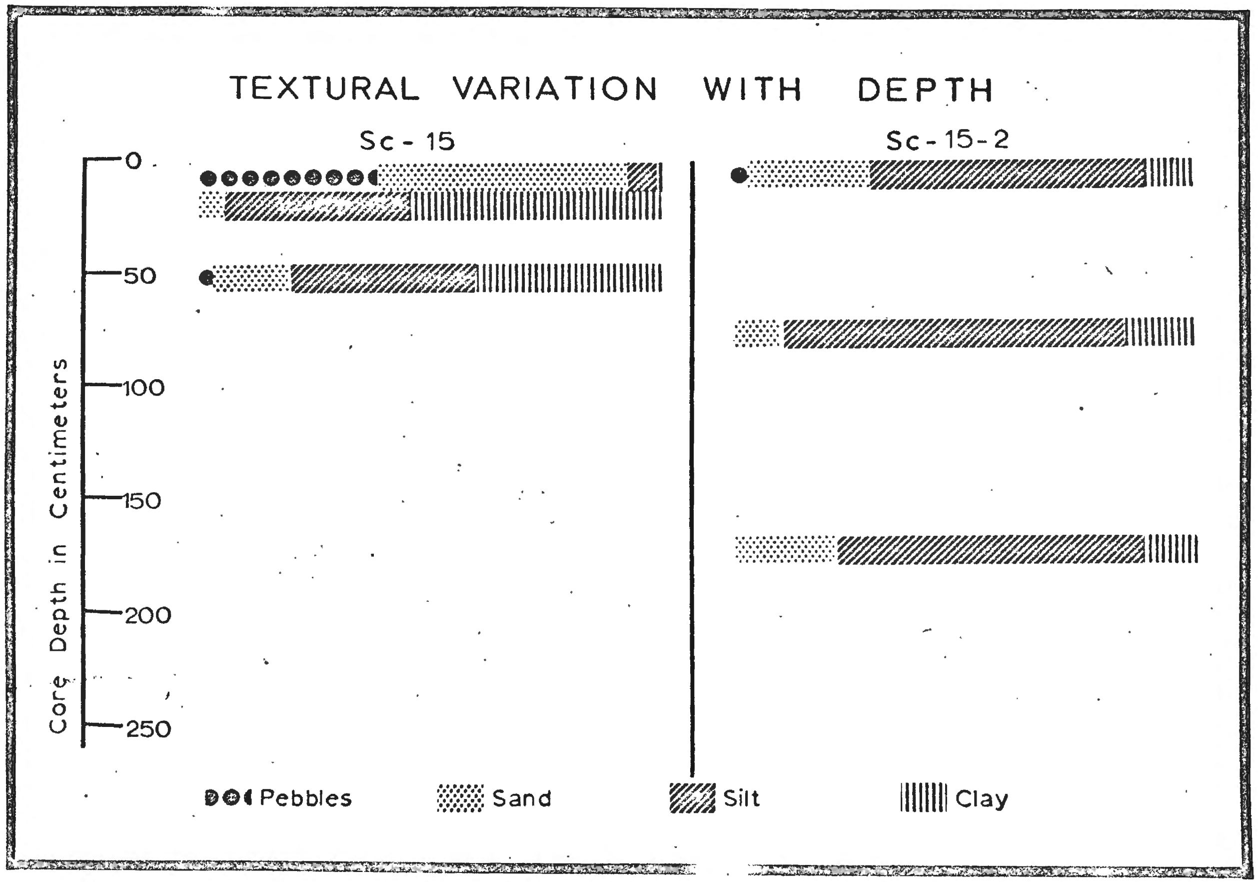


Figure 17. Textural variation with depth.

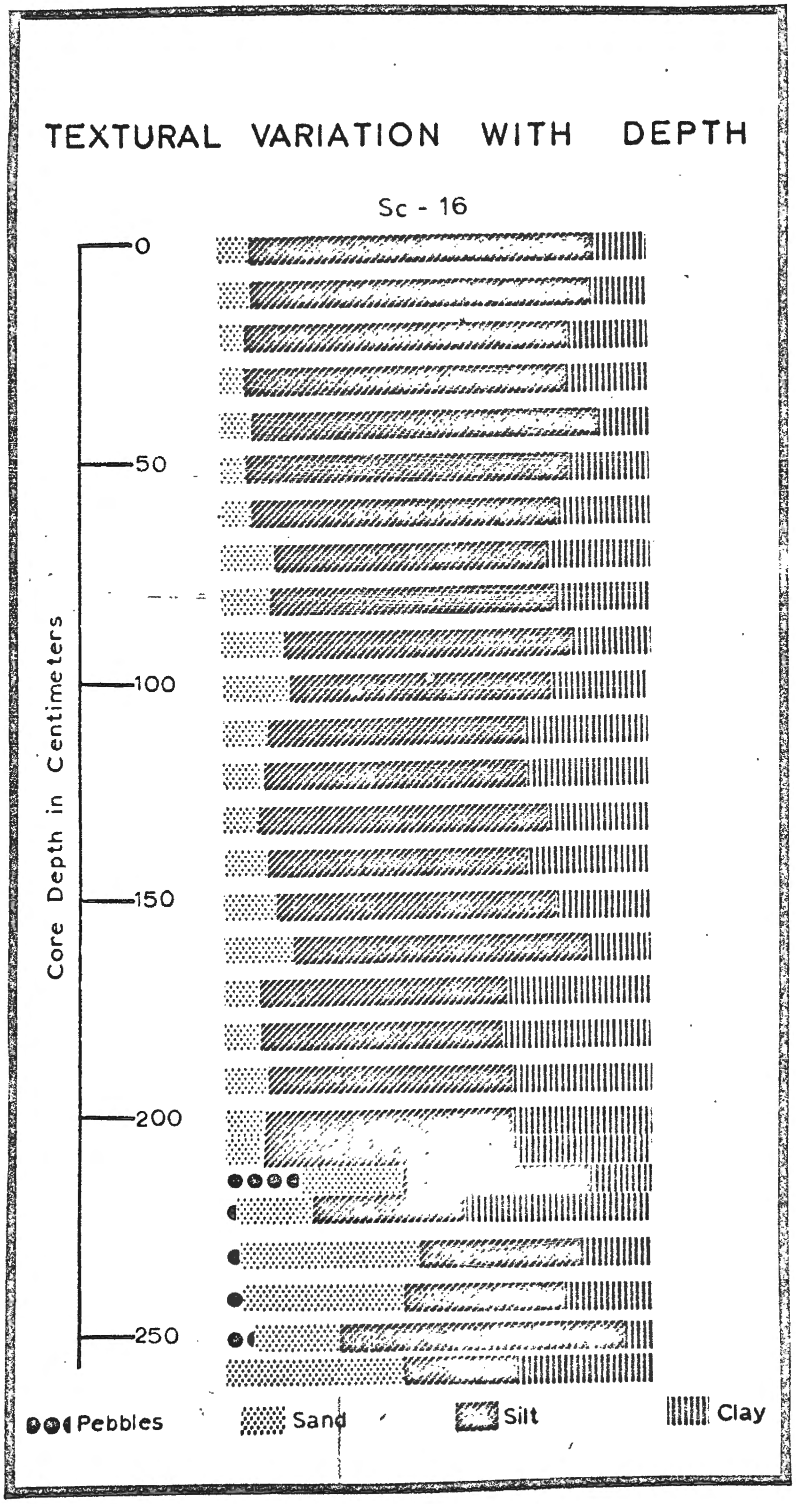


Figure 18. Textural variation with depth.

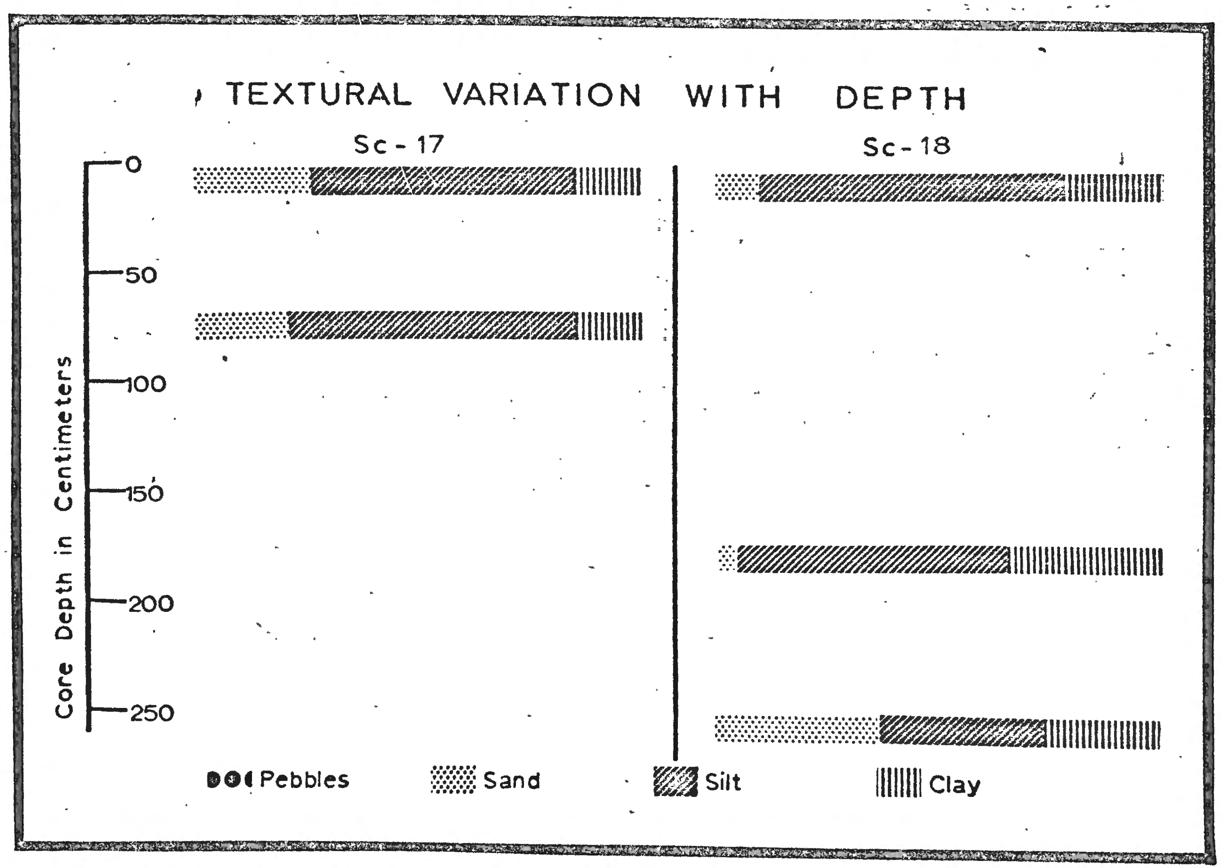


Figure 19. Textural variation with depth.

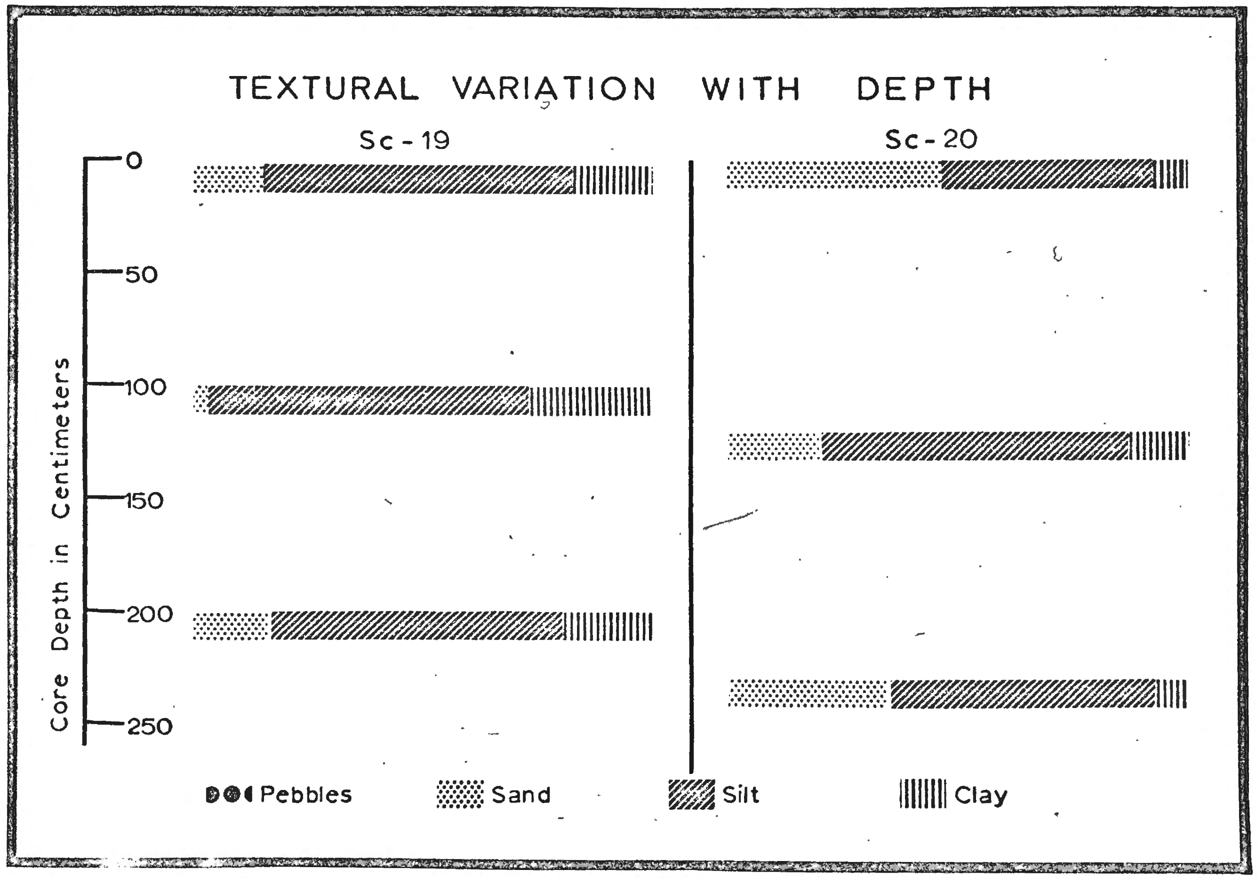


Figure 20. Textural variation with depth.

and shows rapid fluctuations in texture.

The occurrence of coarse sand and pebbles mixed with mud on the continental slope is difficult to explain. Normal sedimentation on the continental slope generally consists of the gradual deposition of silt and clay from suspension (Shepard, 1963). During a lower stand of sea level, active river and beach processes could conceivably have carried coarse sediment over the shelf edge, but if normal bottom currents on the slope were responsible for the dispersion of the coarse grained material, one would expect to find many clean sand and/or pebble layers.

Ice rafting is a process commonly invoked to explain the occurrence of pebbles in dominantly muddy sediments. Studies by Carsola (1954) in the North Polar Sea indicated the extent to which this process can effect sedimentation. The coarser grained material released by the melting ice sinks rapidly to the bottom and mixes with the slowly deposited finer material. The two modes of deposition generally produce a marked bimodality in grain size distribution in the resulting sediment. No indication of a bimodal distribution was apparent in the brown sediment of the Scotian slope. It is conceivable that the continuous grain size distribution of these sediments reflects an interaction between ice rafting and normal bottom currents.

Gravity processes are another mechanism which can produce poorly sorted deposits. Various forms of slumping, flows, and turbidity currents have been described on continental slopes

(Heezen, 1954; Shepard, 1963; Dill, 1962). Pebbly mudstones have been described by Crowell (1957) as resulting from large scale slumping of weak muddy sediments under the load of superimposed gravel deposits. Mixing of the two types of sediment results in the eventual redeposition of a pebbly mudstone, which strongly resembles till deposits. In fact, the distinction can commonly be made only on the basis of slump structures and graded bedding. Large scale structures are beyond observation in most marine enrironments and cannot be inferred from sediment cores. The slump blocks reported by Emery (1965) suggest that gravity processes may have been active in this region. The author feels that the brown sediment reflects deposition from some form of smaller scale gravity movement. Ice rafting, however, was probably quite extensive during the Pleistocene and cannot be rejected, with present information, as a possible mechanism in the deposition of the brown sediment.

The grey sediment is more typical of normal slope sedimentation. The sand fraction is very fine grained and the volume is greatly reduced in comparison to the brown sediment. The dominant component is silt and variations in textures are small and gradual. The change in sedimentation is very rapid as indicated in core Sc-16. A gradual decrease in the proportion of sand in some of the other cores indicates, however, that the trend towards a finer sediment continued after the sharp, initial decrease in grain size.

The increase in sand content towards the top of the grey sediment may represent a gradual winnowing as gentle bottom currents reworked the slowly deposited material.

The surface sand layers could represent an intensification of this winnowing process. Eventually this type of sediment might cover the slope.

PETROGRAPHIC ANALYSIS

General Statement

This study was conducted to determine whether significant petrographic differences existed between, and possibly within, the major sediment types, and to provide an indication of the source material and the environment of deposition of the slope sediments. The material coarser than 63 microns was examined in the coarse fraction study, while the clay fraction study included the material finer than 2 microns.

Coarse Fraction Study

GENERAL DESCRIPTION

The dominant component of the coarse fraction of the slope sediments is quartz. For ease of analysis, feldspar, and possibly other similar appearing minerals have been grouped with quartz. Quartz, however, is the only mineral of any significance in this group, the other grains contributing much less than 1 percent. Quartz occurs in many forms. Some grains are iron stained and the surfaces may be smooth, pitted, or frosted. A complete selection, from well-rounded to very angular grains, is found in most samples.

Ubiquitous accessory components are mica, rock fragments, shell material, and foraminifera. Glauconite, dark terrigenous, and carbonate hash grains are accessory components which are absent from specific samples or sieve fractions.

Mica occurs mostly as flakes of muscovite and small amounts of biotite and phlogopite.

Red, green, and grey siltstones, red and grey sandstones, quartzites, mica schist, quartz-biotite gneiss, basalt, and granite are the principal lithologies found among the rock fragments.

The shell materials consist of fragments in various stages of destruction. The bulk are still relatively fresh although some of the larger grains were smoothed and rounded.

Foraminifera undoubtedly contribute to the shell material as many broken individuals were noticed. For the purpose of this study only those fragments which could definitely be identified as foraminifera were counted. The remainder are included in the shell component.

A black substance was found to be concentrated along with the foraminifera during the CCl_4 flotation procedure. The occurrence of conchoidal fracturing, granular and ribbed fine structure, and combustion using relatively low temperature flames, indicate that this black substance is a hydrocarbon, probably coal. 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 a pale, greenish flaky material, fine shell fragments, and scattered quartz grains, all loosely cemented by carbonate material. The flaky material is likely an altered clay material.

Glauconite was identified as dark green, somewhat knobbly grains with a smooth but finely pitted surface. Flaky aggregates, indicative of the conversion from mica, were not noted.

VARIATION WITH GRAIN SIZE

Description

Figures 21 to 24 show graphically the variation with grain size in selected samples.

Quartz: Quartz shows a very well defined trend of increasing quantity with decreasing grain size. Angularity also increases but not as significantly, as most grains are angular in all size fractions.

Foraminifera: These are not commonly greater than 300 microns in size. They are most abundant between 150 - 300 microns and steadily decline in importance in finer size fractions.

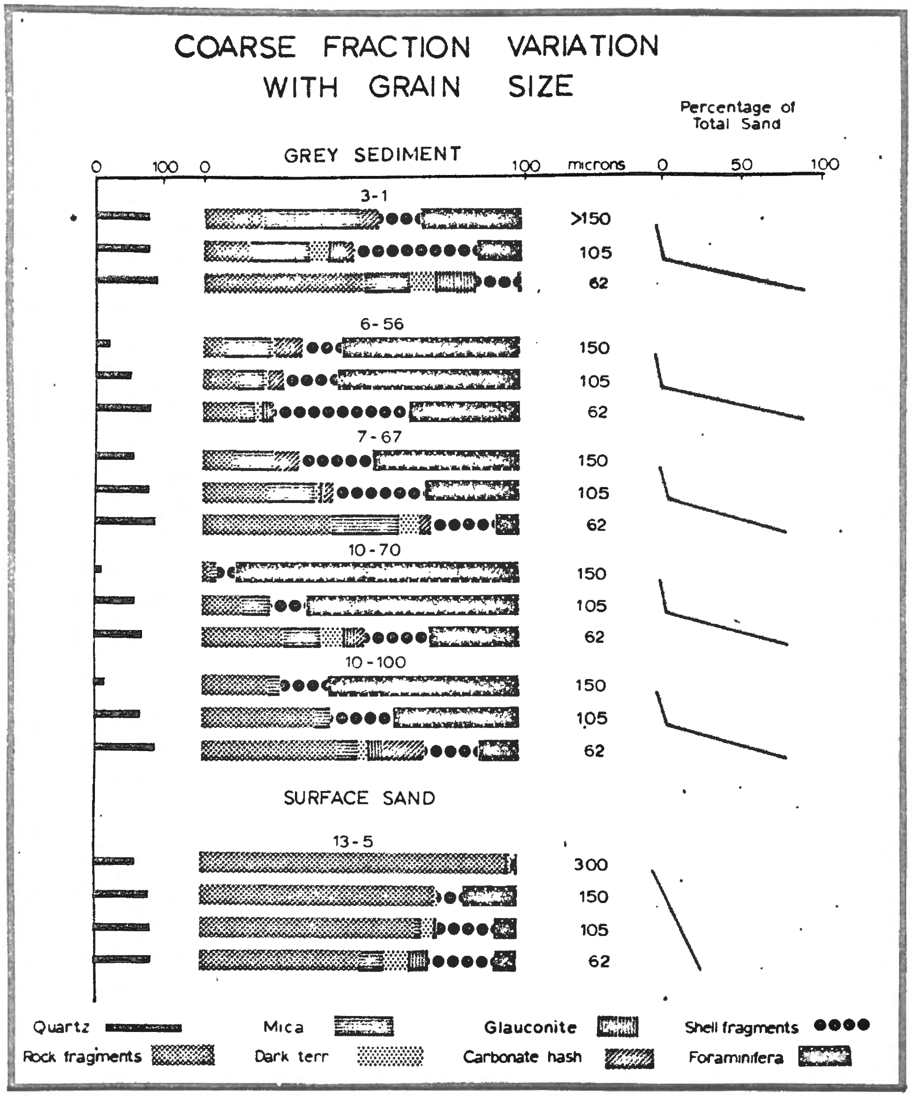


Figure 21. Coarse fraction variation with grain size.

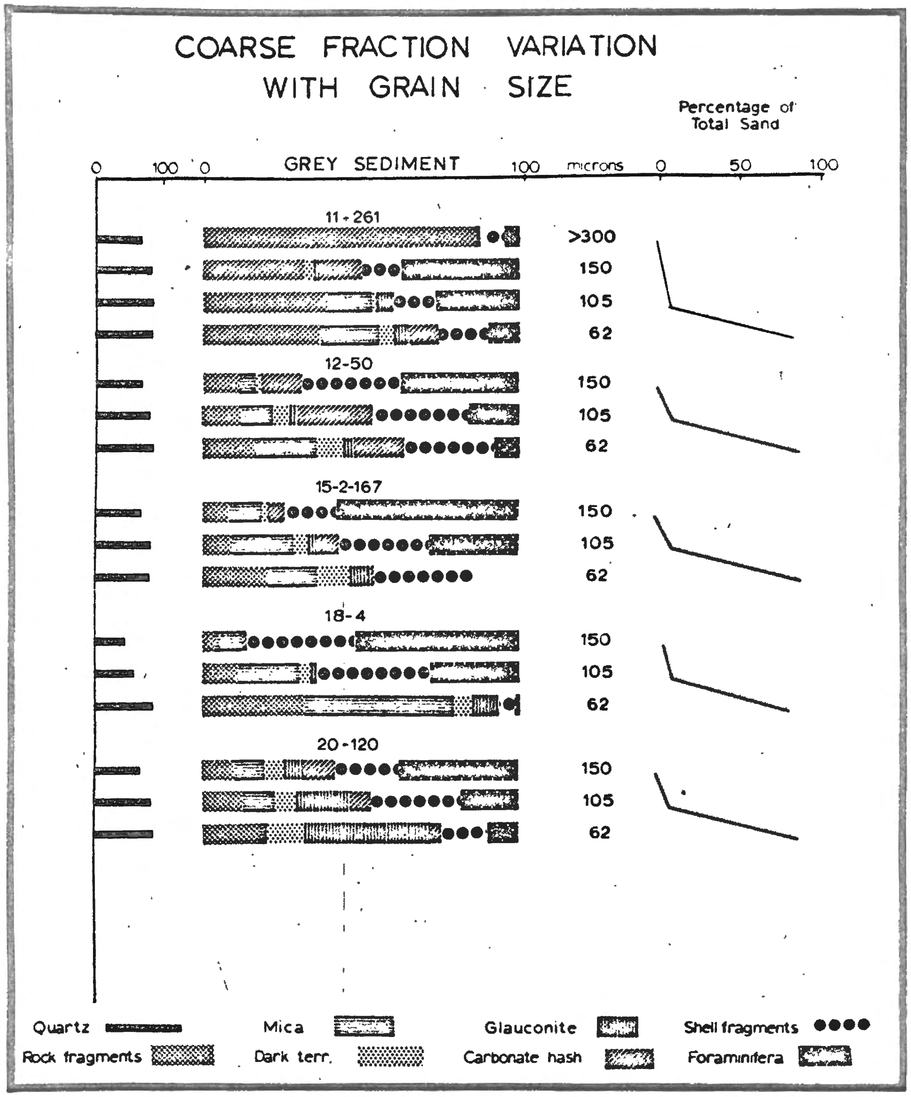


Figure 22. Coarse fraction variation with grain size.

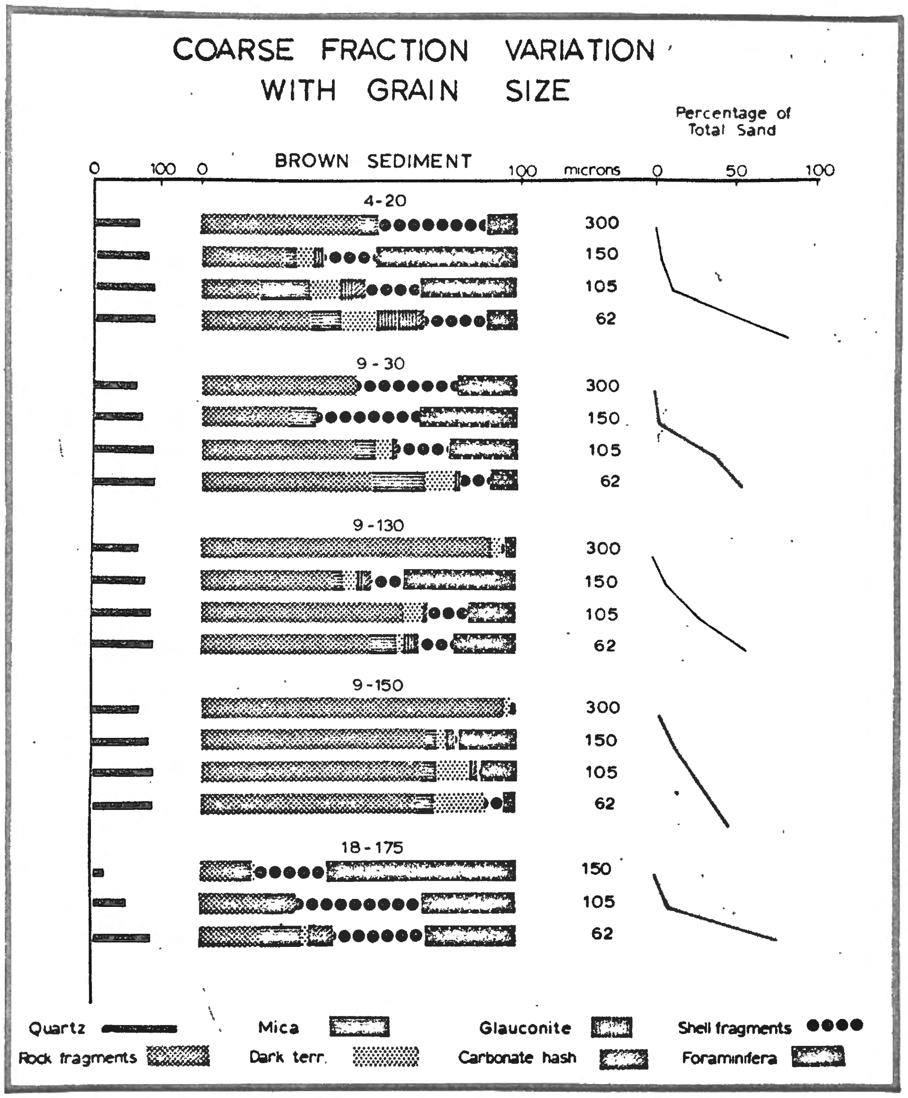


Figure 23. Coarse fraction variation with grain size.

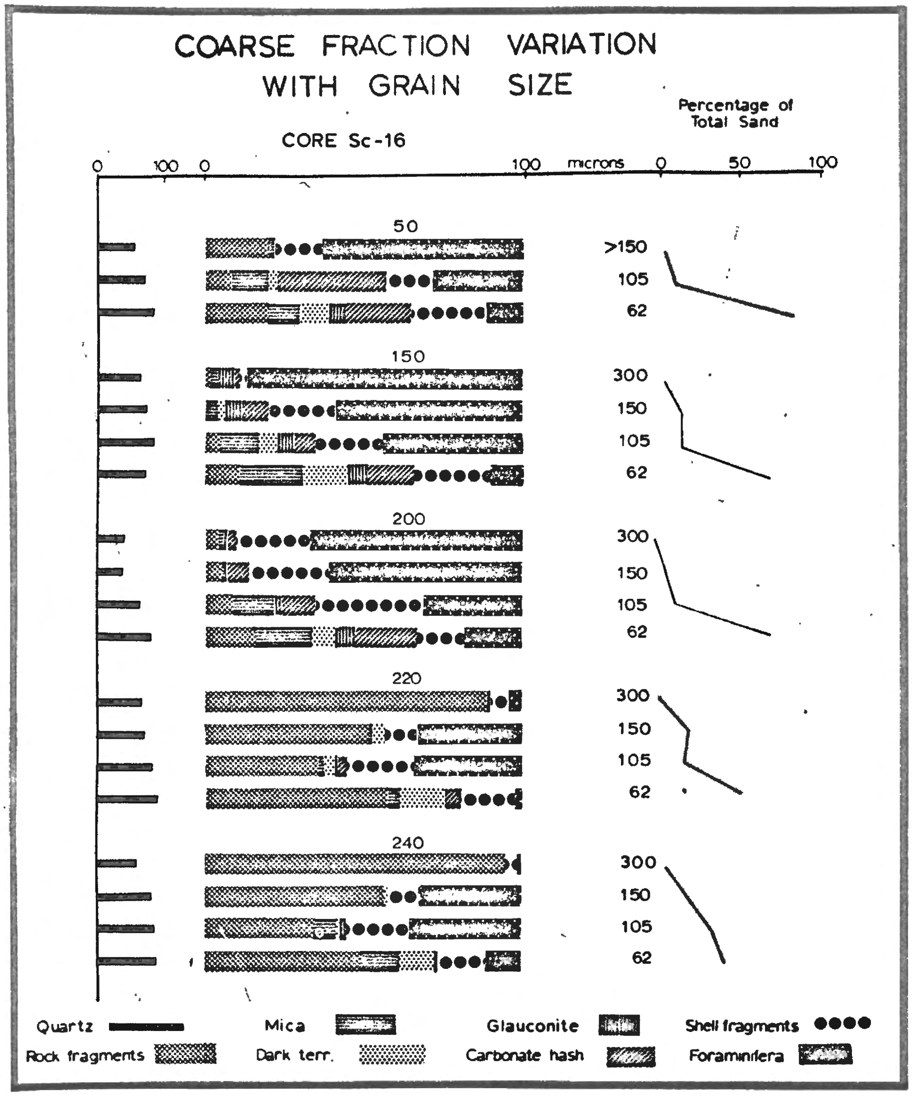


Figure 24. Coarse fraction variation with grain size.

This does not necessarily imply a diminutive in numbers however. Since the total number of grains present increases with decreasing grain size and the quartz contribution also increases, the trend of the foraminifera is not directly determinable. Examination of the foram concentrates indicates a higher proportion of fine tests.

Rock Fragments: Two tendencies are found in this component. Where they are abundant a decrease with grain size is apparent, and vice versa. Lithologically, an increase in basalt fragments is found but no new rock types appear with decreasing grain size. Since the sandstones and plutonic rocks cannot exist in the finest sand sizes, the change does not represent a change in provenance.

Shell: This component is relatively constant but may show an increase in the finer sizes in some samples. In the coarser than 300 micron fraction complete valves of pelecypods and partially broken gastropods are occasionally found.

Mica: Many samples show an increase with decreasing grain size but others show no obvious trend.

Dark Terrigenous: This material also tends to increase in the finer sizes but comparions are difficult as some samples possess medium grained sands with no dark terrigenous material. Generally it is most often found in the finest sand.

Glauconite and Carbonate Hash: No marked tendency is apparent for these components although they are slightly more common in the finer sand sizes.

Discussion

The above descriptions are deceptive in that they imply an independent relationship of the various components. Since the data was obtained using a percentage determination all components are in reality dependent variables. The principal variables are rock fragments and foraminifera. The strong trends shown by these components account for the tendencies in the remaining components. The overall tendency is a decrease in total carbonate material with decreasing grain size. The change is gradual as the increasing percentage of shells and carbonate hash modifies the sharp decline of foraminifera with decreasing grain size.

VARIATION WITH DEPTH

Description

The reconnaissance study did not permit detailed examination of all cores and hence tendencies have been inferred across large spacings. Core Sc-16 has been examined in relative detail and short term changes are taken primarily from this core. In obtaining Figures 25, 26, the breakdown into size classes was eliminated save where abundant material greater than 300 microns was available. Also, for easier comparison, the scales were adjusted so that minor components are exaggerated and the major components subdued.

In general, the terrigenous components behave as a group and

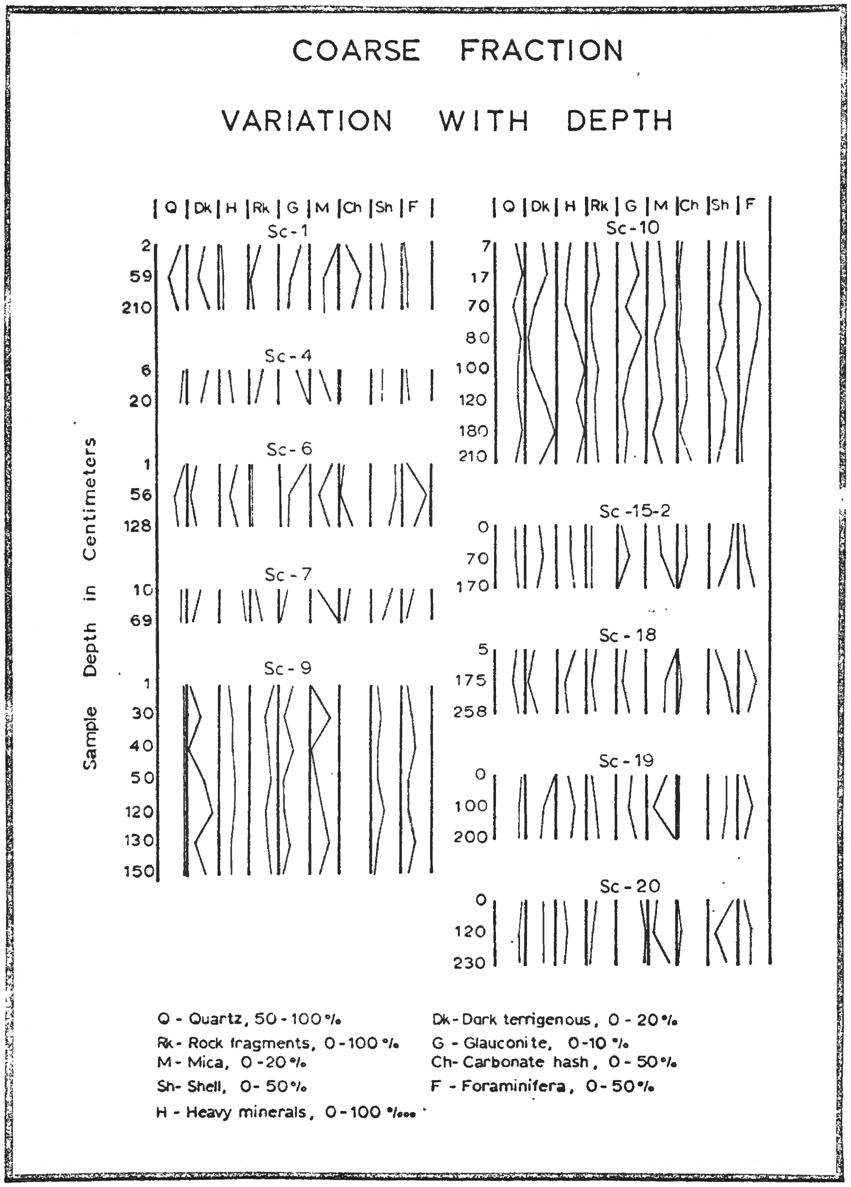


Figure 25. Coarse fraction variation with depth.

the carbonate components as a second group. This grouping of trends is more apparent in the widely spaced samples. Examination of core 16 indicates that short term changes are not nearly as consistent. Quartz and dark terrigenous components vary directly, as do mica and glauconite. Shells and forams have a general similarity of trends, which carbonate hash occasionally follows.

The minor components generally show more rapid changes in percentage than the major components. These fluctuations of both groups are random, however, and no distinct tendencies were noted within the major sediment types.

Discussion

The two groups are seen as terrigenous and pelagic elements. Because of similarities in variation with depth, glauconite is placed with the terrigenous group. It is probably an allochthonous material while carbonate hash appears to be an autochthonous component.

Because of the compositional stability of the coarse fraction, and the lack of definite trends, the depositional environments inferred as being relatively stable, except for a small scale interplay of pelagic and terrigenous components.

VARIATION WITH SEDIMENT TYPE

Description

The greenish grey and reddish brown sediment types are most

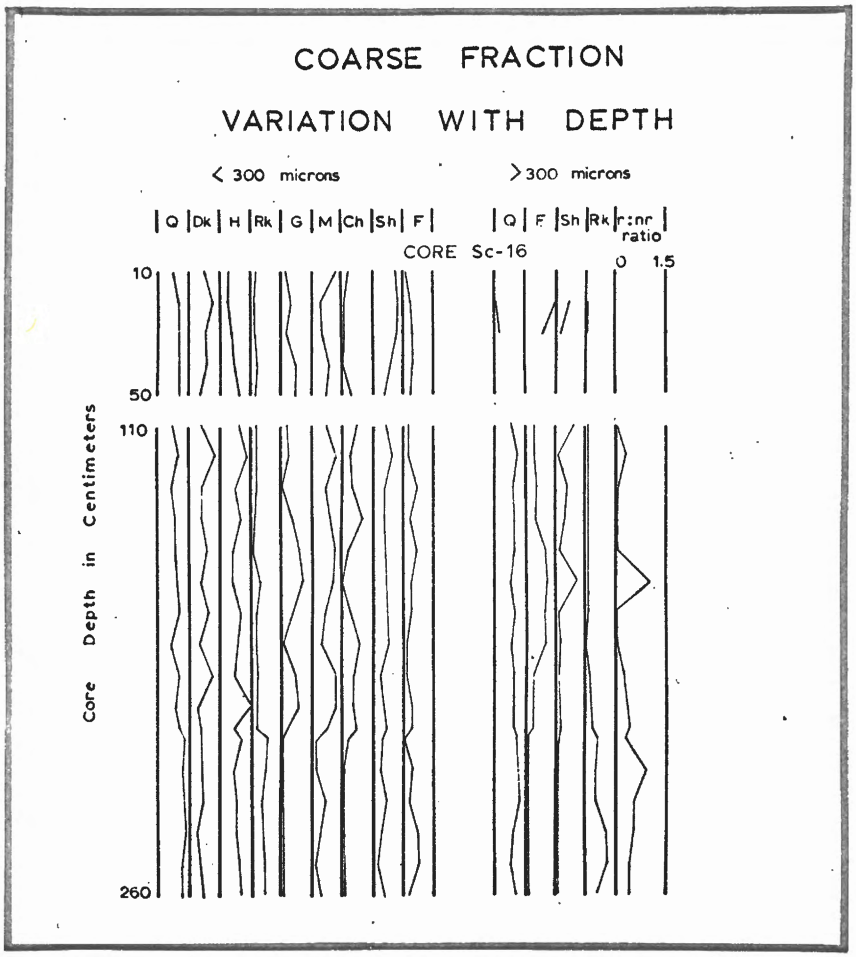


Figure 26. Coarse fraction variation with depth.

easily distinguished in the accessory components. This fraction is predominantly pelagic in the grey sediment and predominantly terrigenous in the brown. Examination of the rock fragment lithologies indicates that while the same rock types are found within both sediments, the brown often shows a greater variety in any particular sample. A greater proportion of red coloured sedimentary fragments is found in the brown. This can be seen in the red : non-red ratio plotted for the coarse sand of core Sc-16 (Figure).

Glauconite is more abundant in the grey sediment. Carbonate hash is also found in greater proportions than in the brown samples. Dark terrigenous grains do not show any change between the two types of sediment.

The absolute abundance of mica, forams, and shells are reduced in the brown sediment but the relative proportions are generally the same in both sediments.

The quartz fraction as well tends to be more abundant in the brown sediment.

Small scale variations are more pronounced in the greenish-grey sediment. Note the abrupt change in the character of the graphs of core Sc-16 at 210 cm.; the contact between the reddish brown and the grey sediments. A triangular plot of rock fragments, total carbonate, and total terrigenous demonstrates a greater variability in the grey sediment and indicates the importance of rock fragments in the brown sediment (Figure 27).

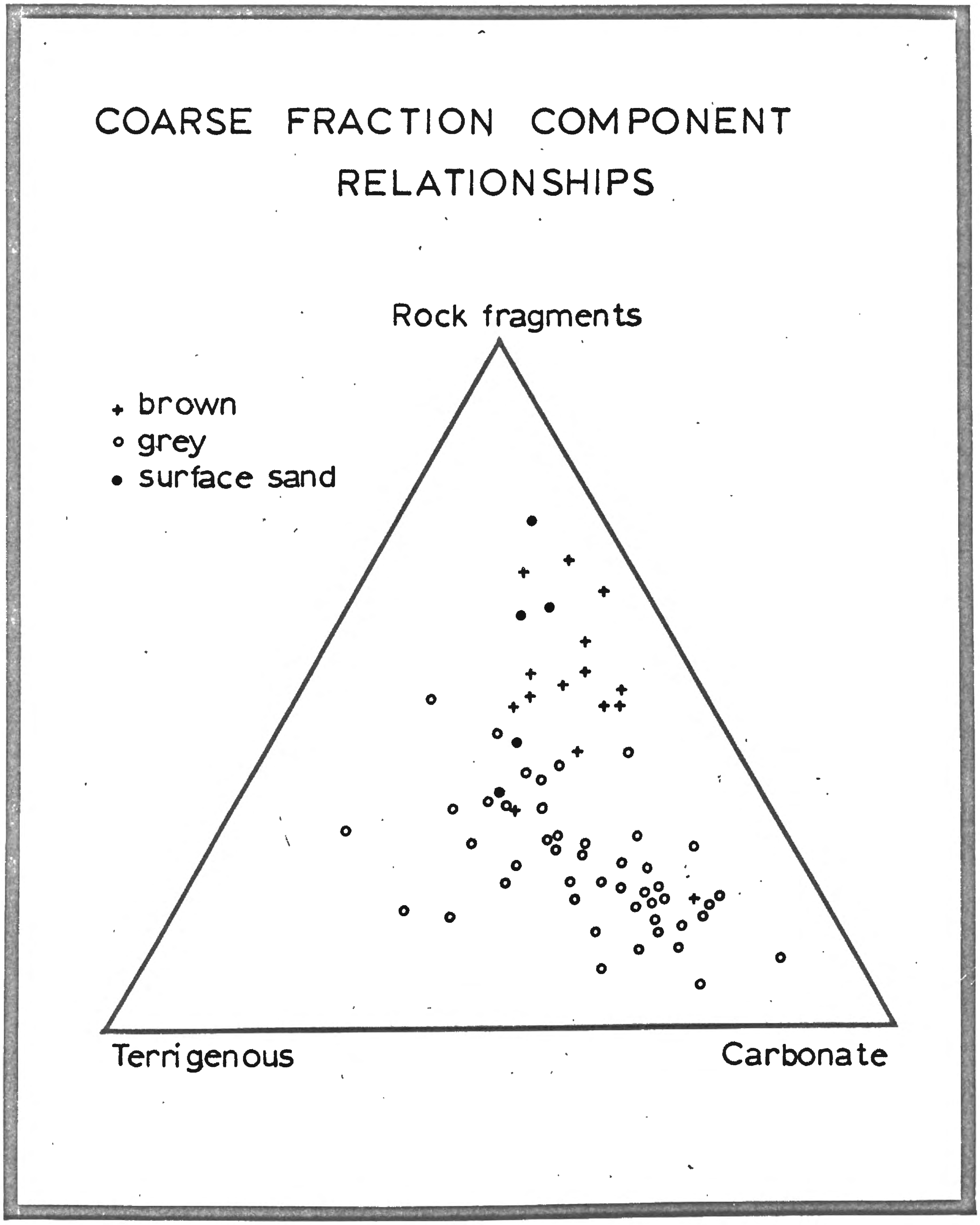


Figure 27. Coarse fraction component relationships.

Discussion

The brown sediment is inferred as being predominantly allochthonous and as having been deposited in such a way as to produce a lithologically homogenous sediment. The grey sediment, while also dominantly allochthonous, appears to have been deposited slowly enough to permit an accumulation of pelagic components and to have been affected by small scale changes in the environment. The source of the grey sediment appears to be similar to the brown save for a diminutive in rock fragments. Red fragments were still available as indicated by the high proportions at specific depths in the cores, e.g. Sc-16 - 160.

Samples Sc-9-1, Sc-13-5, and Sc-15-0 are from the relatively clean sand found at the top of some cores. This material as well is predominantly terrigenous and contains mostly rock fragments in the accessory fraction of the sand. They are very similar to the brown sediment in this respect.

Sample Sc-18-175 is taken from a brown layer within a grey section. The coarse fraction of this material is most akin to the greyish sediment and suggests that these layers are not of the same origin as the main underlying brown sediment.

Heavy Mineral Study

DISTRIBUTION

The contribution of heavy minerals to the 62-500 micron size fraction of the sands is low. The weight of the heavies recovered was generally less than 1 percent and only rarely exceeded 2 percent.

The heavy fraction has been plotted in p.p.1000 along with the other components of the coarse fraction (Figures 25, 26). The variation with depth is, as might be expected, similar to the light and dark terrigenous components.

The abundance of heavy minerals does not vary significantly between the brown and grey sediments but some distinction is possible. Figure 28 is a scattergram relating the heavy mineral contribution and the weight of sample. No relationship can be observed within the grey sediment but the scattering within the brown sediment exhibits a negative trend; there is a tendency for heavy minerals to be more abundant in samples with less sand. This tendency is poorly defined however, and interpretation is difficult. Samples with less sand are generally finer grained and heavy minerals tend to be more common in the finer sand sizes. Another explanation could be that the heavies are lag concentrates in a winnowed deposit. If a sufficient sample could be obtained, size analysis of the heavy fraction might resolve the problem.

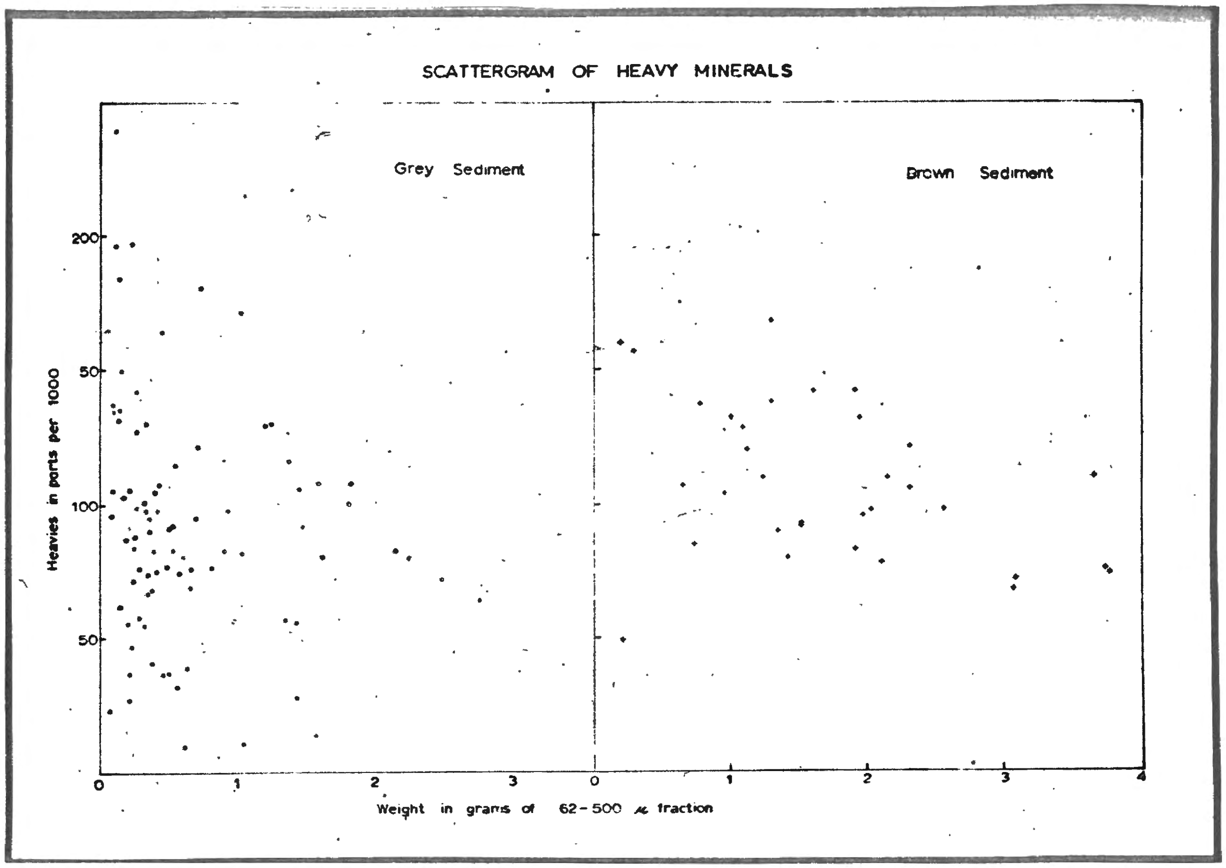


Figure 28. Scattergram of heavy minerals.

COMPOSITION AND PERCENTAGES

Opaque grains were not identified in this study but are considered as a separate group. Their contribution varies between 20-60 percent of the heavy fraction but is most commonly between 25-35 percent. The non-opaques have been separated into two groupings: the major components, which are found in all samples, and the minor components, which occur irregularly.

Major Components

Hornblende is the most abundant mineral of the heavies. While extreme values of 10 and 42 percent were noted most samples contained between 25-35 percent hornblende.

Garnet forms between 10-30 percent of the heavies and varies widely between these limits.

Hypersthene varies between 5-20 percent but is generally about 12 percent.

Augite may form up to 20 percent of the heavy grains but, like garnet, is quite variable.

Minor Components

Alterites are the most common accessory and forms up to 24 percent of the heavies in some cases.

Andalusite, Zircon, and Tourmaline are found in almost all of the 21 samples analyzed and each may attain 8 percent of the sample.

Epidote and Staurolite are not as common as the other minerals

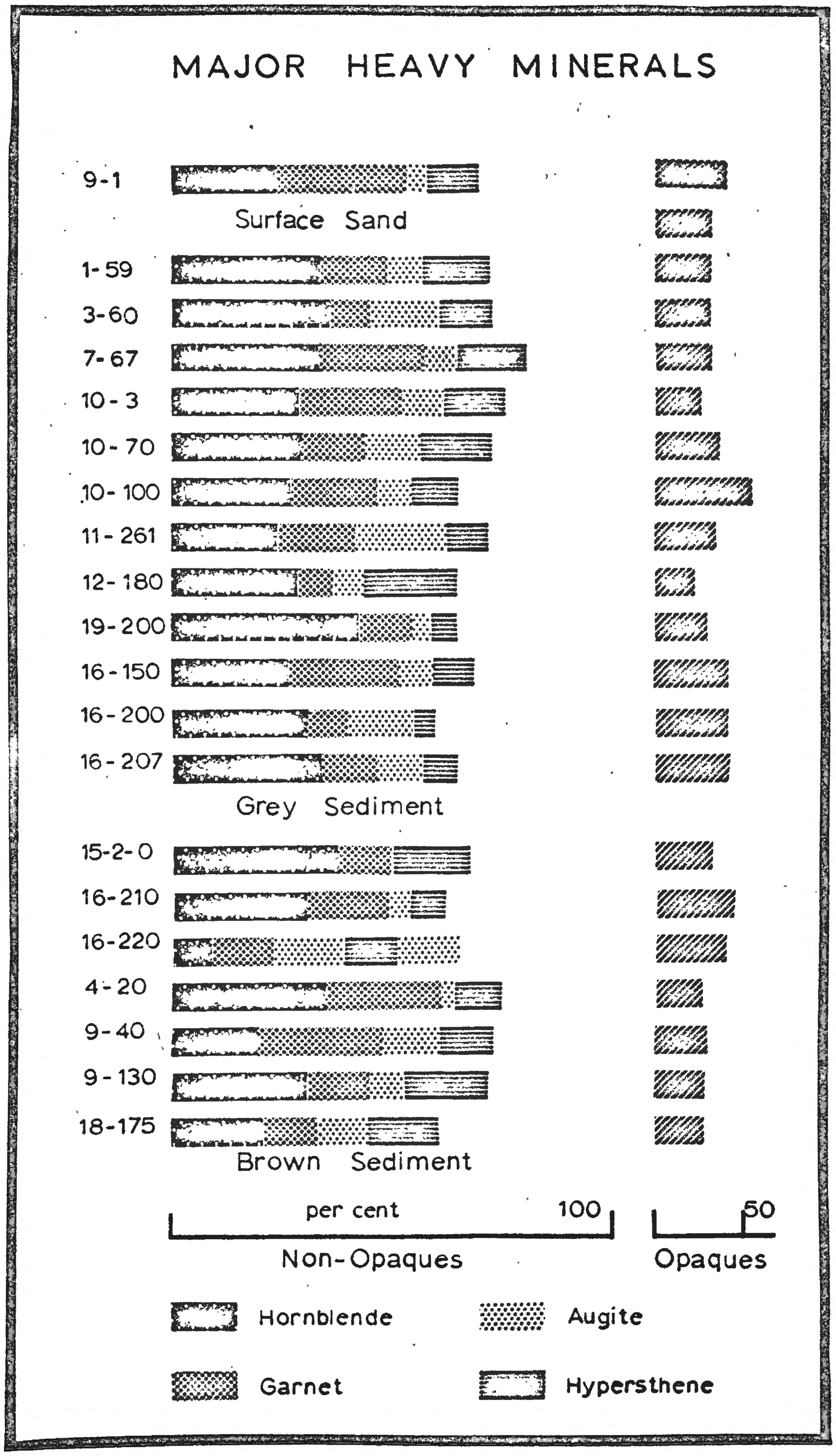


Figure 29. Major heavy minerals.

but form up to 10 percent and 5 percent of the non-opaques respectively.

Saussurite occurs in only 6 samples and varies between 3-11 percent.

'Other' minerals include Titanite, Mica, Brookite, Kyanite, Chloritoid, and Sillimanite and rarer minerals.

DISCUSSION

Identification and counting of the heavy minerals was performed by A.E. Cok, who states that the grains identified are very similar in nature to those found on the Scotian Shelf and beach deposits (A.E. Cok, Personal Communication, 1965). A detailed discussion of the heavy fraction of Nova Scotia beach sands is offered by Nolan (1963).

The data for the major constituents is presented in the form of bar graphs in Figure 29. The uniformity of this group is very noticeable. No distinction can be inferred between the heavy mineral assemblages of the brown and the green sediment types.

The surface sediments of the adjacent shelf contain a similar set of major components but the proportions of garnet and hornblende are reversed. The sediments of the shelf northeast of the Gully show a dominant hornblende component. Although the hornblende is more abundant than in the slope sediments, these are the most comparable of the shelf sediments (A.E. Cok, Personal Communication, 1965).

Figure 30 shows the areal distribution of the minor minerals. Saussurite is found primarily in the brown sediment in the southwest portion of the area. It is noted that alterites do not occur together with saussurite. As saussurite is in reality a type of alterite this data may represent an experimental rather than actual variation.

The northeast group of samples are possibly similar but this is mostly a matter of proportion of accessories rather than of similar mineralogies. Generally, it can be said that the minor constituents are highly variable, even within the same core, and that no zonal groupings could be determined using reconnaissance techniques.

The accessory minerals found are also common on the shelf but again as different proportions. Their proportions like those of the major components, are intermediate between the proportions of the two major shelf suites.

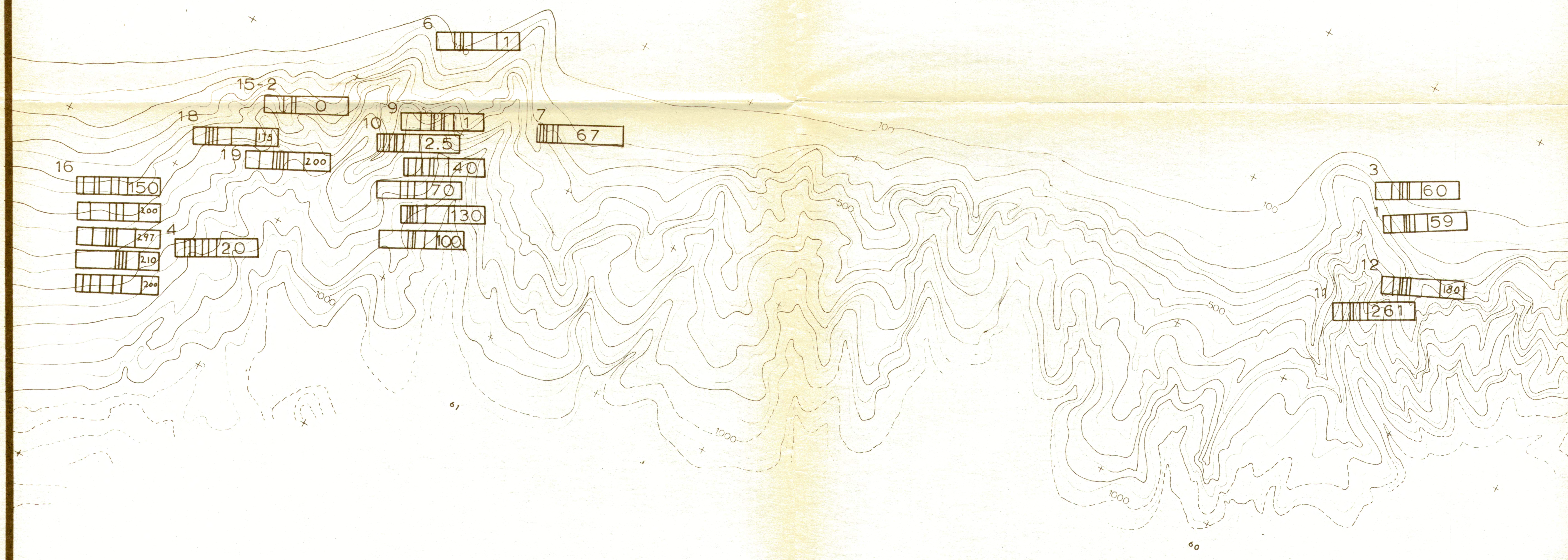
The heavy mineral data suggests that the slope sediments were derived from a relatively unchanging source, or group of sources. It is likely that the shelf acted as a source for the slope sediments. Another possibility is that the shelf and slope had the same sediment source.

FIGURE 30

DISTRIBUTION OF MINOR HEAVY MINERALS

0 - 50%

- ☐ ALTERITES
- ☐ ANDALUSITE
- ☐ ZIRCON
- ☐ EPIDOTE
- ☐ TOURMALINE
- ☐ SAUSSURITE
- ☐ OTHERS
- ☐ STAUROLITE



Clay Fraction Study

INTRODUCTION

The clay fraction was examined, using x-ray diffraction techniques, to determine whether the slope sediments could be classified according to various clay mineral suites. The clay minerals were approached as environment and provenance indicators, rather than from the viewpoint of clay mineralogy, and therefore have been studied as families instead of individual species. For example, the term Kaolinite will include kaolinite, dickite, halloysite, nacrite, and anauxite, since no attempt was made to differentiate these mineral species.

Identification of clay minerals should also involve chemical, electron microscopic, and differential thermal analyses. Again, because it is the character of the sediment, rather than the true character of the clay minerals, that was considered important, generalized x-ray diffraction procedures alone have been used. While the results are not mineralogically definitive, they are sufficient for the purpose of this study.

IDENTIFICATION OF COMPONENTS

The use of flat-layer oriented specimens has been generally adopted for the study of clay mixtures, and various criteria have been established for the identification of the common clay mineral groups.

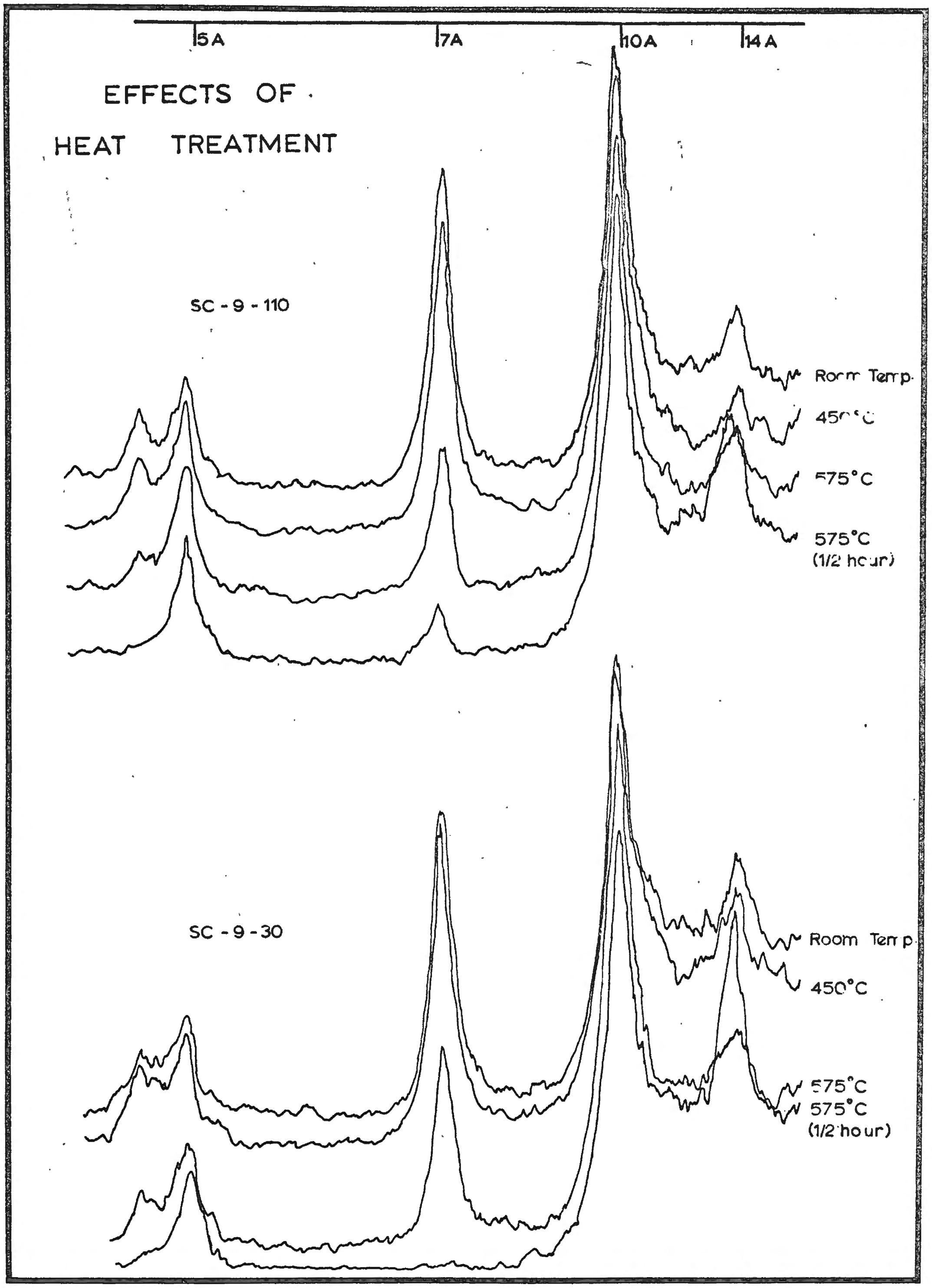


Figure 31. Effects of heat treatment on clay minerals.

Illite, with a 10A basal spacing, is characterized by 001, 002, and 003 reflections at 10.1, 4.98, and 3.33 A respectively. These spacings are not altered by heat treatment, glycolization, or HCl treatment.

Montmorillonite, in the untreated state, has a basal spacing between 12 and 15 A, depending on the amount of water and the type of cations in the expandable layer. In most samples the untreated basal spacing was 14-15 A. After treatment with glycol the lattice expands to 17-18 A, while heating to 150°C collapses the spacing to 10 A. Expandable mixed layer clays have been considered together with montmorillonite. These have been inferred from the broad and irregular peaks in the montmorillonite range. In particular, the glycolated samples revealed minor peaks at various positions between 14 and 18.5 A.

Chlorite is indicated by 001, 002, 003, 004 reflections at 14.2, 7.1, 4.7, and 3.5 A respectively. Heating to 575°C dehydrates chlorite and only the first order reflection is apparent, strongly intensified, on the records. Acid treatment strongly reduces and eventually removes all chlorite lines. Ethylene glycol has no noticeable effect on chlorite. Powder photographs showed a weak line at 1.53 A, corresponding to an 060 reflection of a trioctahedral chlorite. A medium strength 1.50 A line was also found but is taken as the 060 reflection of the dioctahedral illite.

Kaolinite gives first and second order reflections at 7.1 and 3.5 A. As these lines correspond to the second and fourth order lines of chlorite, the identification of kaolinite is a difficult matter. Kaolinite normally decomposes when heated to a temperature of 575-600° C. The behaviour of chlorite to such treatment varies with the degree of crystallinity of the material. In relatively poorly crystalline recent sediments, Johns, Grim, and Bradley (1954), found that chlorite dehydrated at 450°, while Proctor (1960), dealing with Jurassic sediments, found that chlorite did not break down until 575°. In other cases the chlorite does not break down until heating beyond 575°.

Two samples were heated in steps of 100 C ° in order to observe the critical temperatures. In each case no effect was noticeable until a temperature of 575° was reached, and particularly after the sample was heated for ½ hour at this temperature and cooled slowly in the closed oven. The samples heated to this temperature and then quenched in air showed a reduction of the 002 and 003 chlorite peaks. With the more intense treatment the reduction of the higher order chlorite reflections was pronounced (See Figure 31). In one case, only a small 7 A reflection remained while in the other no lines remained save the intensified first order chlorite reflection. Therefore, heat treatment was abandoned as a possible distinguishing parameter, since kaolinite and chlorite decomposed at the same general temperature.

Another criteria distinguishing these minerals is their reaction to digestion with hydrochloric acid. In every sample treated with the acid the 14 A reflection was strongly reduced or completely destroyed while the 7 A reflection persisted, although slightly reduced. Although this would appear to confirm the presence of kaolinite it is not completely diagnostic. Sedimentary chlorites commonly show more intense even-ordered basal reflections. This is particularly the case in iron-rich chlorites (Brindley, 1961, p. 261). The remnant 7 A reflections could indicate the incomplete destruction of the chlorite.

Kodama and Oinuma (1963) have dealt specifically with the problem of the identification of kaolinite in the presence of chlorite and concluded that both heat treatments and acid digestion are insufficient to prove the existence of kaolinite. Their main objection to HCl treatment, however, concerns samples in which the remaining 7 A reflection is very weak, where it would be difficult to distinguish an incompletely decomposed chlorite from a small quantity of kaolinite. In the slope samples the 7 A line is generally quite strong, sometimes exceeding 75 percent of the untreated value. For this reason, and because an infrared spectrophotometer was unavailable, the 7 A value remaining after acid digestion was considered to be diagnostic of kaolinite.

Other minerals identified in the clay fraction were quartz and feldspar. The former was identified by the strong 101 reflection at 3.3 A and by a weaker 100 line at 4.3 A. Feldspar was inferred from the presence of one, and sometimes two, lines in the range 3.16 - 3.21 A. An occasional shoulder along the high angle side of the 7 A reflection also suggested a 6.5 A reflection of feldspar.

SEMIQUANTITATIVE ANALYSIS

Accurate quantitative analysis of clay mixtures is difficult, and although x-ray diffraction is perhaps the best individual method, errors as large as 10 percent can be expected in even the most precise investigations (Hoffman, 1956). In most sedimentological studies, relative percentages or concentration ratios, rather than absolute percentages, are sufficiently accurate.

Differences between samples are the greatest causes of error in quantitative techniques. Proctor (1960) lists the following as variables which influence semiquantitative measurements.

Size of sample
Thickness of sample
Particle size
Uniformity of particle size
Degree of Orientation
Purity of sample
Uniformity of mineral components
Crystallinity
Humidity and temperature
Instrumental variations

Control of sample size, degree of orientation, purity, atmospheric variations and instrumental variations, can be achieved by standardization of experimental procedures. The other variable factors are intrinsic values of the individual samples and cannot be effectively controlled.

The most accurate method of analysis involves the comparison of peak areas with those of internal standards or of prepared standard mixtures. Examination of the above list will indicate the difficulty in using standards. These sample characteristics, which effect peak areas, are almost impossible to reproduce accurately. For this reason, standards are commonly not used and the assumption is made that the peak areas are proportional to the relative quantities of the components present (Johns, Grim, and Bradley, 1954).

It was impossible in this study to standardize the thickness of sediment on the slides because the author was unable to measure the clay concentration of the prepared suspensions. Attempts at removing aliquots of the suspension revealed that the use of different pipettes produced different calculated sediment concentrations. Because the initial concentration was unknown, it was impossible to bring each sample to the same concentration and produce slides of uniform thickness. The value of standardizing this thickness was reconsidered when it was discovered that few investigators attempt this procedure on the grounds that the obtaining of optimum diffraction patterns for different samples demands different amounts of clay on the slides (e.g. Hathaway, 1955).

In this study, only the three slides of each sample are directly comparable although uniform conditions were maintained throughout. An estimate of the reproduceability 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.

The peak areas of different components are not directly comparable because of variations in the ability to scatter x-rays. From theoretical considerations, Bradley (1953) showed that when comparing first order reflections of montmorillonite and illite, the illite intensity must be multiplied by a factor of four to account for the greater scattering ability of the montmorillonite.

Johns, Grim, and Bradley (1954) assume equal scattering factors in the high angle range and compare the 3.5 A peak of chlorite and kaolinite with the 3.3 A peak of illite. This could not be done in the present study because the presence of relatively large amounts of quartz in the slope sediment obscured the illite peak at 3.3 A.

Freas (1962) compared the proportions of illite, kaolinite, and montmorillonite using differential dissolution and monolayer specific surface analyses. By comparing these results with the x-ray diffraction intensities, he developed scattering factors which can be used in comparing first order intensities. He found that the illite intensity must be multiplied by a factor of three in comparison to kaolinite. The kaolinite and montmorillonite peaks were directly comparable. No method was found to determine chlorite independent of x-rays and Freas used an arbitrary factor of three.

To enable gross comparisons to be made with other clay suites, the scattering factors developed by Freas have been used in this study to determine approximate clay mineral percentages.

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 7.1 A were recorded for the untreated sample. Using the same background line and peak widths, the areas of the 14 A and the 7 A peaks were measured on the glycolated and the HCl treated samples respectively.

Illite was measured as the area of the untreated 10 A peak, chlorite the area of the glycolated 14 A peak, kaolinite, the area of the HCl treated 7 A peak, and montmorillonite, the difference in area of the 14 A 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 was then computed and converted to parts per ten of the total.

The decision to use the HCl treated value of the 7 A 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.

TABLE 1

SEMIQUANTITATIVE X-RAY ANALYSIS RESULTS

Sample	Calculated per cent			
Sc-	Illite	Chlorite	Kaolin.	Mont.
4-20	80	4	10	6
7-69	88	3	2	7
9-40	80	4	10	6
10-72	84	3	9	4
10-100	82	5	11	2
11-261	85	2	7	6
16-200	85	2	8	5
16-220	86	2	7	5

Experimentation with various concentrations and periods of digestion with warm HCl tended to confirm this assumption but it was found that the complete removal of chlorite could not be proven conclusively even though the 001 and 003 reflections were reduced to background levels. Identical treatment of a standard kaolinite showed a calculated loss due to acid treatment of approximately 25 percent. When this factor was applied to the kaolinite values obtained as above, inconsistencies became apparent. In some cases the corrected intensity was found to be greater than the original value of the untreated kaolinite and chlorite. This could be accounted for in several ways. The standard kaolinite used was derived from the hydrothermal alteration of a granite and thus is not directly comparable in crystallinity nor in variation of composition and, probably, in grain size distribution as well. Because of its high crystallinity, however, it is unlikely that it would be attacked to a greater degree than the recent sedimentary material of the continental slope. For this reason it is assumed that incomplete decomposition of the chlorite had occurred during acid digestion and that the chlorite contribution could conceivably counterbalance the loss of the kaolinite to the acid.

Because of the occurrence of mixed layer expandable clays the delineation of the 14 Å peak on the ethylene glycol treated sample is sometimes difficult, and this may produce further inaccuracies.

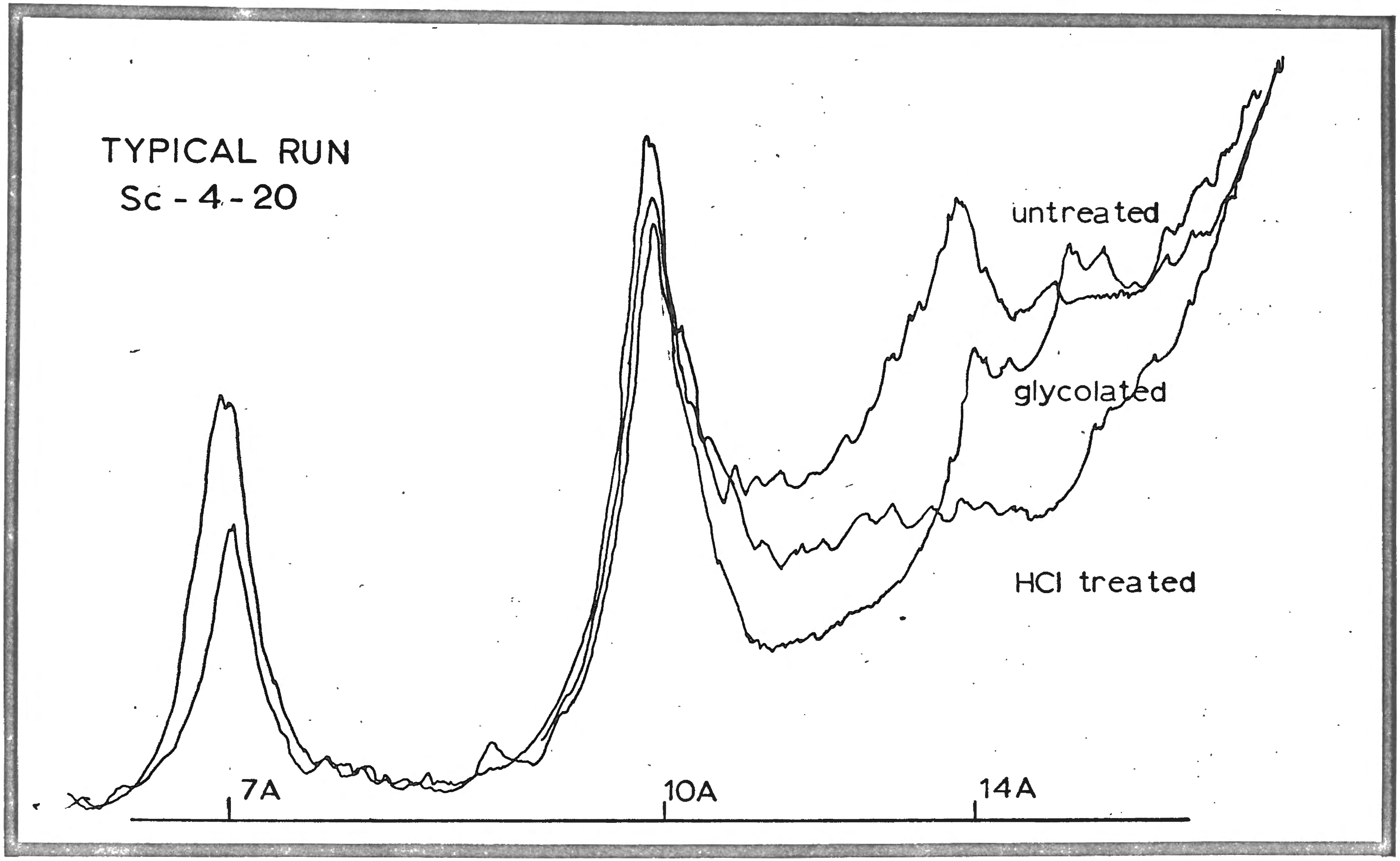


Figure 32. Typical run, Sc-4-20.

Relative percentages of Illite, Chlorite, Montmorillonite, and Kaolinite were obtained for eight samples. Table 1 shows the results of the study.

Illite is the dominant clay mineral, making up 80-87 percent of the samples, if Freas' scattering factors are correct. Kaolinite forms between 2-13 percent, Montmorillonite 3-7 percent, and chlorite between 2-5 percent.

Discussion

This study revealed the uniformity of the clay mineral suite in the slope sediments. The stability of this fraction with time is illustrated by core Sc-16 (Figure 33), and the lateral consistency is shown in the diffractograms of samples taken from different cores (Figure 34). The differences determined in the semiquantitative study are slight and are well within experimental errors of this technique.

Illite is a common clay in soils and is particularly abundant in alkali rich areas such as granitic and metamorphic terrains. Chlorite, kaolinite, and montmorillonite are also developed from the weathering of these rocks in temperate climates (Grim, 1953).

A similar association of clay minerals is reported from the sediments of the Gulf of St. Lawrence by Loring and Nota (1964). These workers reported amphiboles, as well as quartz and feldspar, in the clay fraction. This was used to infer low

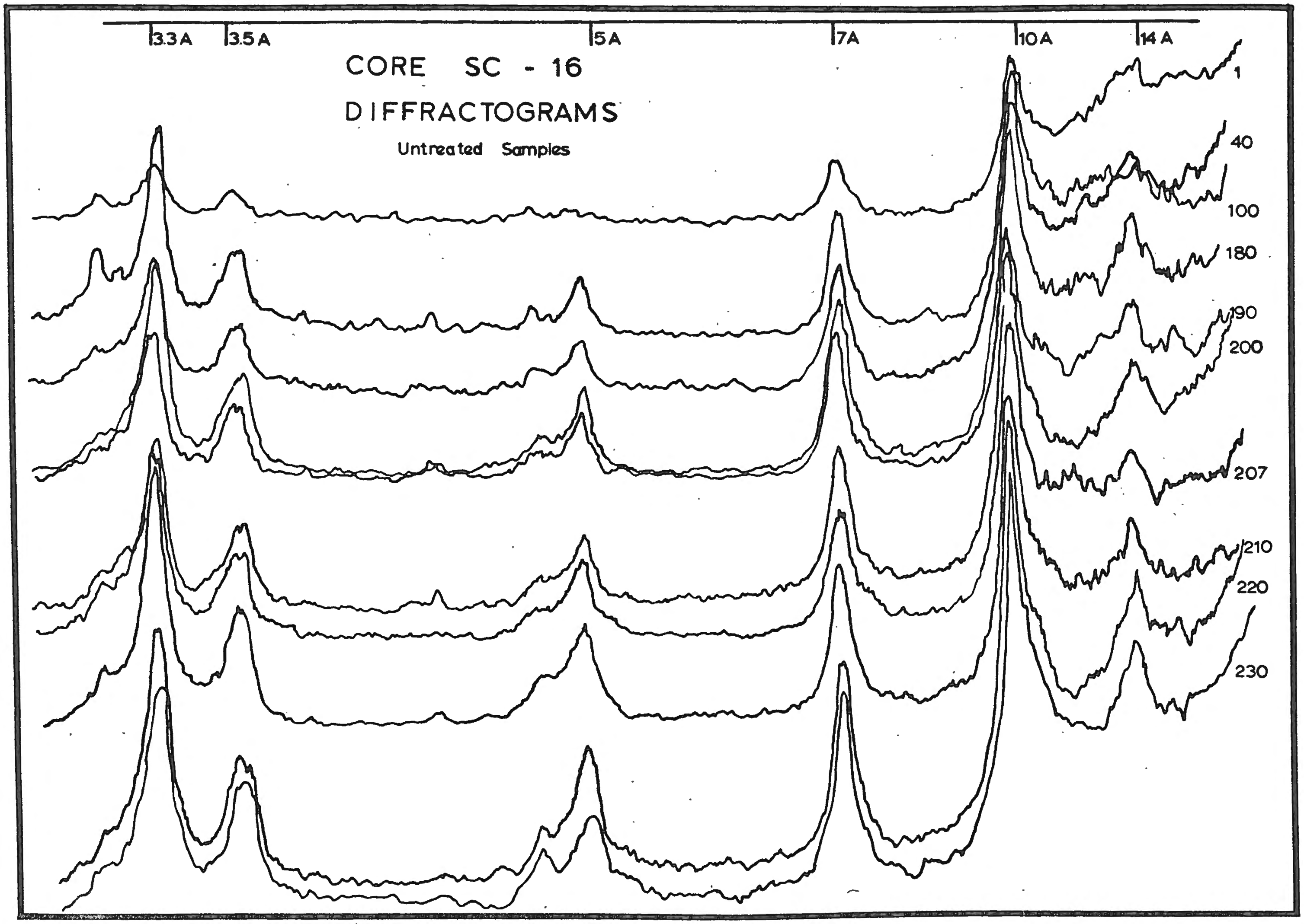


Figure 33. Core Sc-16 diffractograms.

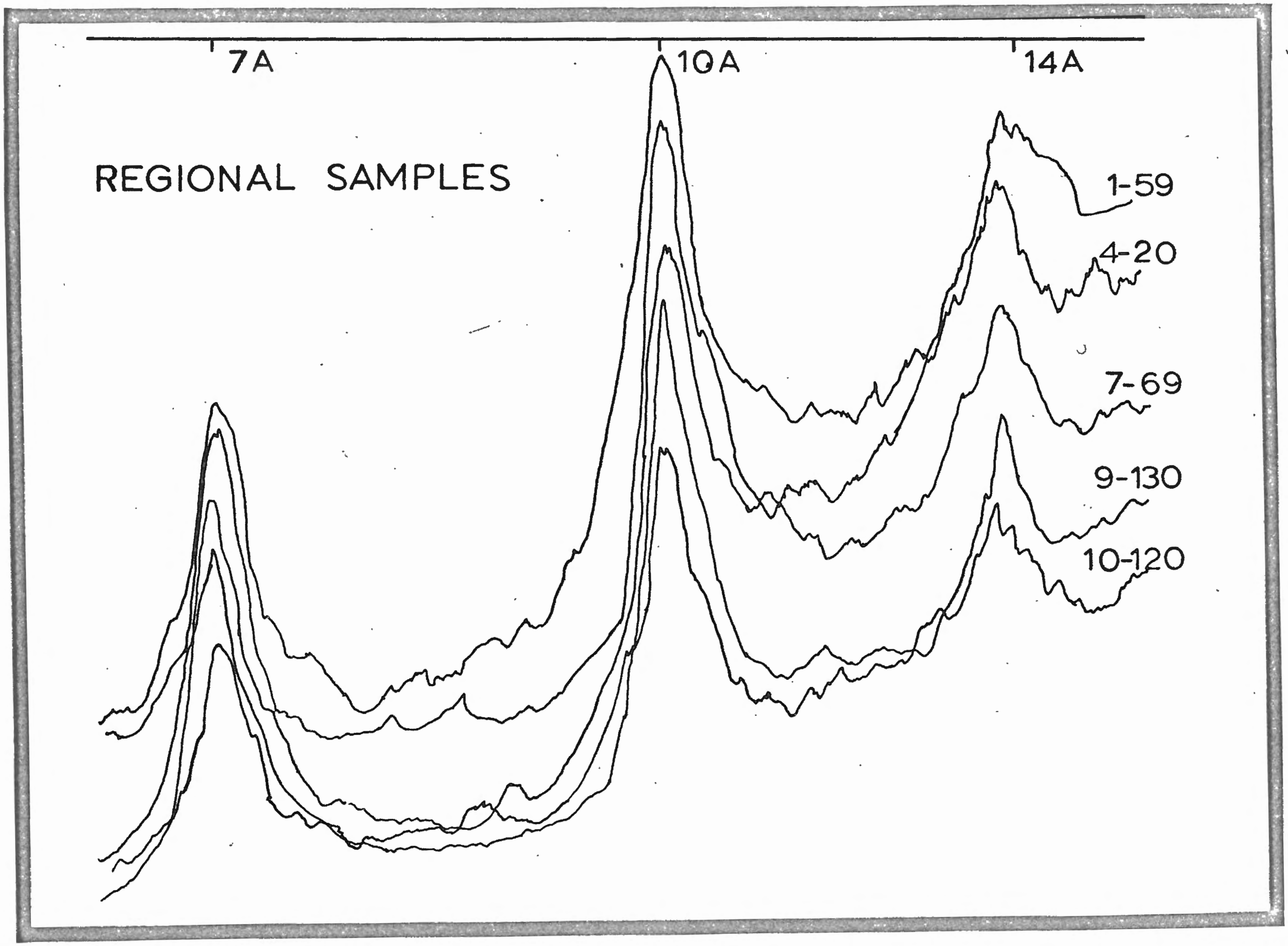


Figure 34. Regional samples.

chemical weathering of the sediments. Unfortunately relative percentages were not determined for the clay minerals (Loring, Personal Communication, 1965) so that a direct comparison cannot be made with the slope sediments.

The striking similarity of all the samples studied indicates a common source for the clay fraction in all the slope sediments. The colour differences represent different oxidation states of iron in the two types of sediment and not different clay mineral suites.

FORAMINIFERAL STUDY

A total of 40 samples, 22 of which were from core Sc-16, were examined by Dr. F. Medioli, who has graciously provided the author with the bulk of the information in this chapter.

Assemblage of Foraminifera

Table 2 lists a total of 31 species found in the samples of continental slope sediment. These represent the species which are common in the samples and do not include foraminifera which are only represented by a few individuals. All the species reported are living in the North Atlantic region at the present time.

Little can be stated concerning the ecology of the foraminifera as they have been poorly studied and the environmental ranges given in the literature are too broad to establish environmental niches. Those species which can be characterized, such as Globigerina pachyderma, Elphidium arcticum, and Nonion labradoricum, indicate that the assemblage is typical of a cold water environment.

TABLE 2

LIST OF FORAMINIFERA

Planktonic

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.)
7. *Sphaeroidina bulloides* d'Orb.

Benthonic

8. *Nonion labradoricum* (Dawson)
9. *Cassidulina norcrossi* Cush.
10. *Cibicides lobatulus* (Walker & Jacob)
11. *Virgulina complanata* Egger
12. *Elphidium arcticum* (Parker & Jones)
13. *Eponides umbonatus* (Reuss)
14. *Globobulimina auricolata* (Bailey)
15. *Cassidulina subglobasa* Brady
16. *Bulimina marginata* d'Orb.
17. *Bolivina subspinescens* Cush.
18. *Bulimina aculeata* d'Orb.

Benthonic (continued)

19. Pullenia bulloides (d'Orb.)

20. Epistomina elegans (d'Orb.)

21. Karreriella brady (Cush.)

22. Uvigerina sp. A - after Cush.

23. Pullenia quinqueloba (Reuss)

24. Reophax atlantica (Cush.)

25. Virgulina fusiformis (Williamson)

26. Buccella frigida (Cush.)

27. Augulogerina augulosa (Williamson)

28. Bulimina exilis Brady

29. Cassidulina neocarinata Thalmann

30. Elphidium incertum (Williamson)

31. Quinqueloculina seminulum Lin.

Stratigraphic Variations

Deep sea quaternary chronology is commonly reflected by variations in colder and warmer water foraminifera. In the Mediterranean area Globigerina pachyderma is considered a marker of colder climatic conditions. Unfortunately, in this area, this species is still living and abundant. Attempts to base a a chronology on the coiling directions of G. pachyderma were without success because left-coiling predominated throughout.

Planktonic : benthonic ratios show significant variations with time (Figure 35). The top and bottom of core Sc-16 have relatively high ratios, with maxima at 80 and 240 centimeters. 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 reduction in benthonic forms, which could result from an increased sedimentation rate with an accompanying deterioration of bottom conditions.

A study of the distribution of the individual species has provided the most information of a stratigraphic nature. In core Sc-16 a total of 29 species were observed. Many of these occur throughout the core but a significant change occurs at a depth of approximately 80 centimeters. Within a range of 70 centimeters, 8 species disappear and 11 species first appear. 3 other species make their appearance within a slightly broader range (See Figure 35). This change corresponds with the position of the younger planktonic-benthonic maxima. It also corresponds with the position

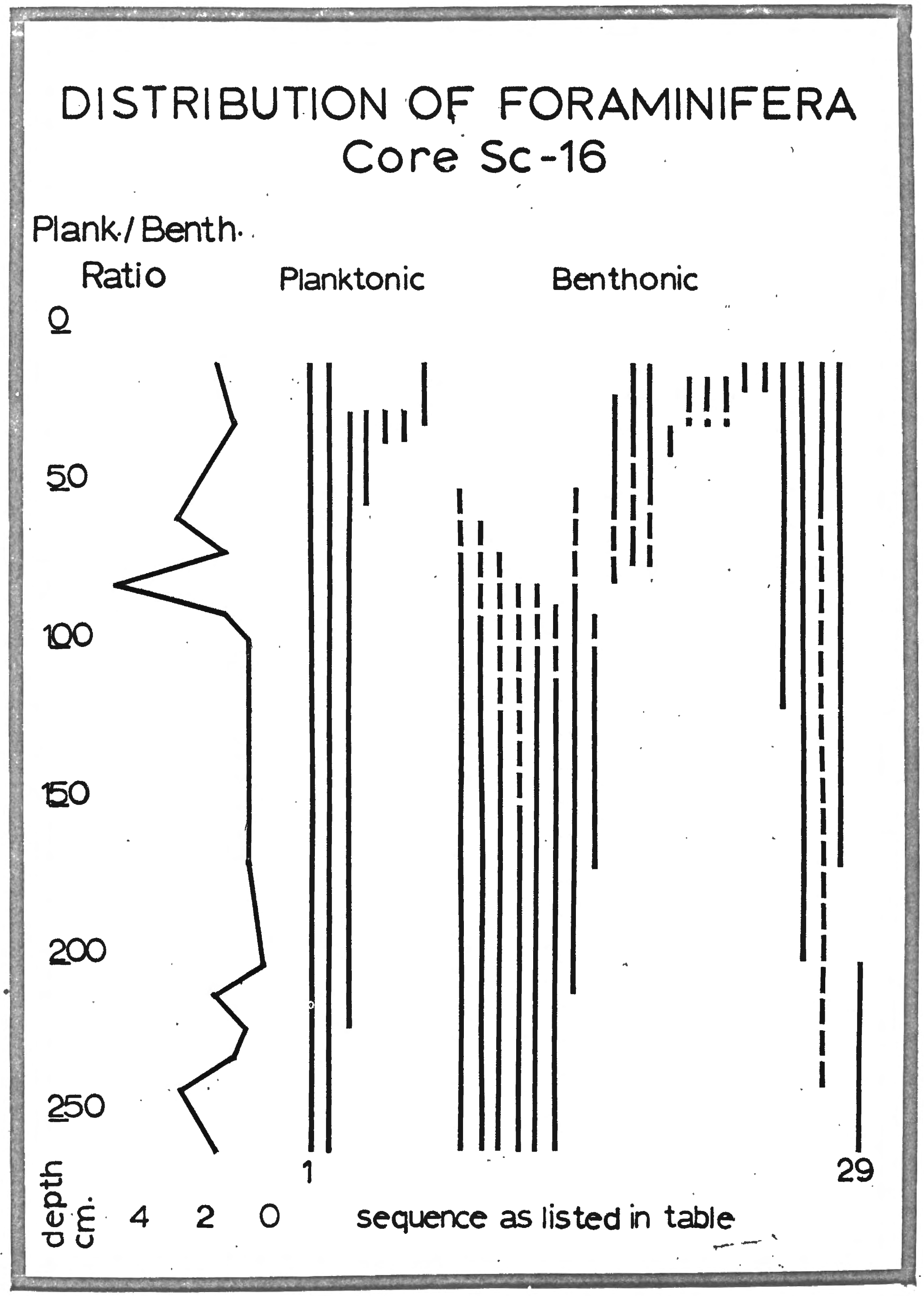


Figure 35. Distribution of foraminifera in core Sc-16.

of the change from cold to warmer water conditions reported by Heezen and Ericson (1964) in a very similar core taken in the Laurentian Channel. Cores taken on the continental rise off Nova Scotia showed this boundary at about 50 centimeters depth (Ericson et al., 1961). This change is assumed to represent the period of rapid rise in sea level at the end of the Wisconsin glaciation. Conolly (1965) has reported a date of 25,000 B.P. for the top of the brown sediment which in core Sc-16 occurs at a depth of 209 centimeters. This would indicate that a position of the Recent : Pleistocene boundary at approximately 80 centimeters is probably correct.

Heezen and Ericson report no climatic change across the grey-brown contact. In core Sc-16, a change involving three species has been observed close to the contact but the significance of this change cannot be understood without further study. Textural considerations suggest that the sharp increase in the proportion of planktonic species in the brown sediment may be the result of an increased sedimentation rate.

Dr. Medioli is continuing the study of the foraminifera of the Nova Scotian continental margin and a more definite interpretation may soon be possible.

SUMMARY AND CONCLUSIONS

Three distinct sediment types have been recognized in this study of the upper continental slope sediments.

The deepest material penetrated was a reddish-brown sediment. It was recovered only on topographic highs, indicating that it was not thickly covered by subsequent sedimentation on these regions, or that erosion has removed most of the covering sediment.

This sediment is a poorly sorted sand-silt-clay which may contain as much as 50 percent sand and 15 percent fine pebbles. The texture varies rapidly over short distances in the cores, indicating deposition by fluctuating currents. This mixture of coarse and fine grained material is difficult to explain by normal current processes. Highly competent processes, such as ice rafting or gravity movements, are required to produce such a sediment in the relatively great depths of the continental slope. The rapid textural fluctuations, and the lack of a marked bimodal size distribution, suggests that gravity processes are the more likely mechanism.

This type of sedimentation generally involves rapid rates of deposition. This is indicated in the brown sediment by the partial preservation of internal structures, the scarcity of pelagic components, the poor sorting and occurrence of coarse-grained material, and the dominance of planktonic over benthonic foraminifera.

The reddish-brown colour of the sediment is due to the presence of ferric ions. The preservation of these oxidation states indicates that the sediment passed rapidly through the strong reducing environment which occurs close to the water-sediment interface.

The greenish grey sediment, which was next deposited, is mineralogically very similar to the underlying brown material. Both contain similar coarse fractions, and their clay suites are indistinguishable. This indicates that the colour difference is due to a slower passage through the water sediment interface; in other words, a slower rate of sedimentation. The persistence of small amounts of red rock fragments is explained by the relative resistance of coarse particles to chemical processes.

Other factors demonstrate the slower rate of sedimentation. The scarcity of internal structures reflects a gradual reworking of the sediment by bottom dwelling organisms. Deposition was sufficiently slow to permit the accumulation of benthonic foraminifera and other pelagic components. The absence of coarse grained materials, and the occurrence of gradual changes in texture, strongly indicates that slow, uniform sedimentation from suspension and possibly weak bottom currents, prevailed during the deposition of the grey sediment type.

It is important to note that the brown sediment, occasionally found within the grey sediment sections, is generally fine grained, and petrographically similar to the grey sediment. These occurrences are interpreted as representing local variations in the environment of deposition. A shift of the strong reducing zone to a position above the sediment interface, or short periods of more rapid sedimentation, could explain these occurrences.

A gradual increase in the proportion of sand sized material towards the surface of the grey sediment was noted in many cores. The thin surface sand layer probably represents an intensification of the processes which caused this trend in the grey sediment type.

The surface sand layer was found in small quantities in several cores and its significance has not been firmly established by this reconnaissance study. Interpretation of its depositional history is difficult because the few samples studied provide ambiguous information. These layers were recovered very often from topographic highs. This would suggest that the high sand content, and the increase in this fraction within the grey sediment, is due to an increase in the winnowing of fines by bottom currents. The absence of abundant pelagic components, however, indicates rapid deposition, rather than an origin through relatively passive winnowing.

Several factors indicate that a progressive change in conditions of the source area is responsible for this change in the sediments. The median diameter of the sediments on the edge of Sable Island Bank lies between 125 and 350 microns. The surface sand layer on the slope shows a similar median diameter while the sand fraction of the top layers of grey sediment have median diameters between 125 and 63 microns. This suggests that the grey sediment was derived from the fine fraction of the shelf sediment. The gradual reduction of the fine fraction at the source, coupled with an increase in bottom current velocities, would explain the increase in the proportion of sand carried to the slope.

The surface sand layer would then represent a sudden increase in the intensity of bottom currents so that the lag material on the shelf is now being gradually redeposited on the slope. Another explanation would be that these sands represent material swept off the shelf edge by intermittent storm waves.

Only one sample of the surface sands was recovered from the valleys on the slope although these valleys would be expected to channel much of the sediment deposited on the slope. A possible explanation for this apparent incongruity could be that the sand deposited on the sides of the submarine valleys would tend to be rapidly carried to the very axes of the valleys, while the sand laid down on the relatively flat tops of the intervening rises would be difficult to remove. Precision positioning was not possible during the sampling program and it is very likely that only one core was taken exactly on the axes of a valley. If this problem is to be resolved, future investigators should pay particular attention to this operational difficulty.

It is difficult to prove whether the adjacent continental shelf was indeed the source of the slope sediments or if these sediments represent material which has bypassed the Scotian shelf.

Red rock fragments, coal, and high hornblende : garnet ratios the provenance indicators of the slope sediments occur in the sediments on the northeastern portion of the shelf but not on the adjacent Sable Island Bank. The similarity of the clay fraction in the Gulf of St. Lawrence region also suggests a transport from the northeast. Red beds outcrop on Prince Edward Island and in Cape Breton. Coal mining is a major industry in Cape Breton.

Faunal evidence indicates that the brown sediment was probably deposited during the height of the Wisconsin glaciation and that the grey sediment was deposited at the end of the Pleistocene and through the beginning of Recent time. It is very probable that the sediments of the northeast shelf were deposited by glacial processes and that similar sediments were transported to the very edge of the shelf.

The outer banks region of the Scotian shelf is relatively shallow and almost certainly was exposed to active erosion during the lower stands of sea level. It is apparent that the brown sediment, being deposited by gravity processes on the continental slope at this time, was derived from this region. The period of littoral erosion, which probably accompanied the transgression of the sea at the end of the Wisconsin glaciation, also would have promoted the transfer of sediment over the edge of the shelf

As the level of the sea rose above the banks and littoral activity ceased, the abundant supply of sediment to the slope was cut off, to that which could be carried by normal, low density currents. This situation was reflected on the slope by the slower sedimentation of the grey sediment.

The similar sediments of the continental slope and northeastern shelf are presently separated by what are considered to be reworked Tertiary deposits. The uncovering of these sediments on the outer banks region indicates the degree to which erosion has stripped away the glacially derived sediment.

The association of the banks region on the shelf with vigorous slope sedimentation is very interesting. It should be noted that the valleys on the continental slope also have an apparent relation to the banks. The change in character of the slope topography to an even, featureless slope coincides almost perfectly with the southwestern edge of Sable Island Bank. Very large slump blocks have been noted on seismic profiling records of the continental slope south of Nova Scotia. No such records are available for the present study area, but it is interesting to speculate that the small scale gravity processes, which are suggested as the means of of deposition of the brown sediment, were associated in time with the formation, or reshaping, of the submarine valleys by large scale mass movements.

The resolution of this problem, and many others, such as the origin of the surface sand layer, and the variations within the grey and the brown sediments, was beyond the scope of this reconnaissance study. It is hoped, however, that a more detailed investigation will be carried out in this interesting region on the basis of this initial interpretation.

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APPENDIX

SAMPLE LOCATIONS AND CORE LOGS

Core Sc-1

Location: 43°32.0 N, 60°01.0 W

Depth: 400 fathoms

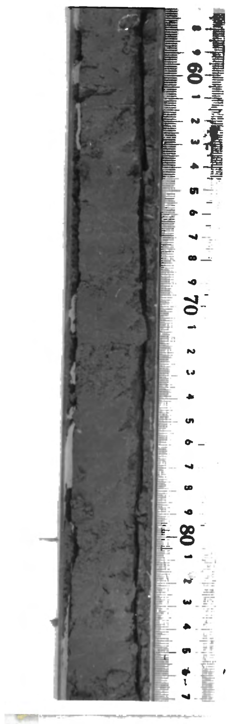
Total Length: 237 cm.

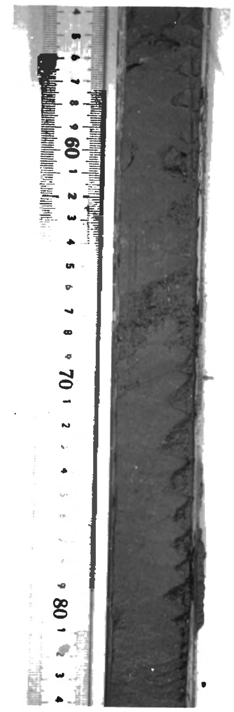
Core Log

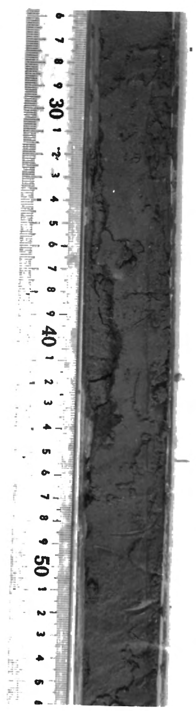
0-45 cm.: Olive grey, 5Y 3/2, homogeneous silt with a few shell fragments and black streaks.

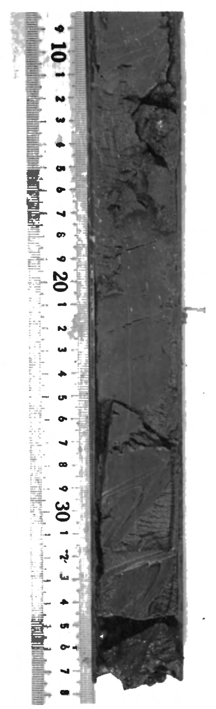
45-237 cm.: Gradational to 5GY 3/2, homogeneous silt with shell fragments and black streaks. Pelecypod shell at 59 cm.

Sampled at: 2, 59, 125, 210 cm.









Core Sc-2

Location: 43°34.0 N, 60°05.0 W

Depth: 310 fathoms

Total Length: 258 cm.

Core Log

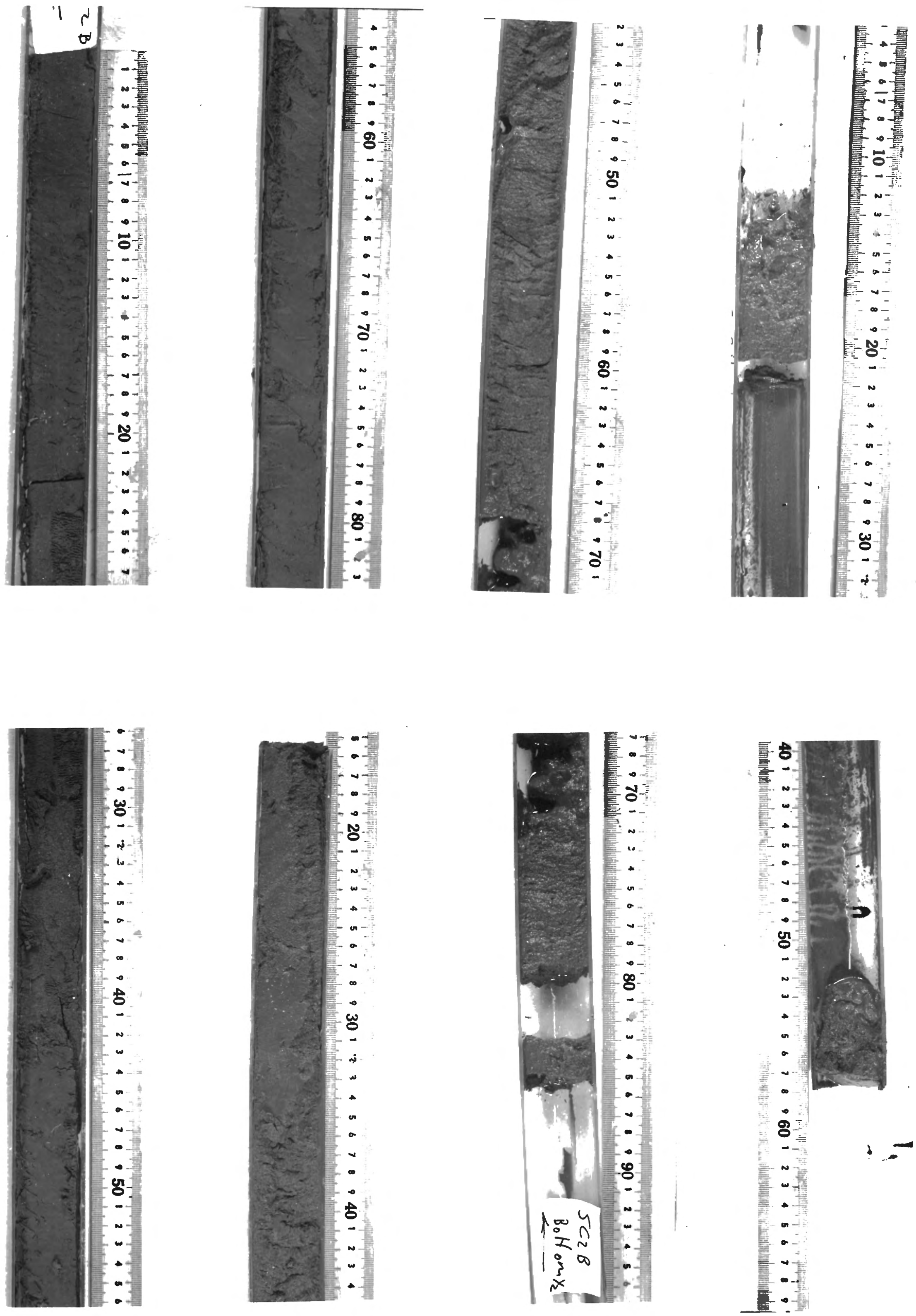
0-21.5 cm.: Olive grey, 5Y 4/1, homogeneous clayey silt. Black streaks between 0 - 3 cm.

21.5-44 cm.: Same but dried along crack, greyish olive, 10Y 4/2

44-179 cm.: Same as top of core.

179-258 cm.: Greyish Olive green, 5GY 3/2, homogeneous clayey silt. Gaps occur at 185.5-213, 220.5-253 cm.

Sampled at: 1, 50, 110, 160 cm.



Core Sc-3

Location: 43°34.0 N, 60°03.5 W

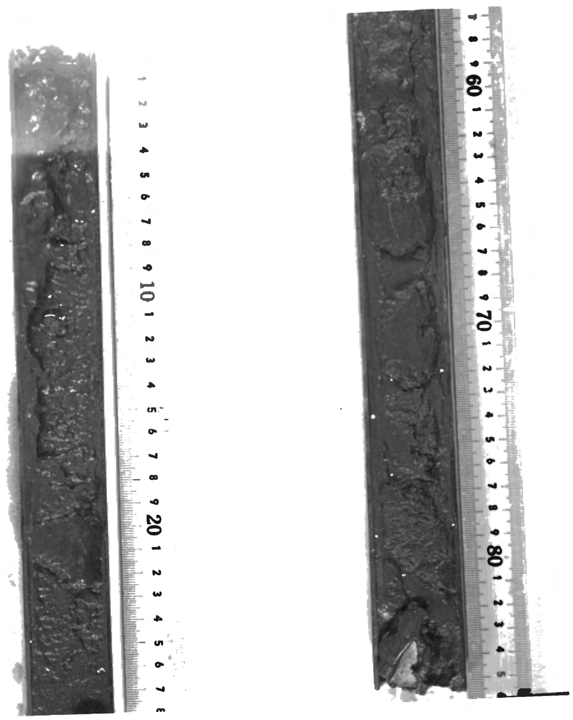
Depth: 250 fathoms

Total Length: 84.5 cm.

Core Log

0-84.5 cm.: Olive grey, 5Y 3/2, slightly sandy homogeneous mud.

Sampled at: 1, 60 cm.



Core Sc-4

Location: 42°58.0 N, 61°33.5 W

Depth: 385 fathoms

Total Length: 109 cm.

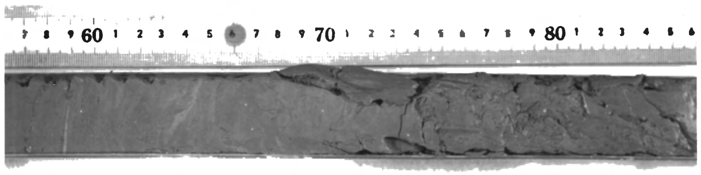
Core Log

0-10 cm.: Sand

10-74 cm.: Greyish brown, 5YR 3/2, clayey silt, with a number of thin bands of medium and light brown sediment and thin sand partings.

Sampled at: 0, 20, 100 cm.

74-109 cm.: Same as above but shows increasing distortion towards the bottom.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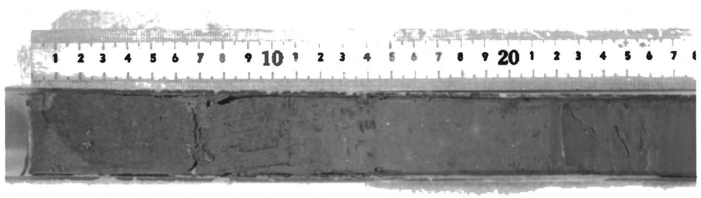
70
80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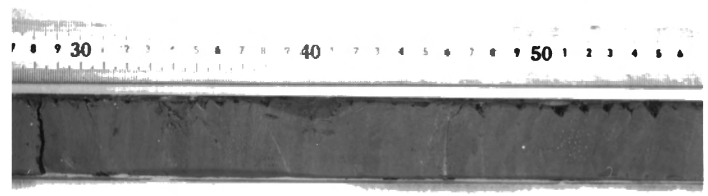
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50

Core Sc-5

Location: 43°09.7 N, 61°16.0 W

Depth: 490 fathoms

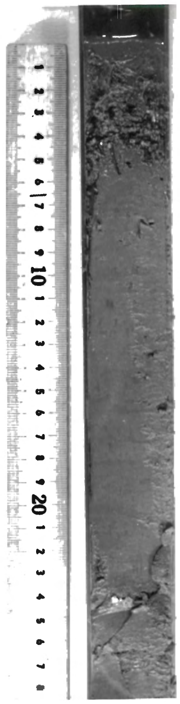
Total Length: 59 cm.

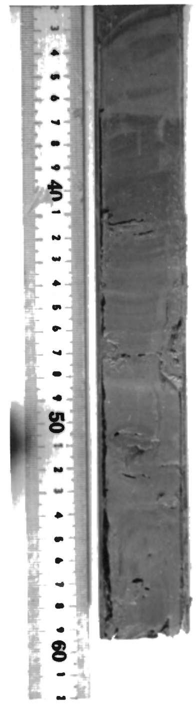
Core Log

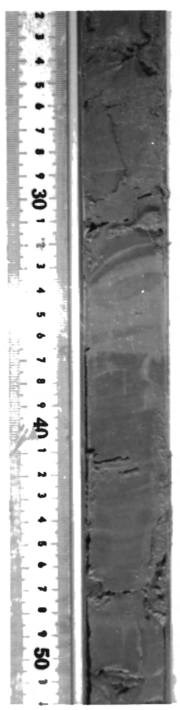
0-5.5 cm.: Sand

5.5-38 cm.: Olive grey, 5Y 4/1, clay

38-59 cm.: Predominantly Olive green clay, 5 GY 3/2, series of fine interbanded lighter green layers.







Core Sc-6

Location: 43°13.0 N, 61°16.7 W

Depth: 270 fathoms

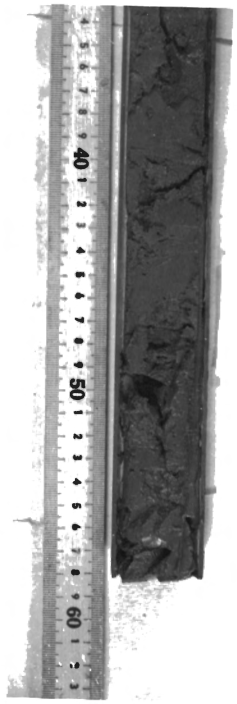
Total Length: 158 cm.

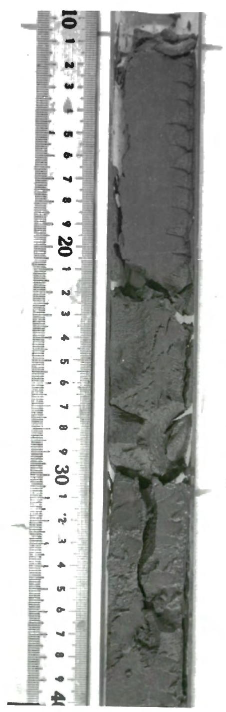
Core Log

0-158 cm.: Greyish olive green, 5GY 4/2, silt with scattered sandy zones and shells.

Sampled at: 1, 56, 125 cm.







Core Sc-7

Location: 43°12.7 N, 61°05.6 W

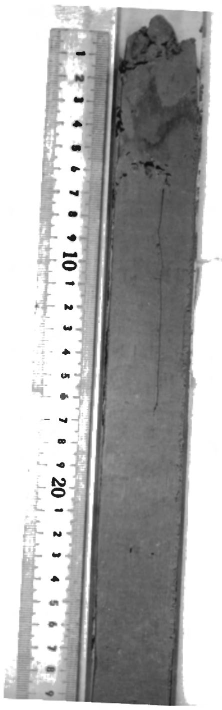
Depth: 450 fathoms

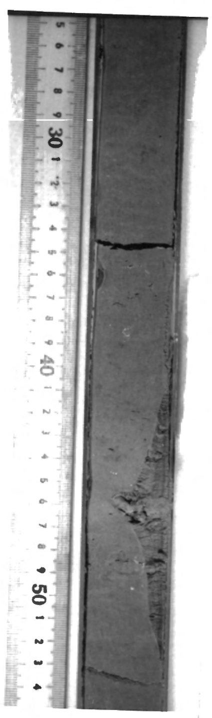
Total Length: 69 cm.

<u>Core Log</u>

0-69 cm.: Dark greenish grey, 5GY 4/1, homogeneous clayey silt with pebbles at 6-7, and 43 cm.

Sampled at: 10, 56, 67 cm.





Core Sc-8

Location: 43°15.2 N, 61°09.2 W

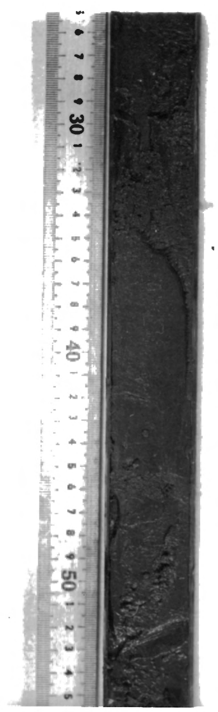
Depth: 410 fathoms

Total Length: 57 cm.

Core Log

0-57 cm.: Olive grey, 5Y 3/2, homogeneous silty clay.

Sampled at: 0, 50 cm.



Core Sc-9

Location: 43°07.5 N, 61°15.0 W

Depth: 520 fathoms

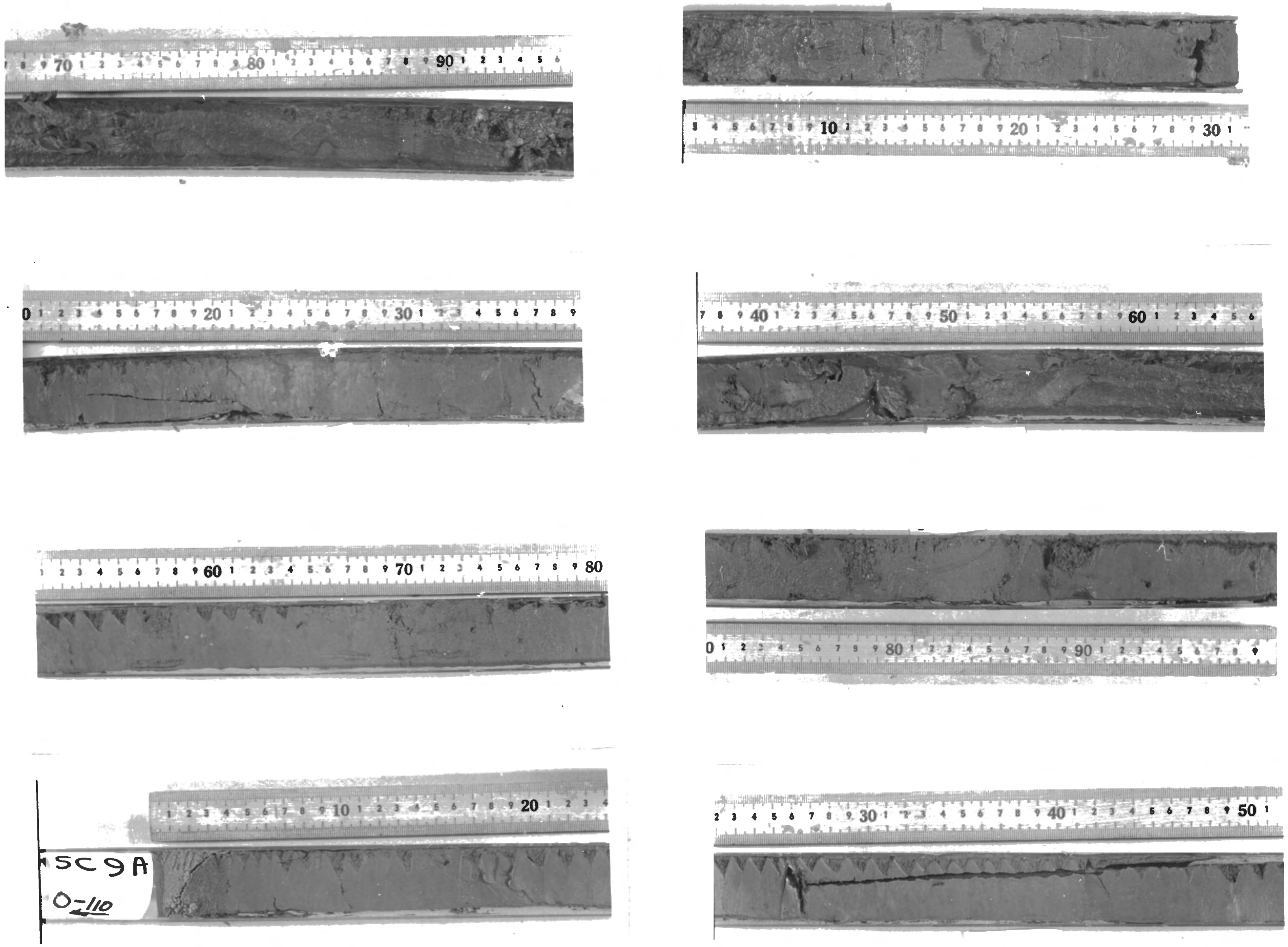
Total Length: 231 cm.

Core Log

0-4 cm.: Sand

4-231 cm.: Dark yellowish brown, 10YR 4/2, grading to slightly redder than pale brown, 5 YR 5/2, sandy silt with zones of varying sand content, occasional shells, sand partings, and red mottled.

Sampled at: every 10 cms.


SC 9A
0-110

Core Sc-10

Location: 43°07.5 N, 61°17.0 W

Depth: 670 fathoms

Total Length: 285 cm.

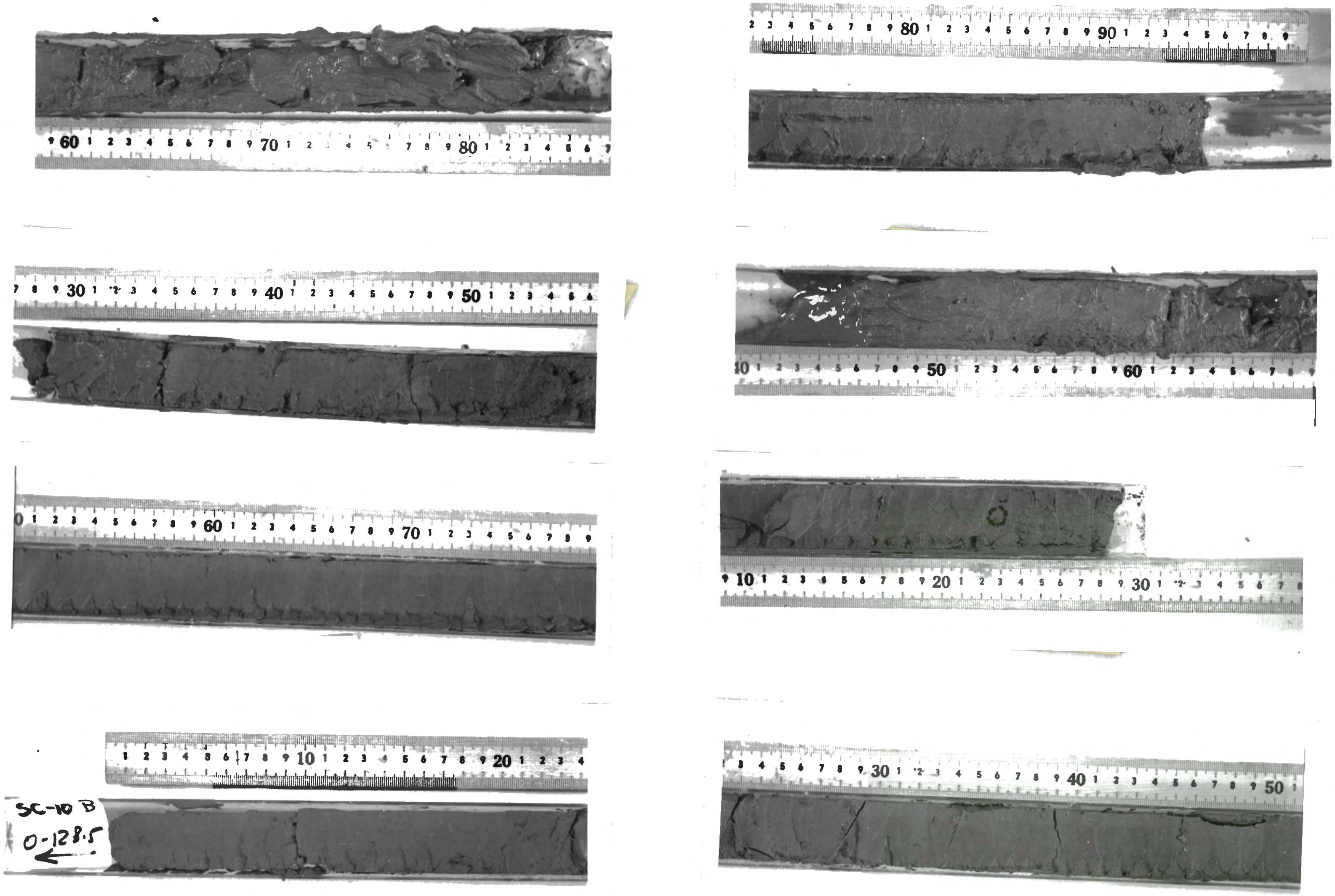
Core Log

0-34 cm.: Grayish olive green, 5 GY 3/2, light olive grey, 5Y 5/2 when dried, silty clay with scattered small black mottles.

34-129 cm.: Same as above but increased mottling, worm tube at 123 cm.

129-285 cm.: Greyish olive, 10Y 4/2 to 3/2, silty clay with scattered black mottles. Gap between 195 and 244 cm.

Sampled at: every 10 cms.


SC-10 B
0-128.5

Core Sc-11

Location: 43°24.0 N, 59°58.0 W

Depth: 550 fathoms

Total Length: 296 cm.

Core Log

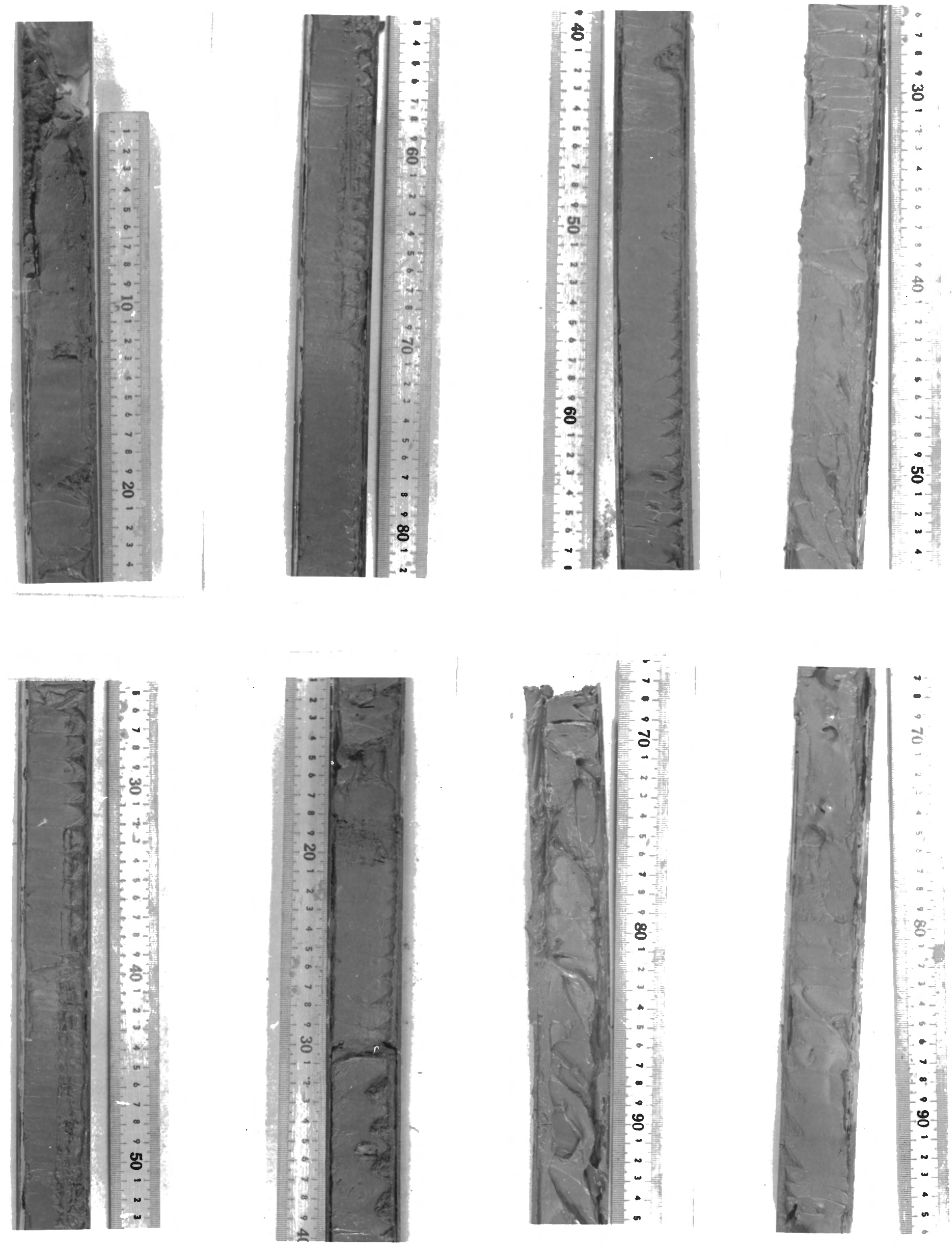
0-8.5 cm.: Olive grey, 5Y 4/2, sandy clay.

8.5-18.5 cm.: Finely interbanded grey and brown, silts, silty clays, and sandy silts.

18.5-163 cm.: Gradational from pale brown, 5 YR 5/2, to Greyish brown, 5YR 3/2, silty clay with occasional black mottles. Sand partings between 91 and 135 cm.

163-296 cm.: Olive grey, 5Y 4/2, homogeneous clayey mud.

Sampled at: 4, 21, 261 cm.



Core Sc-12

Location: 43°29.3 N, 59°56.1 W

Depth: 670 fathoms

Total Length: 196.5 cm.

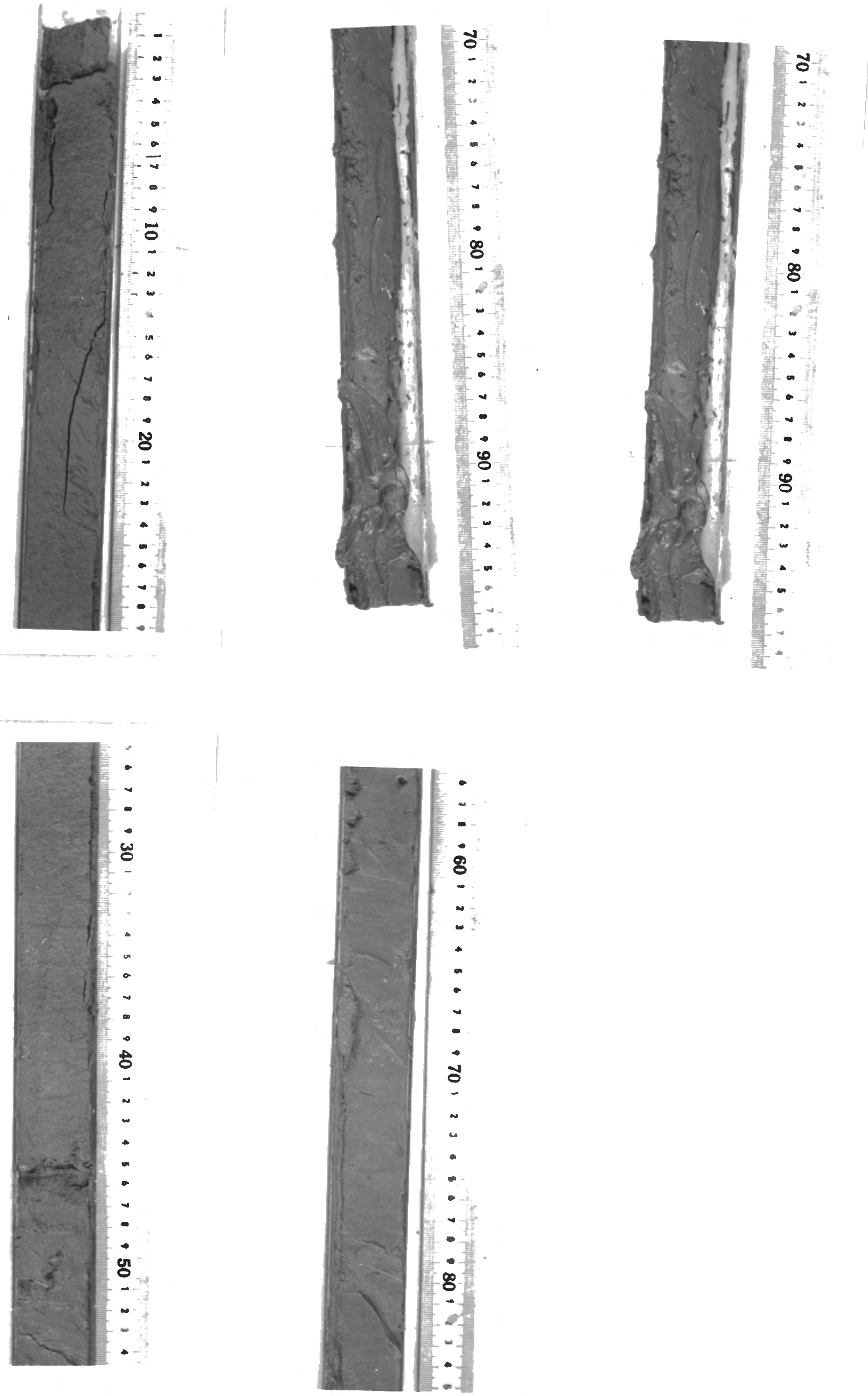
Core Log

0-48 cm.: Olive grey, 5Y 4/1, Dark yellowish brown, 10YR 4/2 where dry, clayey mud, homogeneous.

48-92 cm.: Olive grey, 5Y 4/1, grading to Dark grey, 5GY 4/1, homogeneous silty clay.

92-196.5 cm.: Dark grey, 5GY 4/1, grading to Olive grey, 5G 4/1, homogeneous clayey silt.

Sampled at: 0, 50, 100, 180 cm.



Core Sc-13

Location: 43°21.2 N, 60°28.3 W

Depth: 330 fathoms

Total Length: 104 cm.

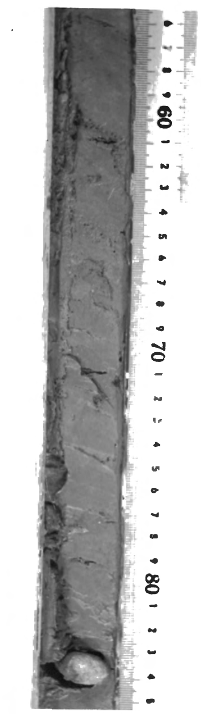
Core Log

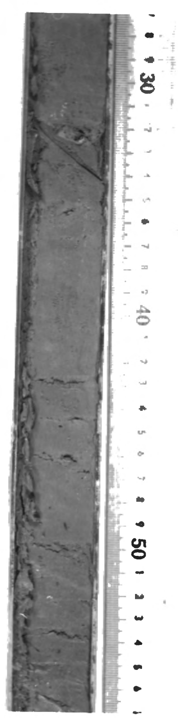
0-7 cm.: Sand and pebbles, slightly muddy below 4 cm.

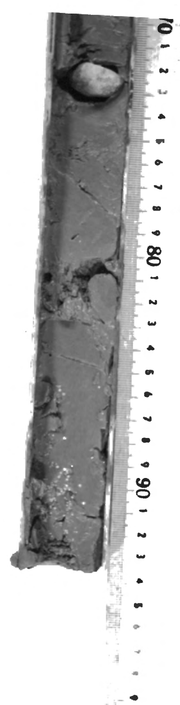
7-13 cm.: Silty sand, Olive grey, 5Y 3/2.

13-104 cm.: Dark yellowish brown, 10YR 4/2, silty clay with small black mottles, sand partings at 35, 71 cm., large pebble at 82-83 cm.

Sampled at: 0, 5, 20, 50 102 cm.







Core Sc-14

Location: 43°19.9 N, 60°26.7 W

Depth: 680 fathoms

Total Length: 141.5 cm.

Core Log

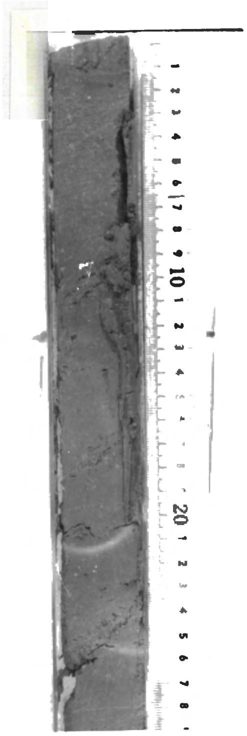
0-11.5 cm.: Medium olive grey, 5Y 4/2, with streaks of Olive black, 5Y 2/1, silty clay, homogeneous.

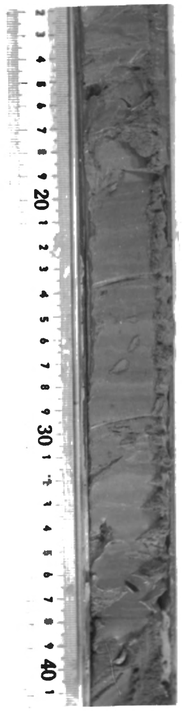
11.5-12.5 cm.: Olive grey, 5Y 5/1, clay.

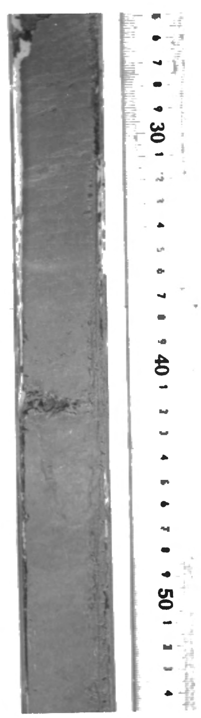
12.5-104 cm.: Medium olive grey, 5Y 4/2, homogeneous silty clay, clay parting at 41.5 cm.

104-113 cm.: Gradational to Dark greenish grey, 5GY 5/1, homogeneous silty clay.

113-141.5 cm.: Series of finely laminated grey, green, brown, and bluish grey silty and clayey muds.







Core Sc-15

Location: 43°19.7 N, 60°29.0 W

Depth: 400 fathoms

Total Length: 78 cm.

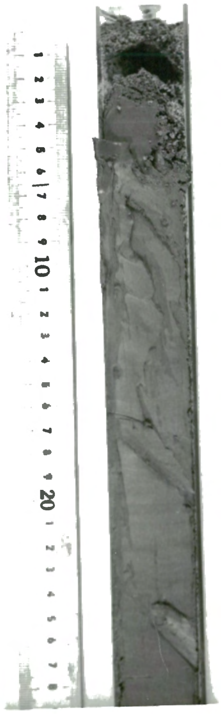
Core Log

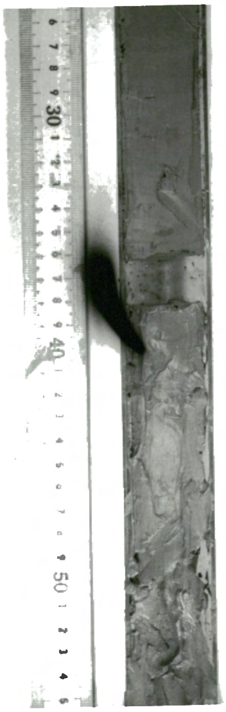
0-3.5 cm.: Sand and pebbles.

3.5-42.5 cm.: Olive grey, 5Y 3/2, homogeneous clay, gap between 36.5 and 38.5 cm.

42.5-78 cm.: Brownish grey, 5YR 4/1, homogeneous clayey silt.

Sampled at: 0, 7, 45 cm.





Core Sc-15-2

Location: 43°05.5 N, 61°27.5 W

Depth: 330 fathoms

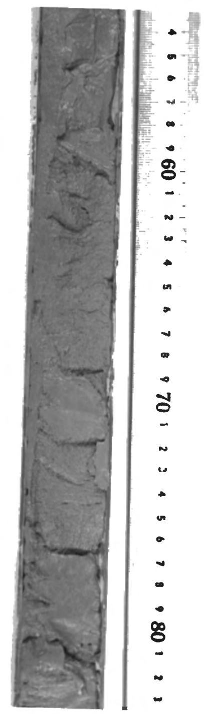
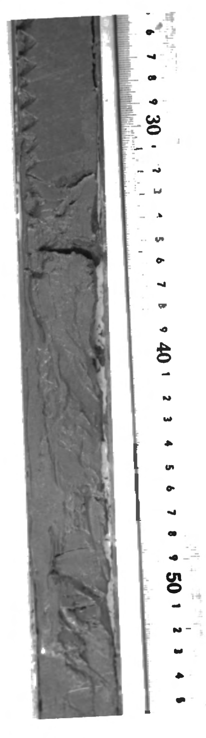
Total Length: 169.5 cm.

Core Log

0-0.8 cm.: Dark yellowish brown, 10YR 4/2, silty clay.

0.8-169.5 cm.: Greyish olive, 10Y 4/2, homogeneous slightly silty clay, mottling occurs below 84 cm., shell fragment at 127.5 cm.

Sampled at: 0, 70, 167 cm.


Core Sc-16

Location: 42°55.5 N, 61°36.5 W

Depth: 290 fathoms

Total Length: 265 cm.

Core Log

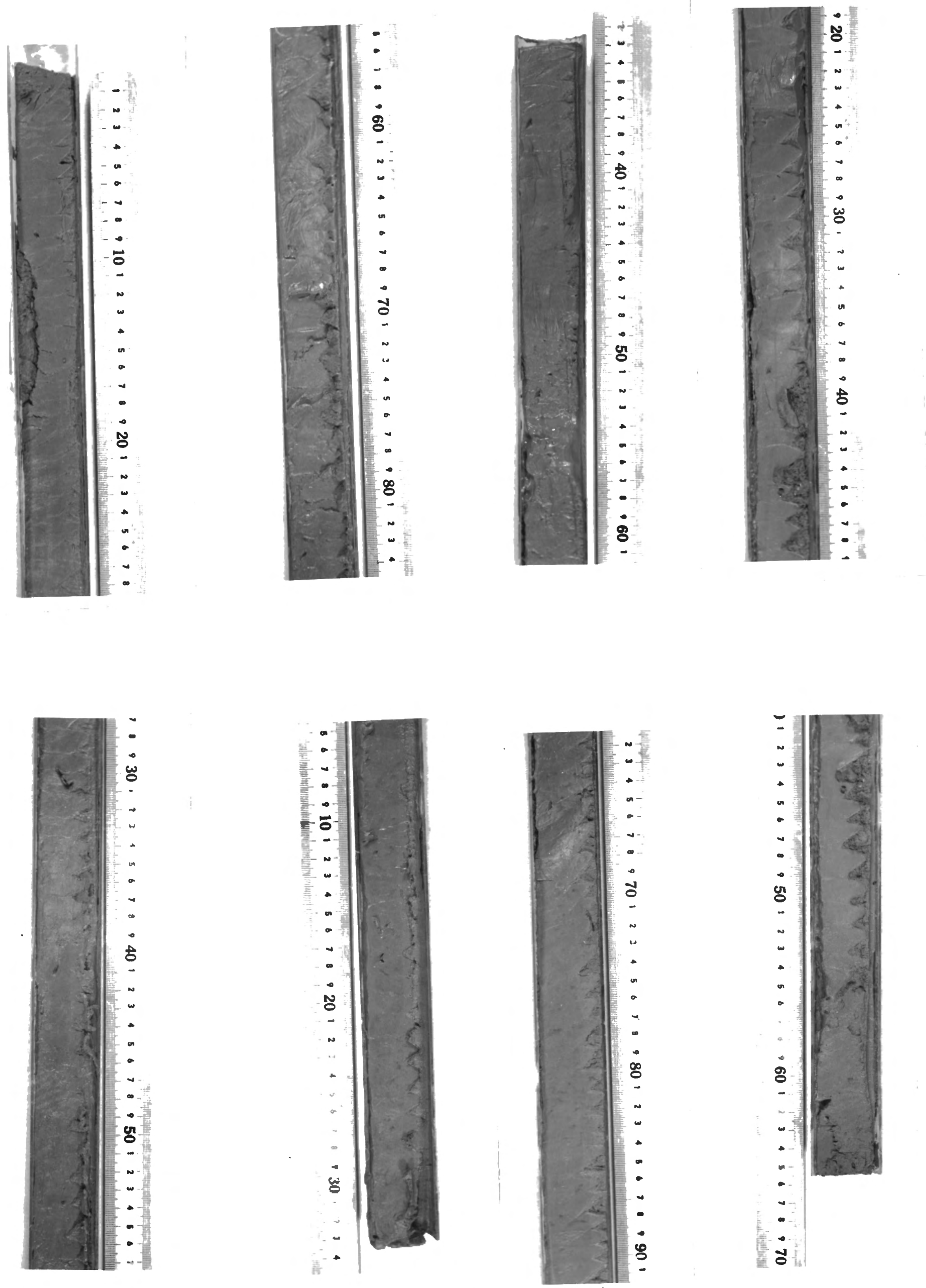
0-95.5 cm.: Olive grey, 5Y 4/1, slightly silty homogeneous clay.

95.5-157 cm.: Same as above with abundant reddish mottles. Sandy partings between 104-109 cm.

157-209 cm.: No mottling but more silty.

209-265 cm.: Greyish brown, 5YR 4/2, sandy silt with pebbles.

Sampled at: every 10 cms.



Core Sc-17

Location: 42°59.3 N, 61°41.0 W

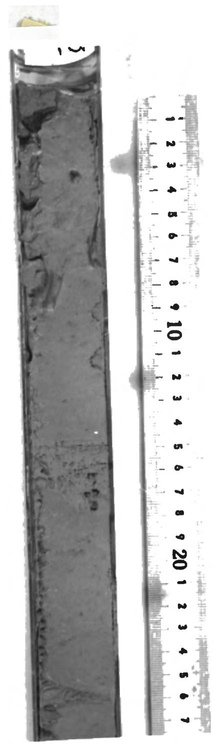
Depth: 210 fathoms

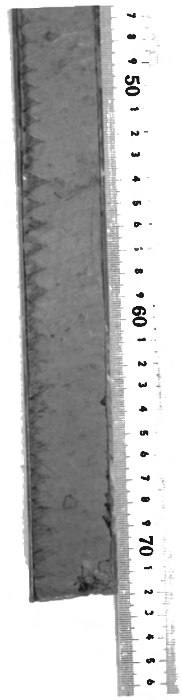
Total Length: 72 cm.

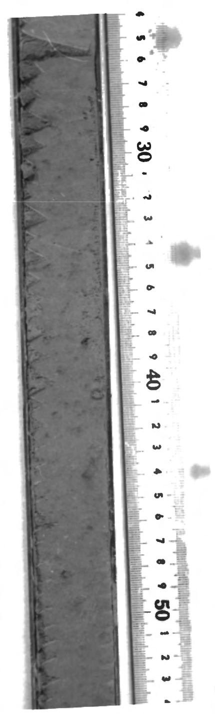
Core Log

0-72 cm.: Dark greenish grey, 5GY 4/1, coarse silty clay with scattered patches of Olive grey, 5Y 3/2, sandy silts, brown pod at 4.5 cm., pebble at 38 cm.

Sampled at: 3, 69 cm.







Core Sc-18

Location: 43°00.5 N, 61°30.5 W

Depth: 440 fathoms

Total Length: 281.5 cm.

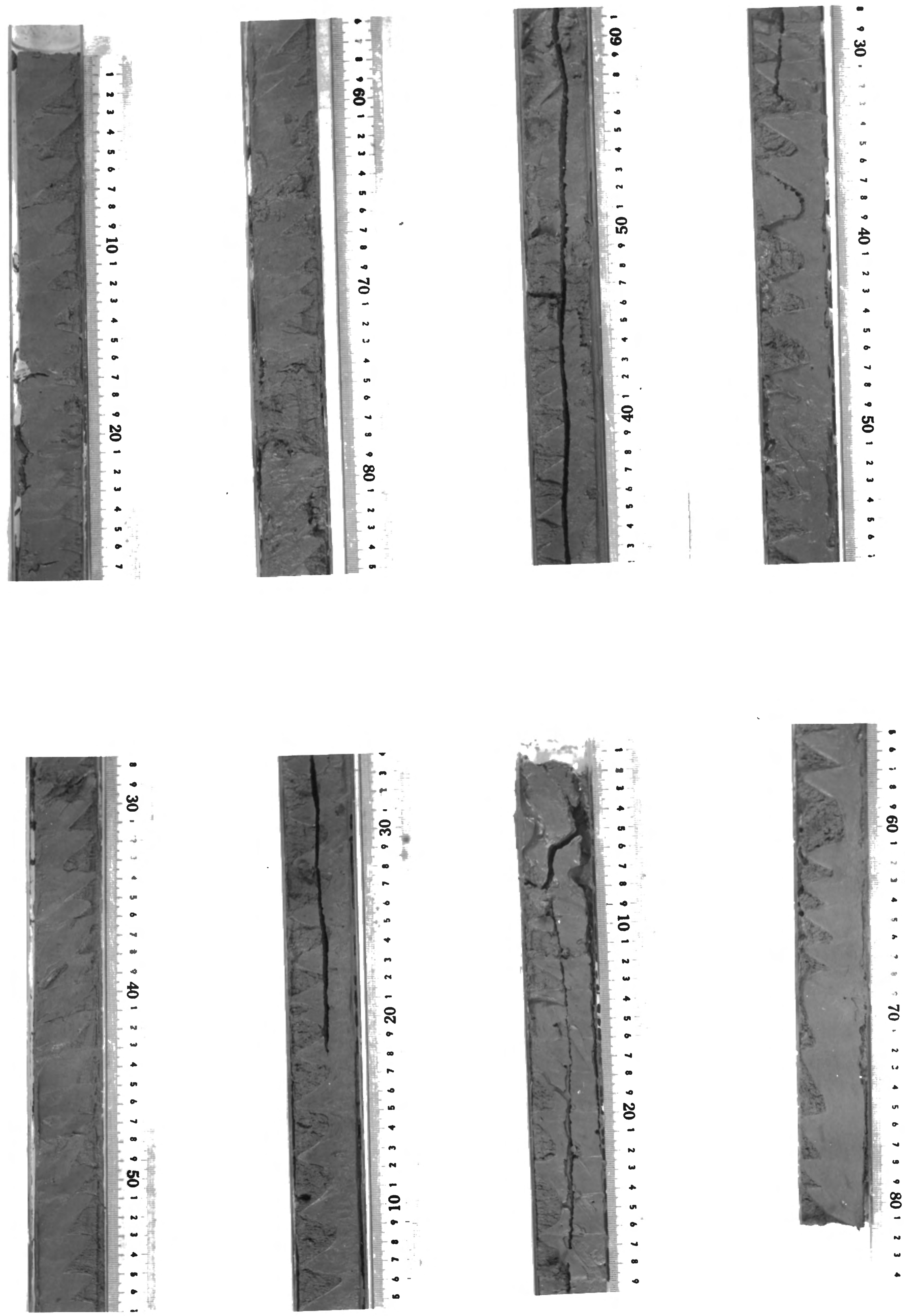
Core Log

0-173.5 cm.: Olive grey, 5Y 4/1, homogeneous silty clay, shell at 110.5 cm.

173.5-190 cm.: Dark yellowish brown, 10YR 4/2, homogeneous silty clay. Worm burrows between 177-190 cm.

190-281.5 cm.: Olive grey, 5Y 4/1, silty clay with brownish grey mottles below 202 cm., Olive grey sandy layer at 232-233.5 cm.

Sampled at: 4, 175, 237 cm.



Core Sc-19

Location: 43°03.3 N, 61°26.0 W

Depth: 630 fathoms

Total Length: 237 cm.

<u>Core Log</u>

0-18 cm.: Olive grey, 5Y 4/1, slightly silty clay.

18-143 cm.: Between Olive grey and Dark greenish grey, 5GY 4/1, slightly silty clay. Mottled below 63 cm.

143-180 cm.: Grades to Olive grey.

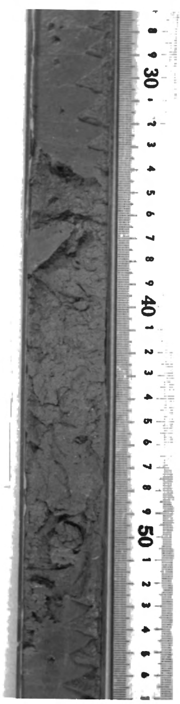
180-222 cm.: Grades to Dark greenish grey.

222-237 cm.: Olive grey.

Sampled at: 2, 100, 200 cm.







Core Sc-20

Location: 43°07.3 N, 61°24.5 W

Depth: 345 fathoms

Total Length: 260 cm.

Core Log

0-2 cm.: Sand

2-28 cm.: Dusky yellow green, 5GY 5/2, and Greyish Olive green, 5GY 3/2 mottles, coarse silt.

28-143 cm.: Mottling lost, colour between the two.

143-260 cm.: Return of mottling with irregular bands.

Sampled at: 0, 120, 230 cm.