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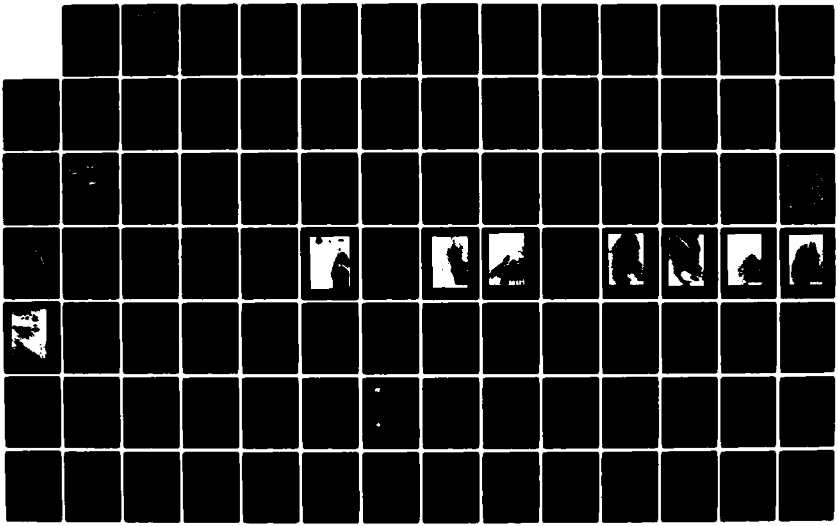

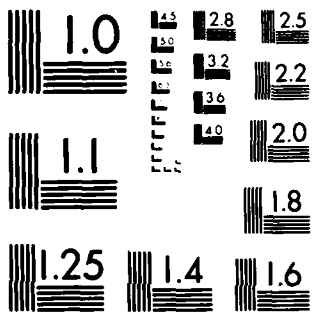

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Seafloor Environments North St. Croix Margin and Virgin Islands Trough

Part 1
Introduction
W.J. Burton*

Part 2
Geology and Geophysics
F.A. Bowles
J. Egloff, Jr.

Part 3
Geotechnical Investigations
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Part 4
Engineering Significance
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FPO-1-82 (26)
December 1982

Prepared by and in Cooperation with
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Naval Facilities Engineering Command
Washington, D.C.
and
Atlantic Oceanographic and Meteorological Laboratories+
National Oceanic and Atmospheric Administration
Miami, FL.

Seafloor Geosciences Division
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Abstract

The Virgin Islands Trough (VIT) is a deep (4500 meters (m)), elongate basin bounded on its north and south sides by steep fault escarpments. The south escarpment forms the north submarine slope of St. Croix Island and has an average gradient of 18-23°, although local gradients vary between 5-47°. The slope is cut by two submarine canyons that terminate at mid-slope. In the case of the larger canyon, erosional debris is carried from the canyon mouth to the basin floor via a system of gullies.

The basin floor is a relatively smooth, gently sloping, turbidite plain that has a sediment thickness in excess of 1.5 seconds (1500 m). Most of this sediment is thought to derive from the Virgin Islands Shelf to the north. Westward transport of sediment in the basin is blocked by a topographic high located at 17°54'N, 64°48'W causing the sea floor to be 300 m higher on the east side of the high. This area of the basin (east of the high) is also considerably narrower than the remainder of the basin because of a major slump and/or tectonic uplift.

Sediment thickness on the north slope of the basin ranges between 0-0.15 sec (0-150 m) but cannot be resolved seismically on the south slope (St. Croix side) where only a thin veneer of sediment exists (a few meters or less). In some areas a hard crust exists just beneath the sediment surface. Visual observations indicate that rock outcrops are generally infrequent. Pelagic deposition, downslope creep, slumping, and turbidity currents are all active mechanisms that transport sediment down the north slope of St. Croix to the basin floor.

The sediments in the VIT are calcareous oozes and texturally fall within the sandy-clay silt range. Sand and gravel are also a major component of the slope sediments, and the highest concentrations occur off Salt River and Cane Bay. Large blocks of coral and rock debris are widely dispersed on the slope. High carbonate content of the sediments, differing depositional environments, and bioturbation appear to be the main factors contributing to high variability in geotechnical properties, sediment type, and sediment texture. Steep gradient, sediment instability, and seismic risk, in

Abstract (continued)

addition to wide ranging variability of geotechnical parameters, make the north slope of St. Croix a potentially hazardous environment for engineering applications.

Preface

This investigation was conducted by the Naval Ocean Research and Development Activity (NORDA), Bay St. Louis, Miss., at the request of the Chesapeake Division, Naval Facilities Engineering Command (NAVFAC), Washington, D.C. Data collection and laboratory analyses were performed by NORDA cooperatively with the National Oceanic and Atmospheric Administration (NOAA), Miami, Florida. Responsibility for the final report was retained by NORDA and NAVFAC.

The purpose of the investigation was to develop a better knowledge of the geological, geophysical, and geotechnical characteristics of the sea floor on the north submarine slope of St. Croix Island, V.I., and in the VIT to supplement long-range planning of Navy activities in this area.

This investigation represents a major improvement in the current knowledge of the seafloor environment in the VIT region. In particular, it is the first investigation involving the engineering aspects of the sediments on the north slope of St. Croix and in the trough. This investigation should be of interest to engineers involved in seafloor operations and to the general marine science community.

FPO-1-82(26)

SEAFLOOR ENVIRONMENTS
NORTH ST. CROIX MARGIN
AND VIRGIN ISLANDS TROUGH

December 1982

Prepared for

Director, Research, Development, Test and Evaluation
Office of the Chief of Naval Operations
Washington, D.C.

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Preface (continued)

addition to wide ranging variability of geotechnical parameters, make the north slope of St. Croix a potentially hazardous environment for engineering applications.

Executive Summary

The seafloor investigations comprising the subject of this report were performed under the sponsorship of the Director, Research, Development, Test and Evaluation (OP-098). The Chesapeake Division, Naval Facilities Engineering Command (CHESNAVFACENGCOM) was assigned the responsibility for accomplishing the tasking. CHESNAVFACENGCOM engaged the assistance of the Naval Ocean Research and Development Activity (NORDA) and the National Oceanic and Atmospheric Administration (NOAA) who had expertise in acquisition and analysis of seafloor data.

Better knowledge of the geological, geophysical, and geotechnical characteristics of the sea floor forming the north margin of St. Croix and the Virgin Islands Trough is essential to long-range planning of Navy activities for the area. Such information is necessary for the development of adequate design of foundations for underwater structures, predicting requirements for anchoring systems, specifying requirements for protection and stabilization of cables, etc. The paucity of published data relevant to the aforementioned sea floor prompted an initiative to obtain the required data and to present it in a format most useful to the practitioner involved in seafloor engineering.

Limited resources of time and money determined the scope of the investigations. Considerable economies of these resources were realized by using "ships of opportunity" that were performing assignments in the general vicinity of the island of St. Croix and the VIT.

During the investigations, precision bathymetric profiling, seismic reflection profiling, dredging, coring, and photographic operations were conducted. Sediment samples were obtained from 40 stations chosen to provide representative samples from the shelf, slope, and trough in the general area of interest. Seven dredge stations and seven bottom camera stations were occupied. Photographic information of the bottom was greatly increased by the acquisition of video-tapes and still photographs taken during three submersible dives (ALVIN).

The geotechnical data have been analyzed only to the extent of establishing the range and average values of basic properties of the soils (such as shear strengths, Atterberg limits, etc.). The samples have been archived so that additional information can be generated later if required.

Detailed investigations of the geotechnical characteristics of the sediments, the active geological processes, and the morphological setting are important considerations for virtually any offshore engineering activity of the north margin of St. Croix. The margin is characterized by three major morphological features: a relatively narrow shallow water carbonate shelf; a steep slope (approximately 23° with steeper local slopes of nearly 50°); and a deep-sea basin which is the eastern portion of the VIT.

The trough, or basin, is asymmetrical and U-shaped in cross-sectional form, with a relatively flat floor that deepens from about 3700 m on the east to nearly 4500 m on the west. The floor of the trough is interrupted at 17°54'N, 64°47.5'W by a topographic high that acts as a barrier to westward sediment transport. Consequently, the sea floor to the east of this feature is about 300 m shoaler than to the west. Slumping or tectonic disturbance (or both) has altered the normal configuration of the trough, causing it to be much narrower east of the topographic high.

The south wall of the trough (northern margin of St. Croix) is cut by two submarine canyons (Christiansted Canyon and Salt River Canyon) that terminate at mid-slope. Christiansted Canyon, the larger of the two, is the principal conduit for transporting erosional debris to the basin floor. This material is distributed from mid-slope to the basin floor via a system of gullies that begin where the canyon ends. Major gullying does not occur elsewhere on the south slope.

Seismic reflection profiles show that the floor of the VIT is a turbidite plain with a sediment thickness of at least 1.5 sec (1500 m). Maximum sediment thickness is about 0.1-0.15 sec (100-150 m) on the north wall of the trough, but cannot be resolved on the steeper south wall (less than 25 m thick).

Extensive bottom photographs show that the south wall of the trough is sediment covered and that rock outcrops are infrequent. Evidence of significant bottom currents was not evident. Attempts to recover sediment samples indicated that the slope sediments are probably less than one meter in thickness and, in some areas, are underlain by a thin (10-15 cm) crust of probable carbonate material.

Shallow water reef material and carbonate debris occur along the shelf, and a thin veneer of carbonate ooze covers the slope.

Sediment recovered from piston and gravity cores in the trough (basin) reveal the presence of clayey silts and turbidite deposits composed of carbonate material from shallow water environments and carbonate debris and tests from middle and deep water environments (abundances of pteropods and foraminifera). The character of these sediments indicates transport of shallow water carbonate material offshore to deeper water environments of the slope and trough.

Initial geotechnical analyses of the upper one meter of sediment reveal average shear strengths of cores ranging between 0.4-1.4 psi (3.1-10 kPa) for the slope and 0.8-5.8 psi (5.8-28.3 kPa) for the trough. Individual values within cores range as high as 10.0 psi (69.1 kPa) at sediment depths greater than one meter. Average sensitivities for the slope sediment cores range between 3.2-6.1 and 4.4-12.1 for the trough (upper 1 m). High sensitivities (8-12) indicate the presence of metastable deposits and considerable strength loss upon disturbance or remolding. Average water contents (percent dry weight) range between 57-77% (101% for grab sample) on the slope and 52%-64% for the trough. The proportions of sand, silt, and clay sized fractions and the nature of the particles (i.e. water filled cavities of carbonate tests), as well as bioturbation in some deposits, strongly affect the variability in the water contents and porosities. Grain densities (solid particles) are fairly uniform 170.4-171.7 pcf (2.73-2.75 Mg/m^3) and wet unit weights average between 97.4-106.8 pcf (1.56-1.69 Mg/m^3 [92.4 pcf or 1.48 Mg/m^3 grab sample]) for slope and trough sediments. Average porosities among cores range between 61-68% for slope sediments and 59-65% in the trough. Whole core averages (depths >1 m) of the geotechnical properties are slightly different.

The steep northern slope of St. Croix and the seismicity of the Virgin Island region constitute a potentially unstable engineering environment, requiring that special attention be given to the location and design of seafloor installations to prevent sliding. Also to be considered is the presence of rugged local terrain, active downslope movement of sediment, sediment cracks, bioturbation, and currents.

The floor of the trough provides a more stable environment because of much lower gradients. This virtue is offset, however, by the fact that the sediments in the trough, as well as on the slope, exist in a metastable state. The calcareous nature of the sediments is also a complicating factor because the dynamic behavior of this sediment type is poorly understood. Evidence suggests that calcareous oozes are susceptible to failure under repeated loadings. Thus, large factors of safety are advisable when choosing bearing capacities for the design of structural footings.

The variability in local morphology, sediment processes, and sediment properties demonstrate the need to obtain detailed data in specific areas of engineering interest along the northern margin of St. *Croix*. In addition, a comprehensive determination of surface and bottom obstructions (man-made) should precede any planned engineering activities.

Contents

Nomenclature

#	number
°	degrees (latitude, longitude, slope or temperature)
'	minutes (latitude or longitude) (foot or feet)
min	minutes (time)
sec	seconds (time)
inch(es)	inch(es)
ft	foot (feet)
μm	micrometer(s) micron(s)
mm	millimeter(s)
cm	centimeter(s)
cc	cubic centimeter
m	meter(s)
km	kilometer(s)
lb(lbs)	pound (pounds)
ton	2000 pounds
psi	pounds per square inch
TSF	tons per square foot
g/cm^2	grams per square centimeter
kPa	kilopascals
PVC	polyvinyl chloride plastic
IPS	iron pipe size
ID	inside diameter
OD	outside diameter
$CaCO_3$	calcium carbonate
fps	feet per second
in/min	inches per minute
mm/min	millimeters per minute
g/cc	grams per cubic centimeter
Mg/m^3	megagrams per cubic meter
pcf	pounds per cubic foot

Nomenclature, (continued)

°C	degrees celsius
%	percent
ppt	parts per thousand
P	load pressure
LL	liquid limit
PL	plastic limit
PI	plasticity index
LI	liquidity index
w	water content
σ_1	maximum principle total stress
σ_2	confining stres
σ_3	confining stress
σ_c	cell pressure
$\sigma_1-\sigma_3$	deviatoric stress
$\bar{\sigma}_c$	effective cell pressure
$\bar{\sigma}_d$	effective compression stress (= $\sigma 1 - \sigma 3$)
$\bar{\sigma}_n$	effective normal stress
$\bar{\sigma}_1$	maximum principle effective stress
$\bar{\sigma}_3$	minimum principle effective stress
τ_F	shearing stress at failure
u	excess pore water pressure
Σ	linear strain (axial strain or shear displacement)
bp	back pressure
ϕ	angle of internal friction
ϕ_{CU}	total angle of internal friction for consolidated-undrained tests
$\bar{\phi}_{CD}$	effective angle of internal friction for consolidated drained tests
$\bar{\phi}_{CU}$	effective angle of internal friction for consolidated undrained tests
γ	wet unit weight
A	pore pressure coefficient

Nomenclature, (continued)

C_c	compression index
C_u	coefficient of consolidation
C_s	recompression swell index
>	greater than
<	less than
~	approximately

Figures

Part 1

Part 2

Figures, (continued)

Figures, (continued)

Figures, (continued)

Tables

TABLES

APPENDIX A

6.7 Tables:

6.8 Plots:

Acknowledgments

The authors express their appreciation for the assistance of the following scientists and technical assistants during field and shorebased activities: Drs. William Harrison, Gideon Almagor, and Terry Nelsen; Messrs. Evan Forde, John Burns, J. Egloff, Roy Burke, Sam Bush, Steve Madosik and Thomas Tuma; Ms. Gail Romero, Sharon Madosik, and Karen Sullivan. Special thanks are due the officers and crew of the U.S. Navy Ships LYNCH and BARTLETT and the NOAA ship RESEARCHER. The support given by NOAA's Atlantic Oceanographic and Meteorological Laboratories during the field activities is gratefully acknowledged. Encouragement given by Drs. H. Eppert, L. Maynard and T. Holcombe is appreciated. Special thanks are due Dr. Dennis Hubbard, West Indies Laboratory, for access to the information and data collected during DSRV ALVIN dives off St. Croix. Support for this project was given by the Naval Facilities Engineering Command, Chesapeake Division, and was sponsored by the Director, Research, Development, Test and Evaluation, Office of the Chief of Naval Operations.

PART I

INTRODUCTION

W.J. Burton

PART I

INTRODUCTION

W.J. Burton

PART 1.
INTRODUCTION

A limited investigation has been performed to determine the geological and geotechnical characteristics of a selected geographical region that incorporates a portion of the northern margin of the Island of St. Croix, U.S. Virgin Islands, and the adjacent Virgin Island Trough (VIT). The gathering and analyses of the data have taken place intermittently over an extended period of time, beginning in 1980. The effort has been performed jointly by the Chesapeake Division, Naval Facilities Engineering Command (CHESNAVFACENGCOM); the Naval Ocean Research and Development Activity (NORDA); and the National Oceanic and Atmospheric Administration (NOAA). This report summarizes the results obtained from the observations and analyses of the data and provides insight into the placing of underwater structures and equipment on or beneath the sea floor. Such applications are of interest to a wide-range of activities within both the Navy and NOAA.

1.1 Purpose of Investigation

This project was an interdisciplinary effort integrating geology, geophysics, and geotechniques to provide fundamental data for offshore engineering applications on a carbonate island margin. More specifically, this investigation is concerned with the engineering properties of the surficial sediments, the morphological characteristics, and the processes active on the margin.

1.2 Geographic Area

Figure 1.1 depicts the geological environments of interest, including the outer shelf and slope off the north side of St. Croix and the neighboring VIT where precision bathymetric mapping, seismic reflection profiling, dredging, coring, and camera operations were conducted. Water depths ranged from tens of feet (ft) on the shelf to greater than 13,000 ft (4000 meters (m)) in the trough. The overall region investigated is considered to be favorably situated from the standpoint of using the deep portion of the VIT in combination with shore mounted equipment positioned on St. Croix.

1.3 Scope

The extent of this investigation was limited by time and funding considerations. Economy of both these resources was realized by using "ships of opportunity," that is, vessels that were working in the vicinity of the VIT and could incorporate the tasks of this project into their schedules.

Bathymetric, seismic reflection, dredging, and bottom photography operations were conducted to determine the morphology, primary sediment patterns, and active sediment processes of the north margin of St. Croix and VIT (Part 2).

Piston core, hydroplastic gravity core, and Shipek grab samples were recovered for geotechnical and sedimentological study (Part 3).

Selected data were reported for the upper 18 ft (5.5 m) of surficial sediments; however, the greatest emphasis in this report is on the upper 3 ft (1 m).

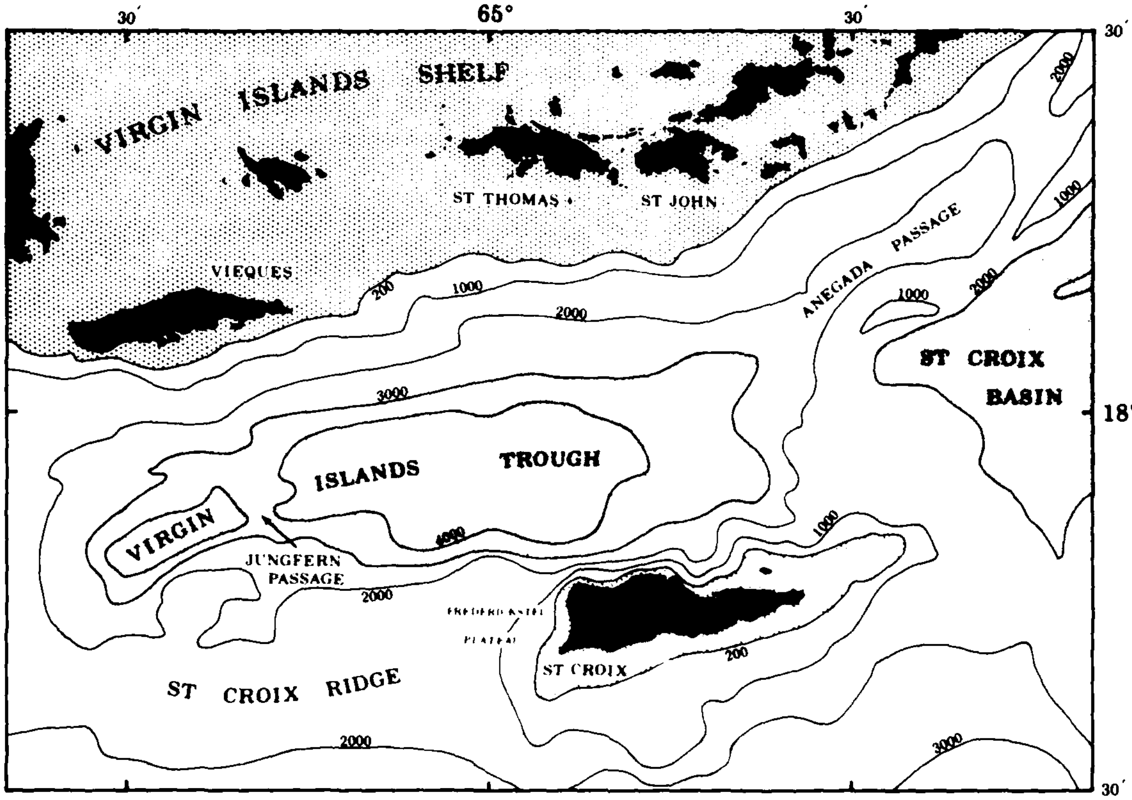

Figure 1.1 Bathymetric map showing the regional geologic setting of the Virgin Islands Trough area.

PART 2

GEOLOGY AND GEOPHYSICS

F.A. Bowles

J. Egloff, Jr.

PART 2.
GEOLOGICAL AND GEOPHYSICAL OBSERVATIONS

The following sections discuss the results of the joint geological and geophysical investigations undertaken by NORDA and NOAA in the Virgin Islands Trough and on the north margin of St. Croix. In addition, they provide a geological setting for the geotechnical investigations and engineering interpretations discussed in Parts 3 and 4.

2.1 Previous Investigations

St. Croix Island represents an exposed portion of the east/west-trending St. Croix Ridge (Fig. 1.1). Immediately to the north, the deep, elongate VIT separates St. Croix from the Virgin Islands shelf and the islands of Vieques, St. Thomas, and St. John. Evidence strongly indicates that the VIT is a graben structure formed by post-Miocene extensional forces [2.1, 2, 3, 4]. At the 3000 m isobath the VIT is approximately 55 nautical miles (nm) wide, although the actual floor is better defined by the 4000 m isobath. The VIT consists of two basins, the smaller of which is at the extreme west end of the trough and is separated from the larger basin by a narrow sill having a water depth of about 3600 m. The east and west extremities of the trough lead into the Anegada and Jungfern passages, respectively, which provide the deepest link between waters of the Atlantic Ocean and Caribbean Sea [2.5].

Holcombe et al. [2.6] have presented a geological study of the Frederickstcd Plateau area (Fig. 2.1), in which they provide detailed bathymetry, seismic reflection profiles, bottom photography, and sediment engineering information. They also assembled all available data published prior to 1975 and, where appropriate, have synthesized it into a detailed and comprehensive summary of the geology and geophysics of St. Croix Island and adjacent sea floor. Significantly, nearly all the references up to the time of their report deal primarily with aspects of island geology, the broad regional features of Caribbean geology, and specifically with the sea floor west of the island where the St. Croix Tracking Range is located. Thus, outside of the Range area, little direct information exists for most of the sea floor adjacent to St. Croix.

Frassetto and Northrop [2.7] published the results of an early bathymetric survey of the VIT between approximately 69°50'W and 65°50'W. Their bathymetry map compares well with the regional bathymetry shown by Garrison et al. [2.8] which was also used as the base map for Figure 1.1.

Both maps show the VIT as an elongate, flat-floor feature bounded by a steep southern escarpment (up to 43°, [2.7]) which forms the north island-slope of St. Croix. Aside from showing a large first-order indentation in the isobaths off Christiansted Harbor, neither bathymetry map reveals any fine-scale detail.

A later survey by Shepard [2.9], however, does provide more detailed bathymetry of the north slope of St. Croix between about 64°39'W and 64°55'W. This data also reveals a steep escarpment, but suggests over-steepening in some places and gentler slopes in others. Although this is probably the case, it is noteworthy that the detail displayed in Shepard's bathymetry does not appear to be warranted by the number of survey lines. His contours do, however, plainly reveal the existence of a large canyon-like feature directly off Christiansted

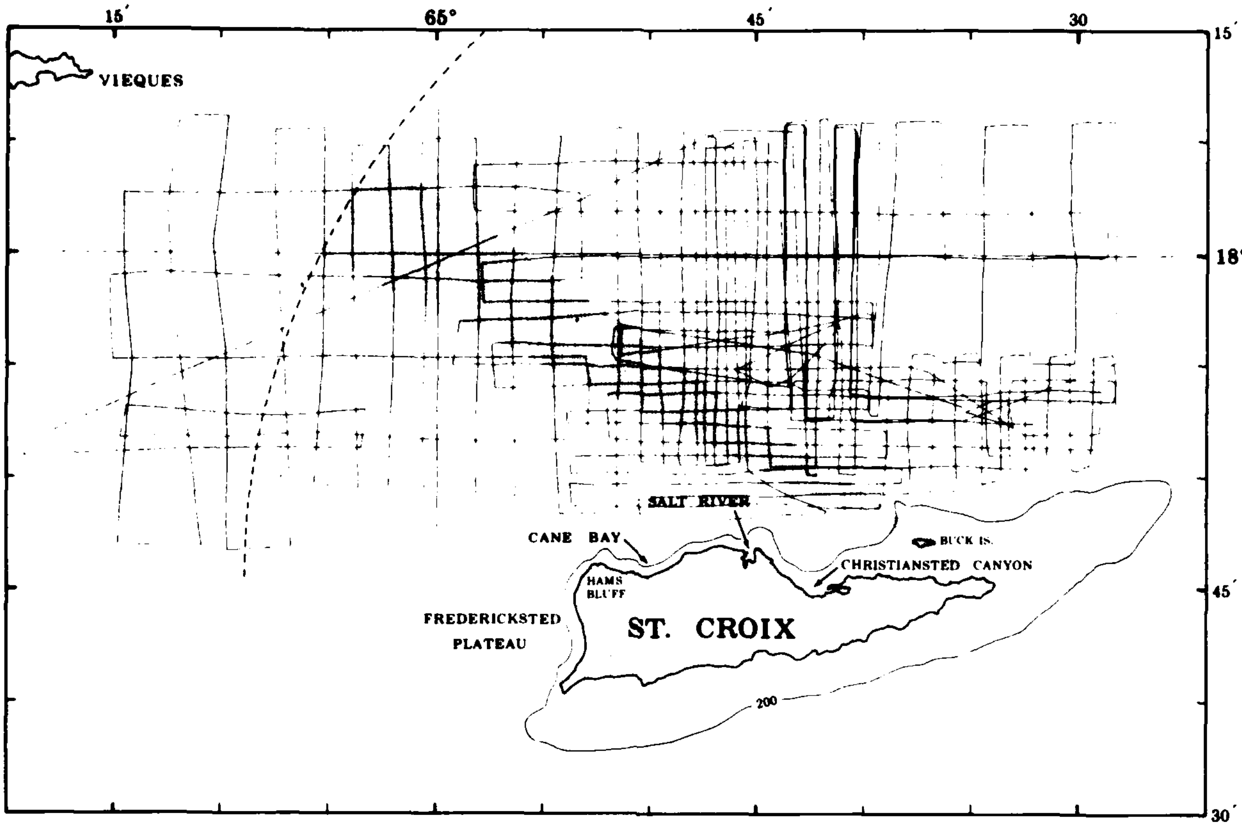

Figure 2.1. Ship's survey lines along which seismic reflection and 3.5 kHz profiles were collected. Stippled area delineates "shadow zone" where reception of transponder located on east end of island was shielded by Buck Island. Dashed arc shows maximum extent of signal reception for this transponder.

Harbor. Interestingly, the canyon terminates at a depth of 2600 m above the base of the escarpment. A smaller, similarly discontinuous "canyon" is also indicated off Salt River. Bottom Current studies in the upper portions of these canyons [2.10] show that the currents are generally slow (rarely exceeding 0.33 feet per second (fps) (10 cm/sec)) but exhibit high-frequency alterations of direction and occasional periods of relatively strong down-canyon flow.

In general, the south escarpment intersects the floor of the VIT with a sharp, angular contact, indicating the absence of a depositional fan [2.9]. Some echograms, however, reveal a hummocky topography at the base of the slope, suggesting possible slumping of material.

Holcombe et al. [2.6] note that the flat character of the floor of the VIT is indicative of a turbidite plain and suggest that much of the sediment contribution to the plain may originate on the island of St. Croix and on the crest of the St. Croix Ridge. In this regard, it is significant that little information exists in the literature concerning the nature and source of the sediments in the VIT. Hubbard et al. [2.11] have recently investigated the quantity and distribution of shallow-water sediments and biological debris to the VIT off St. Croix. Details of their investigation are presented in Section 2.4.5.

In addition to the investigations mentioned above, nearshore, shallow-water hydrographic surveys around St. Croix have been, and are continuing to be, conducted by NOAA's National Ocean Survey.

2.2 Area of Investigation

The extent of the investigation area is shown by the ship's track chart presented in Figure 2.1. Initial plans called for detailed surveying to be done at two locations; one off the general area of Salt River and the other north of the east end of the island. These areas are evident in Figure 2.1 by the greater density of track lines (0.5-1.0 nm line spacing) relative to the remaining areas where much wider reconnaissance survey lines were run (2.0-4.0 nm). Because the survey coverage west of about 64°55'W was broad, the data collection was incomplete (no seismic reflection, no bottom photographs, three cores), and as the area was of secondary importance, this report deals almost exclusively with the sea floor and sediments north of the island.

2.3 Operational and Technical Considerations

The following subsections provide specific information relating to the research vessels, equipment, and procedures used.

2.3.1 Vessels

The first bathymetric, seismic, coring, and dredging operations for this investigation were carried out aboard the USNS LYNCH in August 1980, followed by additional bathymetric surveys and bottom photography by the USNS BARTLETT in November 1980. Normal survey speed during both ship operations was approximately 8 knots.

The most recent surveying and bottom sampling operations were conducted with the NOAA ship RESEARCHER in August 1981 (discussed in Part 3.).

2.3.2 Data Collection

To explore and evaluate the seafloor conditions and nature of the sediments, the following operations were accomplished.

- Installation of an acoustical, short baseline positioning, and tracking system.
- 3.5 kilohertz (kHz) bathymetric profiling.
- Seismic reflection profiling.
- Collection of sediment samples.
- Collection of rock samples.
- Collection of bottom photographs.
- Acquisition of additional bottom photographs taken by the submersible ALVIN.
- Laboratory testing of physical and engineering properties of sediment samples (Part 3).

The location of camera stations, and ALVIN dive sites are given in Section 2.4.1. Locations for sediment samples are given in Part 3.

2.3.3 Equipment

The following equipment was employed in support of the survey operations:

- Bathymetric Survey System:

  --Transducer--EDO, Model 240 H, 3.5 kHz, hull-mounted
  --Transceiver--ORE, Model 140
  --Recorder--Raytheon LSR-1811-10, electrostatic

- Seismic Reflection System:

  --Sound source--Teledyne, Model 27290, 30,000-Joule "Sparker"
  --Hydrostreamer--Teledyne, Model 28420
  --Amplifier--Teledyne, Model 300 LF
  --Recorder--Raytheon LSR-1811-10, electrostatic

- Navigation--Racal Decca, Model 540 Digital Distance Measuring System:

  --Range--Line of sight to 35 miles
  --Accuracy--±1 m, typical
  --Resolution--0.1 m

- Photography--Hydro-Products, 70 millimeter (mm) multi-exposure cameras (2) and electronic strobe lights (2)

- Dredging--Benthos chainlink bag dredge

- Coring--Ewing piston corer, hydroplastic gravity corer, Shipek grab sampler

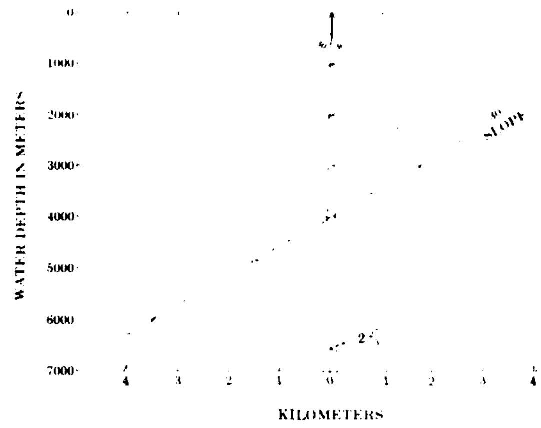

Figure 2.2. Generalized diagram showing relationship of widebeam and narrowbeam echosounders with sloping sea floor of 30°. Dashed line represents hypothetical rough bottom.

2.3.4 Data Quality

The following factors are critical regarding the quality of the data collected.

2.3.4.1 Errors Resulting from Beamwidth

The geometrical relationship between the sea floor and spherical wave front of the sound pulse emitted by wide-beam echosounders can create errors in the measurement of water depth and feature shape (resolution). In the latter case, the role of side echoes in obscuring the true shape of sea floor features has long been appreciated [2.12, 13, 14]. Any sharp projection above the sea floor gives a hyperbolic echo trace resulting in distortion of seafloor topography by generally increasing the apparent width of a feature, although its actual height is preserved. The critical factors involved are the feature's radius of curvature relative to the radius of curvature of the echosounder's wave front. An echosounder will, with reasonable accuracy, resolve a feature if the radius of curvature of the wave front is much larger than that of the feature. However, distortion results when the reverse is true.

In general, wide-beam echosounders (30° half-angle) preserve features whose wavelength (or width) is greater than the water depth in which they operate. As shown in Figure 2.2, at a water depth of 4000 m the area of sea floor insonified is about 4600 m. Thus, at this depth a feature would have to be approximately 5 km wide to be resolved by the echosounder. At shallower depths the radius of curvature of the echosounder's wave front (i.e., the insonified area) decreases with the result that resolution increases. For example, resolution at a depth of 2000 m is about 2500 m (Fig. 2.2). Clearly, feature resolution is improved by reducing the wavefront radius of curvature. This can be accomplished by towing a transducer close to the bottom or by limiting the half-angle of the transducer through beam forming techniques. Figure 2.2 compares the width of a narrow-beam echosounder (2-2/3°) with that of the wide-beam (60°) showing that the narrow-beam is capable of much finer feature resolution.

More importantly, however, from the standpoint of bathymetry, are the inaccuracies in recorded bottom depth. According to Krause [2.13] a transducer will receive an echo from any part of the sea floor that is tangent to the spherical wave front, provided the echo takes place within the half-angle of the transducer; outside the half-angle the sound energy emitted and, therefore, the return echos are too weak for detection purposes.

On a sloping sea floor the echo does not originate from directly beneath the ship (as in the case of a flat sea floor) but from a point where the slope is tangent to the curvature of the wave front. This relationship is demonstrated in Figure 2.2 and two observations can be made:

- With a typical wide-beam echosounder (30° half-angle) a 30° gradient is theoretically the steepest slope that would produce an echo trace. For steeper slopes there is no point of tangency with the wave front (unless the half-angle is increased). In reality, however, this is not the case. The geometry of the beam pattern produced by a transducer is such that side lobes exist that are capable of producing bottom echoes. Moreover, slope irregularities produce scatter, which is detected by the transducer. As a result of these factors, slopes in excess of 30° can be "seen" but their echo trace may be weak and diffuse.
- The point of tangency occurs upslope; thus, there is a downslope horizontal displacement of the recorded depths relative to the ship's position. For example, a depth of about 3000 m is recorded when the ship is actually in 4000 m of water. This results in an apparent horizontal displacement of approximately 1750 m in the downslope direction for the 3000 m contour. As water depth or bottom slope decreases the point of tangency moves closer toward the vertical, resulting in more accurate water depth measurements. Clearly, these considerations will have their greatest effect on the south wall of the VIT where steep gradients are encountered.

Nares [2.15] and de Vanssay de Blavous [2.16] have also shown that for a sea floor of constant gradient, the echo trace is less than the actual seafloor gradient. Krause [2.13] notes, however, that for slopes up to 15° the difference is negligible and that even up to 30° the departure in gradient is not very great (about 3°).

2.3.4.2 Resolution of Sediment Cover

Seismic reflection profilers and echosounders operate on exactly the same principles. The important difference in these two systems is in their sound frequencies. Seismic reflection profilers utilize pulses of low frequency sound that have the important advantage over high frequency pulses (used by echosounders) of being less attenuated by traveling through sediment or rock. Thus, seismic reflection profilers have the ability to display thick sediment accumulations and deep structure, therefore providing a means of determining the geometric relationships between the sediments and underlying basement structure. The cost of this ability is resolution loss of fine-scale features such as thin sediment cover.

In general, as the thickness of a layer becomes less than 1/4 wavelength of the sound energy, it is likely to escape detection. Thus, a thin sediment cover overlying a rock (basement) surface would not be seen or, alternately, a thin layer within a thick sequence of sediment would not be seen. The limiting resolution of layer thickness for the typical 3.5 kHz echosounder is about 12 centimeters (cm). Seismic reflection profilers, however, operate over a range of frequencies, with the most power falling in the 50-100 kHz range for a "sparker" sound source. As a result, the theoretical resolution is approximately 15-30 m. Under optimum conditions (precisely tuned equipment, flat bottom) 25 m resolution has been achieved in the field. Routinely, however, it is reasonable to expect about 50 m resolution. Thus, an area may appear sediment-free in a reflection profile but could have an appreciable sediment cover.

In addition to this, there are numerous distortions which can occur because of wide beamwidth and the compressional wave velocity structure of the sediment cover. An excellent treatment of these distortions can be found in Tucker and Yorston [2.17].

2.3.4.3 Navigational Errors

Ship's position was continuously monitored using the Racal-Decca Trisponder navigational system, that consisted of ship-mounted master unit and two remote transponder units on the island of St. Croix. Calibration of the master and remote units was done on the island prior to survey. This was accomplished by placing each remote unit a known distance from the master unit and then making the necessary calibrating adjustments.

The two remote transponder units were positioned at the east end of the island and at the Ham's Bluff lighthouse, respectively (Fig. 2.1). The transponders were omni-directional with a line-of-sight range of 35 miles. This was sufficient for dual transponder coverage of all the survey area (Fig. 2.1) discussed in this report except for the "shadow zone" where reception of the east point transponder was masked by land obstacles: in one case Buck Island and in the other case the projection of land at Salt River. Within the shadow zone, the ship's position was determined by using the Ham's Bluff transponder in conjunction with visual sitings and radar sitings. In those areas where both transponder signals were simultaneously received, position accuracy is estimated to be 10-30 m. Where only one transponder signal was received, position accuracy could be as poor as 1/4 mile. In the shadow zone directly north of the island, where good visual and radar fixes were obtained, position accuracy is somewhat improved.

2.4 Results and Interpretations

The following discussion presents the principal observations and conclusions of this investigation.

2.4.1 Bathymetry

The geomorphology of the survey area is summarized by the bathymetric map shown in Figure 2.3 (also see pocket insert), and selected bathymetric profiles are shown in Figure 2.4. The profiles, which are oriented north-south, clearly reveal the asymmetric cross-sectional shape of the VIT. The extreme eastern end of the trough begins as a narrow, V-shaped cleft (profile 1). At about 64°39'W (Fig. 2.3) the trough, although still narrow, changes into a more U-shaped feature with a flatter floor (profile 2). An asymmetrical U-shaped form is maintained for the remainder of the VIT although it is considerably wider west of about 64°52'W (profile 11).

The most impressive feature of the area is the steep submarine slope off the north side of St. Croix. According to Shepard [2.9], the slope is remarkably steep having an average declivity of 50% (about 26°). Slope calculations, based only on the uppermost and lowermost slope contours in Figure 2.3, yield a somewhat lower range of values (18°-23°). These values, however, reflect a smoothly sloping surface with no irregularities. Clearly, this is not the case; the narrowing and widening of the contours is indicative of local slope irregularities. To obtain a more realistic appraisal of the slope, gradients were calculated at 23 locations over horizontal distances ranging from 0.2 nm to 3.25 nm. These calculations reveal considerable local variability in gradient, with values ranging from a low of 5° to a high of 47°; the upper slope generally exhibits gradients in the 25°-35° range, whereas the lower slope has values in

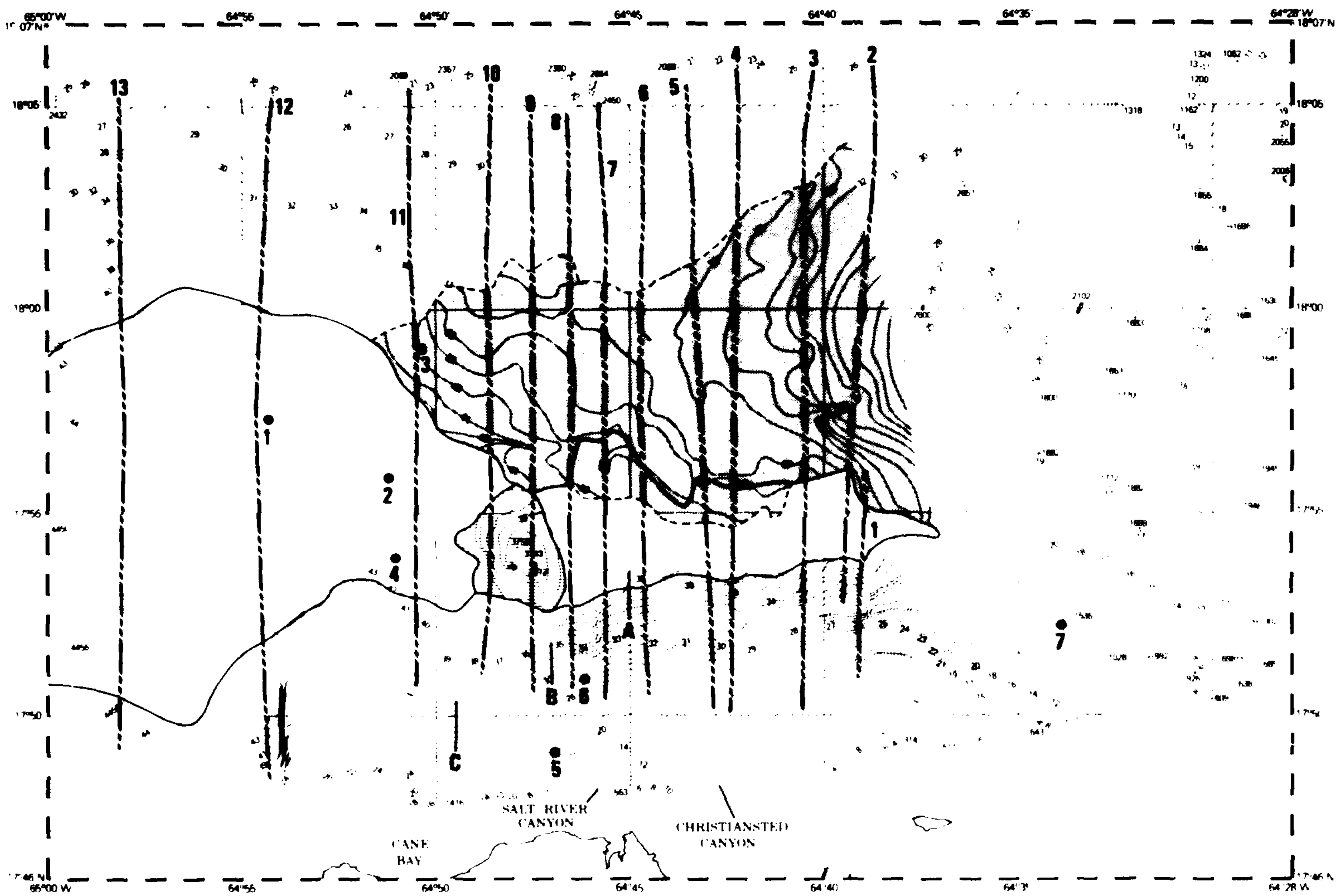

Figure 2.3. Bathymetric map based on survey lines shown in Figure 2.1. Stippled area represents hummocky area (slump?). Diagonal dashed lines define area of gullied topography. Solid line pattern shows large outcrop in axis of trough. Numbered, parallel, broken lines locate 3.5 kHz profiles shown in Figure 2.4. Solid lettered lines show location and approximate extent of ALVIN dives. Solid dots are locations of bottom camera stations.

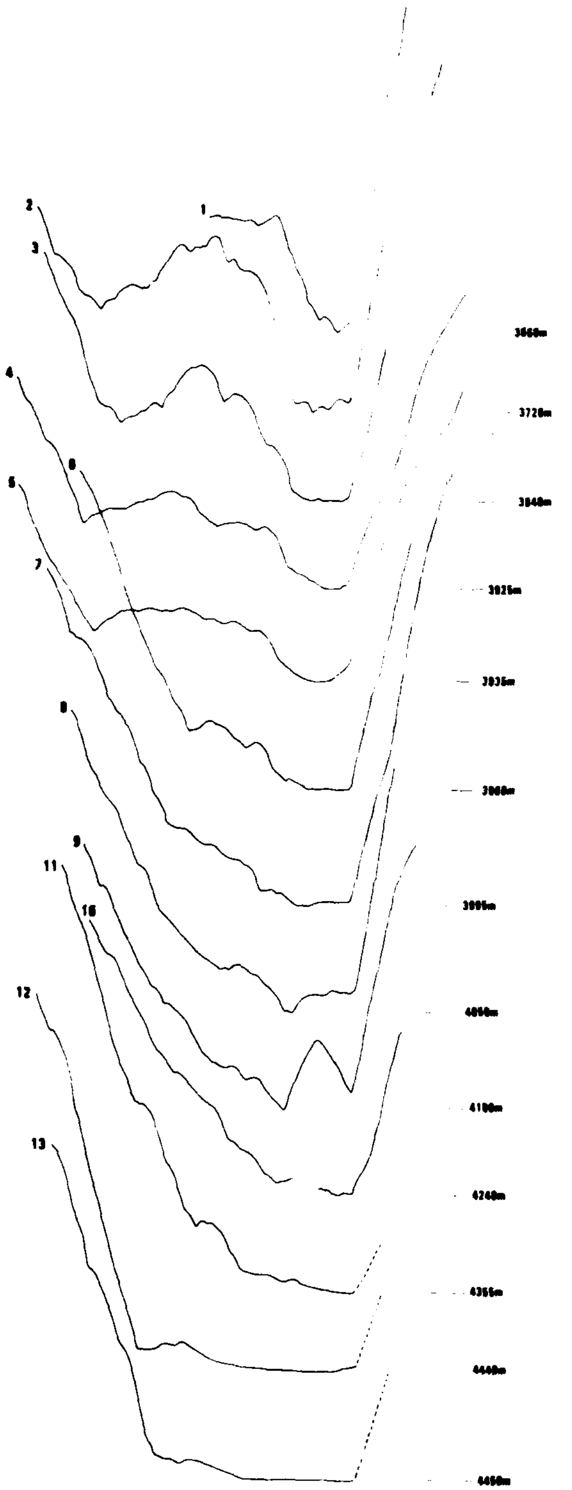

Figure 2.4. North-south topographic profiles across the Virgin Islands Trough. The numbers correspond to the numbered north-south lines in Figure 2.1.

the range of 8°-19°. Generally speaking, the upper slope west of Christiansted Harbor is the steepest along the island slope, except off the extreme western end of the island where the contours indicate a steep N-S trending escarpment (perhaps steeper than 50°).

The steepness of the south wall is a strong indication that it is a fault scarp. Presently, the only direct evidence of faulting was reported by Dill [2.8] who observed fault gouging along the south wall.

East of Christiansted Harbor, the slopes are generally less steep than those to the west. At approximately 64°40'W the lower slope contours turn gently to the north marking the presence of an extensive submarine bank (1900 m) that separates the VIT from the St. Croix Basin to the east (Fig. 1.1). North of 18°05'N the bank shoals (1062 m), narrows, and trends toward the northeast as the Barracuda Ridge, which forms the southern boundary of the Anegada Passage (Fig. 1.1).

The entrance to the Anegada Passage is marked by a prominent northeast-trending reentrant in the contours west of about 64°45'W and north of 18°00'N. A similar, but southeast-trending reentrant or "bight" is formed where the contours of the south wall turn northward. Unlike the Anegada Passage reentrant, which marks a major deep water access to the North Atlantic, this southern reentrant shoals rapidly and appears to lose major expression at about 1000 m.

The northern wall of the VIT is clearly not as impressive as the southern wall, which is steeper and intersects the floor of the VIT at a more acute angle (Fig. 2.4).

The trough floor (generally outlined by the 4000 m contour) achieves its major width and deepest depths (nearly 4500 m) west of about 64°52'W. East of this longitude the floor narrows rapidly and shoals, gradually losing expression at about 64°40'W where the bottom rises from 3800 m to 1900 m over a horizontal distance of about 6 nm.

The regional downslope gradient of the trough floor is from east to west and north to south. Thus, the axis of deepest depths is situated at the base of the south wall. These gradients suggest that the Virgin Islands Shelf may be the dominant source of sediment for the VIT and that sediment transport along the trough floor is generally east to west.

The generally flat floor of the trough (1°-2°) is interrupted by a prominent topographic high (3743 m) situated at about 17°54'N, 64°48'W (Figs. 2.3, 2.4; profiles 9, 10). The sea floor to the east of this feature is about 300 m shoaler than to the west, indicating that sediment has been trapped behind the high.

The contours along the north wall of the VIT do not reveal any significant geomorphologic features. In contrast, the south wall (i.e., north slope of St. Croix) has a prominent canyon-like indentation at approximately 64°43'W, directly off Christiansted Harbor. Near shore the walls of the upper canyon form an asymmetric profile, with the west wall sloping more steeply (28°-33°) than the east wall (18°). Downslope the walls slope more gently as the canyon broadens into a shallow valley. Correspondingly, the floor of the canyon exhibits a steep upper gradient (11°) and a gentler gradient (5°) below the 2600 m contour. These values are in general agreement with Shepard [2.9].

Although Christiansted Canyon can be traced shoreward cutting through the fringing reef off the harbor entrance [2.10], it is curiously discontinuous in the downslope direction and shows no topographic expression below a depth of about 2800 m. In this respect, Christiansted Canyon is atypical relative to other canyons that extend to the base of the slope that they dissect.

A much smaller, but similarly discontinuous canyon-like indentation also occurs directly off Salt River Bay. As shown by Shepard and Dill [2.10], Salt River Canyon is well-developed in its upper reaches, but our contours show that it loses expression by about 1700 m.

Examination of the bathymetric profiles reveals considerable fine-scale relief, generally in the range of a few meters to several tens of meters, which may represent shallow gullies cut into the St. Croix slope. This impression is fostered by the fact that N/S profiles typically show a hyperbolated but generally smooth, sloping surface, whereas E/W profiles (across slope) reveal a very hummocky, dissected topography. This is to be expected since N/S survey lines would essentially parallel linear, downslope-trending features, generally missing them and, therefore, show "smooth" slope profiles; E/W survey lines would cross such features and show irregular topography. Hyperbolae, which appear in the N/S profiles, may indicate oblique crossing of gullies or, alternately, outcropping rock ledges.

In most profiles (Fig. 2.4), the south slope of the VIT maintains nearly the same steep angle and sharply intersects the floor of the trough. This is also true for the north wall west of about 64°52'W (Fig. 2.4, profiles 12 and 13). East of this longitude, however, a clear demarcation between the floor and north wall of the VIT is not always obvious. In profiles 7-11 the wall-to-floor transition is obscured by irregular, hummocky topography. Eastward (profiles 1-6) the hummocky area becomes progressively more defined to the extent that it forms a topographic entity separate from the floor and wall. In this respect, the hummocky area does not appear to "belong." Indeed, if the north wall in profiles 1-6 is projected downward to about the level of the trough floor and then across to the south wall, the profiles resemble profiles 12 and 13 with the hummocky area clearly appearing anomalous. In addition to this, it is coincident with a dramatic narrowing of the VIT (Fig.2.3). These considerations suggest that the hummocky area may represent a mass of slumped material that has partially covered the floor and lower north wall of the VIT, thus altering its normal configuration as expressed farther west (profiles 12 and 13).

2.4.2 Seismic Reflection

Acoustic basement is usually defined as the deepest continuous reflector observed in seismic reflection profiles. In most situations, it represents volcanic or "true" basement and usually marks the base of the unconsolidated sediments. The seismic reflection profiles collected during this investigation are presented in Figures 2.5-2.9 and are keyed to the track chart shown in Figure 2.10. The profiles clearly show a variable sediment distribution in the VIT. The south wall appears to be virtually sediment-free (see Part 2.3.4.2) whereas the north wall shows a thin, slightly hummocky sediment accumulation. In contrast, the axial portion of the trough contains a thick, acoustically laminated accumulation of sediment. Cross-sectional profiles of the VIT (Figs. 2.6, 2.9) show that the axial sediments in the trough form a wedge-shaped body with the subbottom reflectors dipping and thickening southward, where they terminate abruptly against the south wall of the trough. This geometry strongly suggests, once again, that the sediments are derived from the north, i.e., the Virgin Islands Shelf. East of the topographic high situated in the trough axis (Fig. 2.8), the trough sediments range between 0.5-1.0 (0.1 second [sec] approximately equals 100 m) sec in thickness, but thin as they onlap the high and VIT margins. West of the high, the sediments achieve a thickness of at least 1.5 sec. In general, for the area west of the high, one could expect the sediments to be routinely 1.0 sec thick or more, except near the margins where the sediments onlap the walls of the trough.

Sediment thickness on the lower north wall appears to be about 0.1-0.15 sec, but thins to zero as the slope shoals and steepens. At the base of the slope, in the area of hummocky topography (Fig. 2.3), sediment thickness ranges between 0.15-0.50 sec, with most values falling in the 0.2-0.3 sec range. In this area, and the trough in general, it is impossible to establish sediment thickness with confidence because of the inability to clearly define the basement reflector.

The southward tilt of the trough sediments is most pronounced in profile L'M' (Fig. 2.6) where the subbottom reflectors appear to onlap deep structure beneath the area of hummocky topography. This suggests that tectonic movement may have uplifted this part of the trough floor, effectively narrowing the trough as well as producing the irregular surface topography. As previously noted, a large basement high does exist in the axial part of the trough, and there are suggestions of smaller basement protrusions (profiles L'M' and N'O'), indicating tectonism at one time or another. Although this provides an alternative to massive slumping as the main reason for the anomalous nature of the VIT in this area, it does not completely eliminate slumping. Tectonic movements could easily dislodge sediment from the walls of the trough.

Surprisingly, there is no evidence of major slumping in the western protions of the VIT (west of 64°52'W) as indicated by the sharp contact the base of the south escarpment makes with the trough floor (Fig. 2.4). A similar contact is often observed for the north wall as well (Fig. 2.4, profiles, 12 and 13); however, irregular relief usually characterizes the trough floor at the base of the north wall. Although this relief, in some cases, resembles slump topography, more often its form suggests deep-rooted sediment disturbance related perhaps to seismicity (see following section).

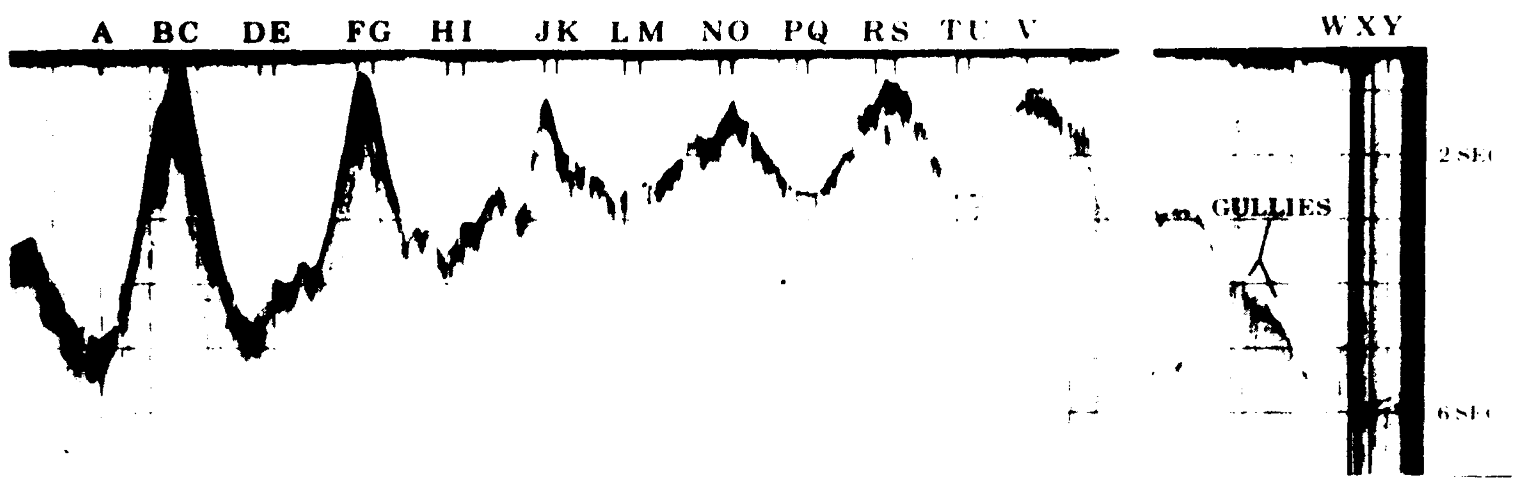

Figure 2.5. Sesimic reflection profiie showing south wall of the Virgin Islands Trough; 1 sec = 750 m in water and about 1000 m in sediment.

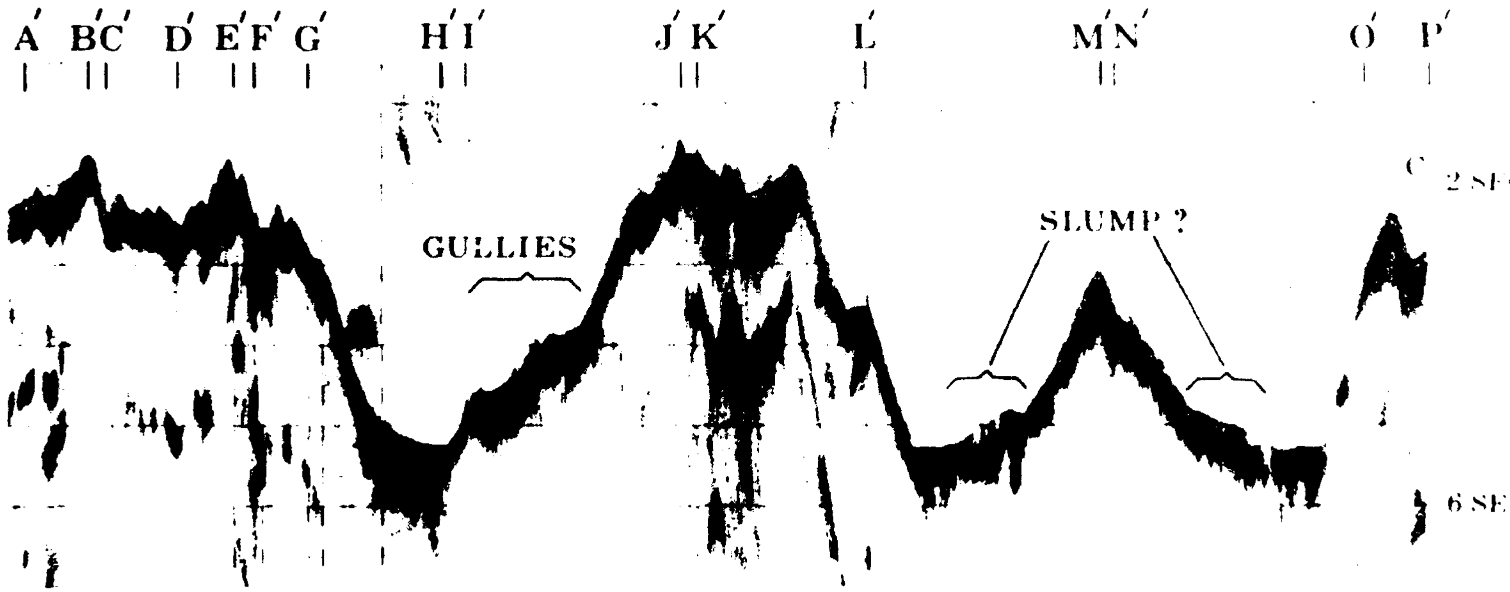

Figure 2.6. Seismic reflection profile showing the south wall (A' - G') and north-south crossings of Virgin Islands Trough. The letter C marks Christiansted Canyon; 1 sec = 750 m in water and about 1000 m in sediment.

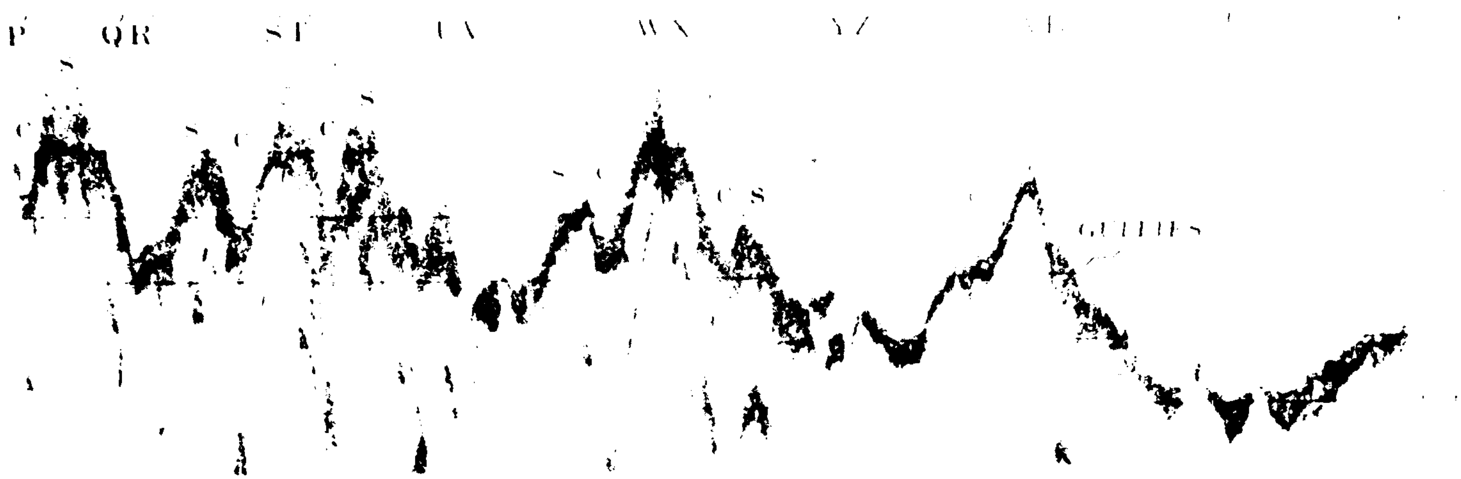

Figure 2.7. Seismic reflection profile showing the south wall of the Virgin Islands Trough and multiple crossings of Christiansted Canyon (C) and Salt River Canyon (S); 1 sec = 750 m in water and about 1000 m in sediment.

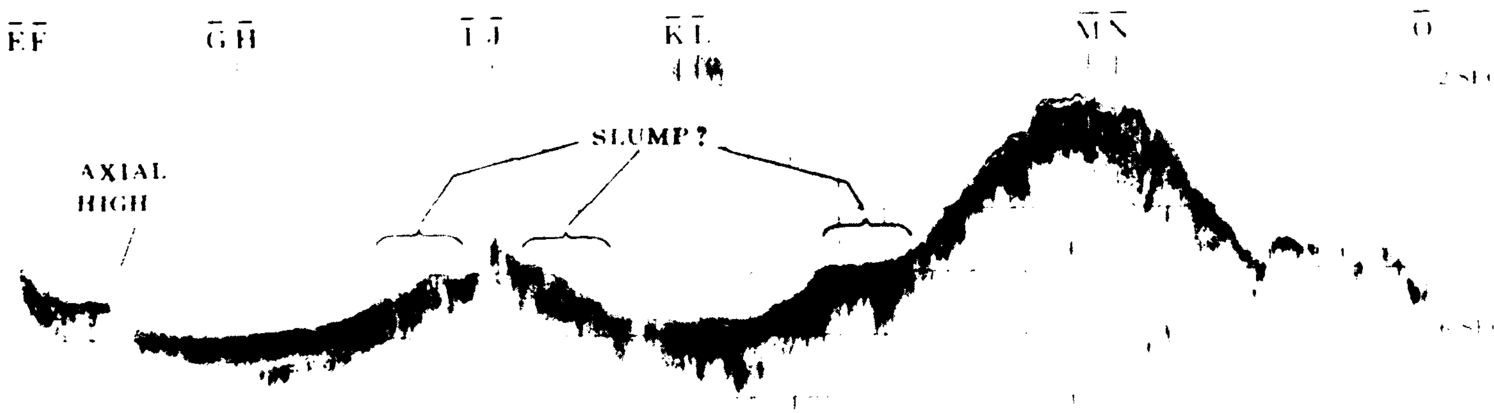

Figure 2.8. Seismic reflection profile showing east-west profile down the axis of the Virgin Islands Trough; 1 sec = 750 m in water and about 1000 m in sediment.

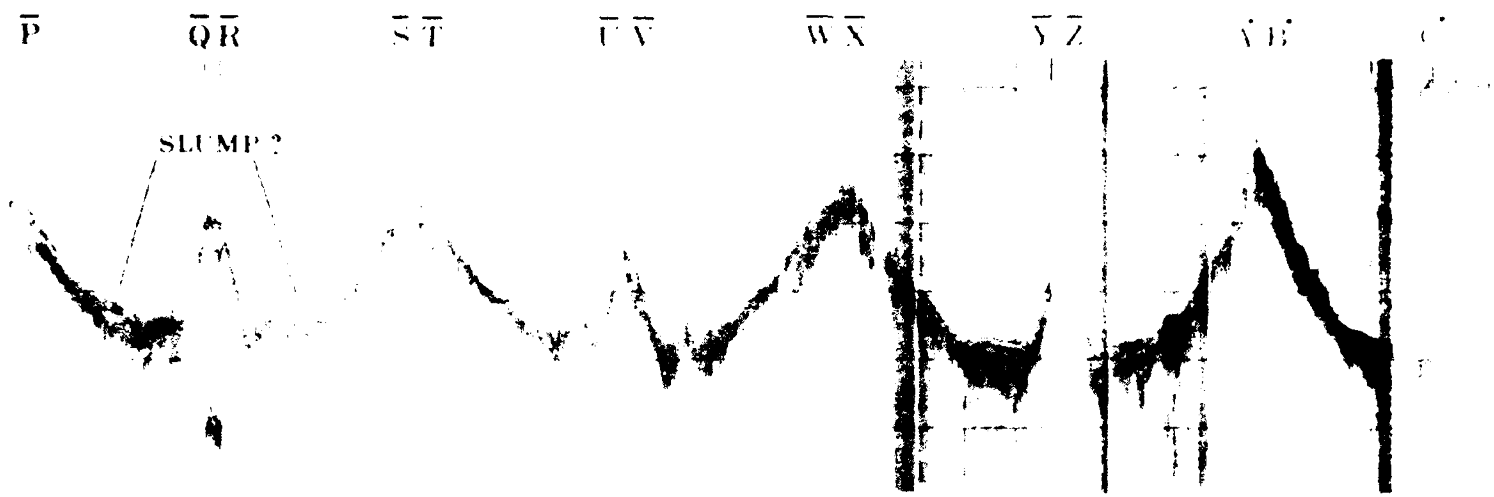

Figure 2.9. Seismic reflection profile showing north-south crossings of Virgin Islands Trough; 1 sec = 750 m in water and about 1000 m in sediment.

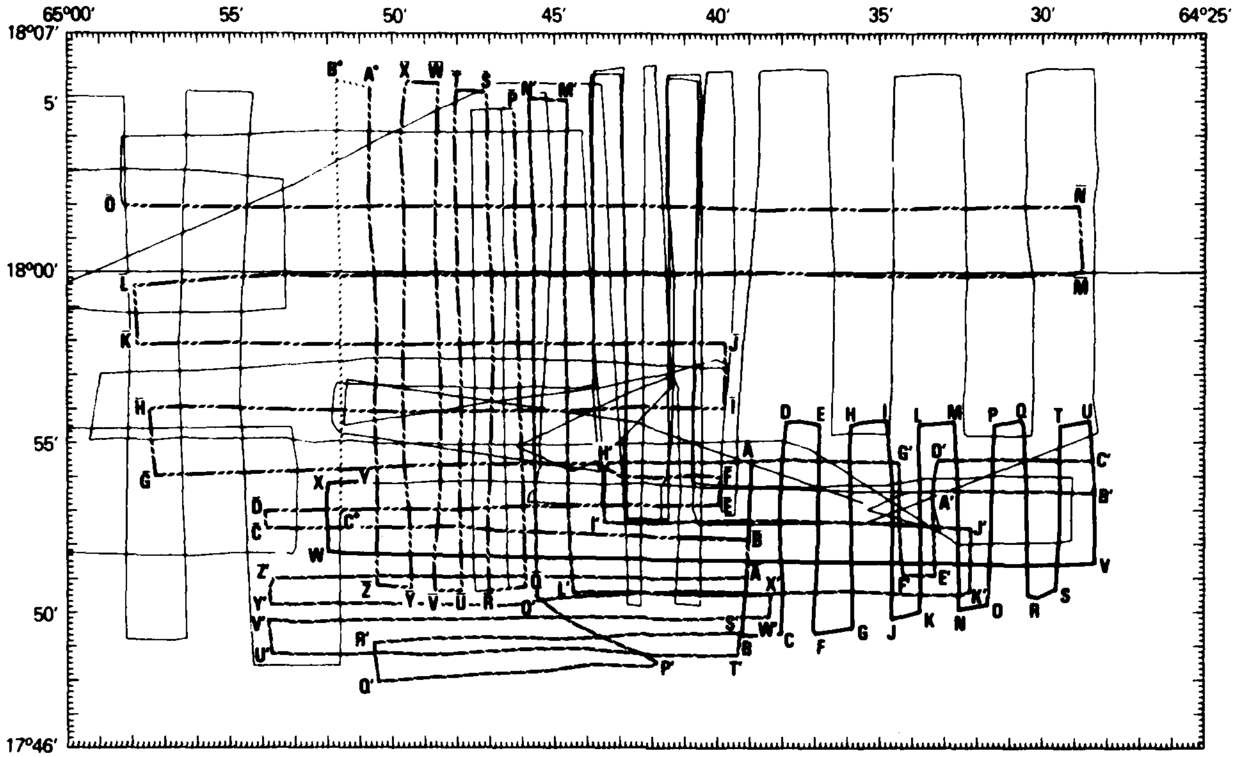

Figure 2.10. Ship's track showing the location of seismic profiles in Figures 2.5-9. The lines are shown in different patterns as a visual aid. The letters correspond to the letters in Figures 2.5-9.

The floor of the VIT strongly resembles a turbidite plain. This is indicated not only by its generally smooth surface, but particularly by the thick and conformably bedded sequence of reflectors that make up the sedimentary section and is characteristic of regions of known turbidite deposition (abyssal plains). One can surmise, therefore, that the axial sediments of the VIT consist of sand/silt layers alternating with layers of fine-grained terrigenous clay minerals and calcium carbonate. In those areas where the floor of the trough approaches 4500 m, lower carbonate contents can be expected (relative to shoaler areas) because this is approximately the depth at which major dissolution of calcium carbonate occurs. The seismic reflection profiles reveal no major acoustic discontinuities that might represent periods of erosion, nondeposition, tectonism, etc., indicating that the trough has probably experienced a long, relatively uneventful period of pelagic deposition randomly punctuated by eposides of turbidity current deposition.

It is important to add that each "reflector" seen in the profiles of the trough sediments does not necessarily correspond to an individual turbidite layer. If a sound pulse produced a single wavelet, then each turbidite layer would indeed produce a single reflector. The sound pulse, however, produces a complex wave train. Therefore, the interaction of sound with a turbidite layer results in several "reflectors." For this reason, the extensive sequence of reflectors seen in the trough sediments is only indicative of the presence of numerous turbidite layers. The same explanation applies to any major reflecting surface such as the seafloor itself. Indeed, even steep slopes appear to have a veneer of sediment because of this artificial layering effect.

The seismic reflection profiles also indicate, like the bathymetric profiles, that the south wall of the VIT is creased by gullies. Cross-sectional profiles show a uniformly smooth slope whereas across-slope profiles show a hummocky topography. This is well illustrated by Figure 2.6. Profile H'I'; is oriented N/S and shows a smooth, steep escarpment. Profile I'J' marks an abrupt change in direction to E/W and shows a correspondingly abrupt change to hummocky topography. Two hummocky areas on the lower slope (Fig. 2.3) eventually merge into one area extending to the trough floor. The westernmost area is clearly associated with Christiansted Canyon. The last profile (Z'A' Fig. 2.7), showing the final vestige of the canyon, occurs at 17°51.5'N (Fig. 2.3). The next traverse (profile VW, Fig. 2.5) reveals a broad area of low, hummocky topography directly in front of the canyon. Successive profiles show that the hummocky area broadens in a fan-shaped pattern and merges with the eastern hummocky area. This last area, coincides with the prominent reentrant, or bight, formed by the contours off the eastern end of the island (Fig. 2.3).

It is apparent that sediment and rock debris are being transported downslope via a few large, well-defined conduits on the upper slope, but on the lower slope, this material is transported to the floor of the VIT by a series of small gullies. The possibility that the hummocky topography actually represents slumps seems unlikely because one could then expect rough topography to appear in N/S as well as E/W profiles.

It is evident (Fig. 2.3) that the gullies feed sediment directly to the narrow, eastern portion of the VIT where it has obviously been contained (Fig. 2.8, profile FG) by the topographic high that "plugs" this part of the trough.

A distinctive gully pattern does not appear in the seismic profiles that cut across-slope west of Christiansted Canyon. Some gullying of this part of the slope is indicated in the 3.5 kHz echograms; however, downslope movement is probably more uniformly distributed along the slope, with the result that gullies (if any) are probably small and widely spaced. Of particular significance is the absence of a well-defined gully pattern off Salt River Canyon, implying that this canyon is not a major conduit for sediment transport.

The system of gullies on the lower slope off Christiansted Canyon can be attributed to the premature termination of the canyon at midslope. The gullies can be compared, in a sense, to the network of turbidity current channels that develop off the mouth of a major river. Erosional down-cutting of both canyons was probably stopped, or at least was dramatically reduced, by the existence of more resistant material at this point on the slope.

2.4.3 Seismicity

Holcombe et al. [2.6] have summarized existing information concerning the seismicity of the St. Croix area. Since then, a considerable amount of additional information has been gathered due to the establishment of a network of seismic stations [2.19]. Although the basic tectonic interpretation of the area remains unchanged, the network has allowed the seismicity of the Virgin Islands region to be resolved with an accuracy and sensitivity previously unavailable.

Most of the seismic activity occurs north of the islands and is associated with the boundary between the North American and Caribbean lithospheric plates. Superficially, this boundary is expressed as the Puerto Rico Trench; at depth it is manifest as a downward-sloping (45°) zone of shallow to intermediate focus earthquake foci that extends beneath the Virgin Islands Shelf.

Earthquake foci associated with the VIT are all shallow events (less than 20 km deep) and represent intraplate seismicity not directly related (if at all) to the downgoing seismic zone. The VIT, as noted, appears to be a manifestation of north-south extension, however, it may also accommodate an important component of strike-slip motion [2.20] along the north wall, which is coincident with the Anegada Fault Zone.

Holcombe et al. [2.6] concluded that weak events in the VIT region probably occur daily, but are detectable only with sensitive instrumentation; that moderatly strong events (intensity 4-6) occur infrequently (perhaps 3 or 4 per 200 years); and that major events (intensity 7 or more) are rare. The VIT has a history of destructive seismic activity as shown by the two major earthquakes (intensity 7-7.75) it produced in 1867 [2.21]. Significantly, in nearly 400 years of recorded history there is no record of a great earthquake (intensity 7.8 or more) in the area of the plate margin between 63°-67°W, leading Frankel et al. [2.22] to speculate on whether such an earthquake can ever occur in this area.

Perhaps the most significant observation revealed by the seismic network was the frequent occurrence of swarms of earthquakes, that is, several events (5-100's) produced within a small source area (less than 10 km) over a few days [2.22]. Most swarms occurred along 19°N between 64°W-65.2°W and were associated with the plate boundary. Major swarms, or sequences whose largest event was of magnitude greater than 4, only occurred in this area.

Three swarms were associated with the VIT. One occurred south of Vieques at about 17.9°N, 65.50°W and a second about 15 km to the southwest. The third, and most active swarm area, was centered at about 18.1°N, 64.9°W south of St. Thomas, roughly at the base of the north wall. Events with intensities of 3.2 were recorded.

The results from the seismic network and earlier analyses [2.23] indicate that the north wall is the major focus of seismicity for the VIT area and that it is presently active.

2.4.4 Dredging

During the LYNCH cruise, seven attempts were made at dredging the north slope off St. Croix to determine the nature of the slope (i.e., rock outcrops, loose rock debris or talus, mud, etc.); Only two attempts yielded samples. This material consisted of a few cobble-sized, dark rock fragments and occasional coral. The angularity of the rock fragments indicated that they had experienced little reworking (such as in shallow-water, high energy environments) and may have been derived from submarine outcrops. Although the ship was firmly anchored by the dredge on two occasions (indicating that the dredge was snagged on an outcrop of rock), wire tensions were generally low as the dredge was dragged across the bottom, suggesting that rock outcrops were not abundant. In addition, the meager sample recovery suggests that large debris (10-20 cm and more) is not abundant on the slope. These conclusions are generally supported by the visual observations discussed in the following section.

2.4.5 Visual Observations

Bottom photographs taken during the BARTLETT cruise and principally by the submersible ALVIN (January, 1980) provide the most direct information concerning the seafloor environment of the VIT. Camera stations and dive sites are located in Figure 2.3.

Photographs taken of the trough floor (Fig. 2.11A) are monotonously similar in appearance, all conveying the impression of a flat, soft bottom that has been disturbed only by the activity of bottom dwelling creatures, as shown by the presence of numerous small mounds, depressions, tracks, and trails (lebensspuren). None of the photographs show any

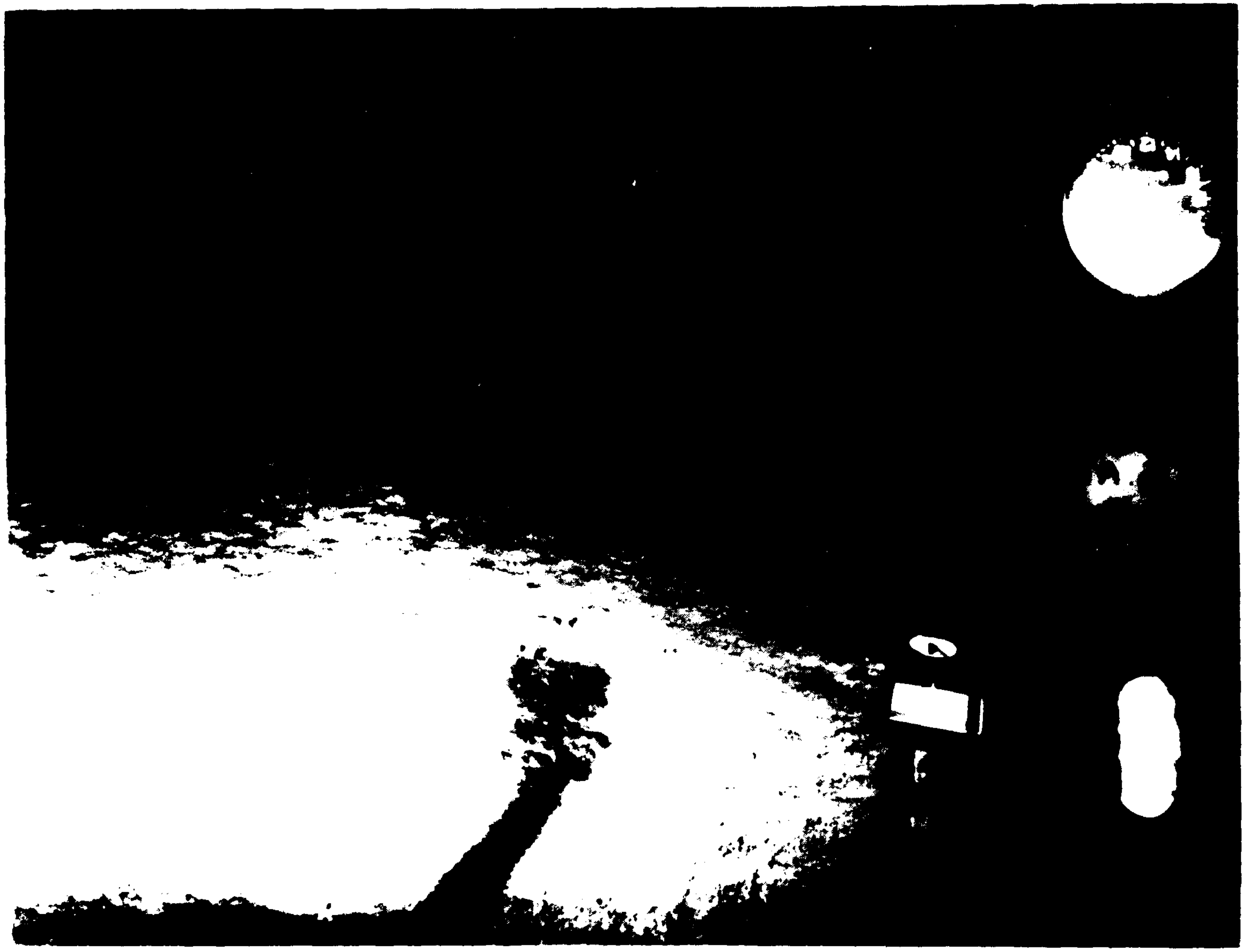

Figure 2.11A. Selective bottom photograph showing the floor of the Virgin Islands Trough.

sign of the sedimentary microrelief associated with bottom current activity; thus, tranquil bottom conditions are indicated.

Moderate to abundant lebensspuren are displayed in the trough photography, suggesting a large animal population. Owens et al. [2.24] have noted, however, that in areas of low sedimentary deposition, animal signs may be preserved. Thus, bottom photographs may show the sum of animal activity over a very long period of time. Because the lebensspuren on the trough floor are plentiful and biota is sparse, many of the lebensspuren may be quite old. Some lebensspuren are well-defined, while others have a smoothed appearance. Such selective smoothing by bottom currents is unlikely. It is reasonable to conclude, therefore, that many of the lebensspuren are indeed old, and have been gradually smoothed by slow pelagic deposition, and that destructive turbidity currents have not been recently active.

The most extensive photographic coverage focused on the south wall of the VIT where the submersible dives were made off Christiansted Canyon, Salt River Canyon, and Cane Bay (Fig. 2.3). Approximately two hours of continuous videotape (black and white) coverage was collected at each site, in addition to numerous still color photographs. The visual information and the written logs are condensed in the following paragraphs.

2.4.5.1 Christiansted Canyon

Site A, located off Christiansted Canyon occurred in water depths of 3950-3503 m. A typical photograph of the bottom is shown in Figure 2.11B. In general, visual estimates of the slopes ranged from 10° to 30° with most observations in the 12°-20° range. These estimates are in good agreement with the slope calculations based on the bathymetric map (Fig. 2.3). The observations also confirm that the lower slope off the canyon is indeed gullied. N/S trending ridges and valleys were frequently observed and produced a swale-like, or undulatory, topography on some areas of the slope. Estimated height of the ridges was 2 m or less with a spacing of about 10 m, and they appeared to be whitish outcrops of clay-like material.

Large outcrops of massive clay-like material produced a hummocky cliff/terrace topography between water depths of 3850-3530 m. Slopes on the smooth terrace areas appeared to be gentle (10°) and sediment covered, whereas the terrace faces were considerably steeper, forming cliff-like escarpments (Fig. 2.11C) several meters high in some cases. Attempts to sample fragments of lightcolored material similar to the outcrops showed that it was soft and easily broken.

Visual observations indicated that the bottom sediment was fine-grained. Analyses of collected samples by Hubbard et al. [2.11] showed that sand-sized material generally accounted for about 25% of the total sediment. Mean grain-size varied between 0.0156-0.0625 m, indicating that the sediment was primarily a medium to coarse silt. The existence of appreciable finer-grained sediment, however, is indicated because the submersible frequently raised a cloud of sediment which remained suspended. Predictably, grain size generally decreased toward the deep basin. The concentration of shallow-water constituents (coral, coralline algae fragments, ostracods, benthic foraminifera, molluscs, and rounded rock fragments) ranged between 7-43%, increasing toward the island.

Very coarse-size debris generally consisted of pebble (a few millimeters) to boulder-sized (up to 60 cm) rock and coral fragments widely scattered over the slope. Occasionally, this debris occurred in slightly greater concentrations, and heavy accumulations were observed in what appeared to be channels or gullies.

Figure 2.11B. Selective bottom photograph showing the floor of the South Wall.

Figure 2.11C. Selective bottom photograph showing the floor of the South Wall.

2.4.5.2 Salt River

Several features off the Salt River Canyon area (Site B) distinguished this part of the slope from the Christiansted Canyon area. Although the maximum estimated slope was only 5° greater off Salt River Canyon (35° versus 30°), the slopes were consistently steep (20°-30°). This was also evidenced by frequently observed zones of sediment cracking, suggesting slope instability. The cracks appeared as deep, narrow, linear features. Slope instability was further demonstrated by the submersible touching bottom and causing the sediment to crack.

Another striking feature is the much greater amount of coarse debris (Fig. 2.11D), noticeably, a gravel component (up to 7 mm) comprised primarily of coral rubble and rounded, terrigenous clastic pebbles [2.11]. An appreciable number of cobble and boulder-sized fragments were also observed (maximum size 80 cm x 150 cm).

Perhaps the most significant feature of the area is the existence of a hard substrate or "crust" (Fig. 2.11E) that is generally covered by about 10-15 cm of sediment. Attempts to retrieve sediment cores (by ALVIN as well as BARTLETT and LYNCH) were largely unsuccessful because of the coarse nature of the sediment and also the hard, impenetrable crust. In outcrop the crust appears to be cemented calcareous material at least 10 cm thick. The existence of the crust indicated that the "failure" cracks previously noted could not be too deep unless the crust has cracked as well.

The presence of small ridges indicated that this portion of the south slope may also be gullied; however, this was not as apparent as off Christiansted Canyon.

2.4.5.3 Cane Bay

The slope off Cane Bay (Site C) resembles the Salt River area because sand and gravel also form a significant portion of the sediments (Fig. 2.11F). Sediment analyses [2.11] show that silt and clay-sized material comprised roughly 50-75% of the total sediment on the lower third of the dive transect with mean grain-size falling between 0.0156-0.125 mm. Their results for the remaining two-thirds of the transect show a sharp increase in coarse constituents, with sand and gravel together comprising roughly 80-90% of the sediment and mean grain-size ranging between about 1-16 mm. Shallow water constituents were consistently more abundant (50-93%) than off Christiansted Canyon. Much of the gravel consisted of pebbles, fist-sized cobbles, and boulders as large as 50-100 cm (Fig. 2.11G). In areas of abundant cobbles the highest concentrations were estimated at 2-3 cobbles/meter; in areas of high concentration, boulders were spaced about 8-10 m apart.

Estimated slope gradients were generally intermediate (15°-25°) to the Salt River and Christiansted Canyon slopes. Although the Cane Bay slope appeared relatively uniform and topographically monotonous, it was marked in certain areas by a swale-like topography produced by low ridges. Most impressive was the occurrence of a large outcrop of bedded (layered) rock at 3085 m that formed a vertical escarpment of 7-10 m (Fig. 2.11H). The bedding planes dipped toward the island, which is consistent with the regional dip of the exposed island rock. The dark color and bedded appearance of the outcrop suggest that it could be a part of the thick Caledonia Formation that outcrops on St. Croix Island.

A hard substrate or crust, covered with a thin sediment veneer, was also observed in this area. Several cores successfully broke through, suggesting that the thickness and/or hardness of the crust is variable; soft sediment occurred beneath the crust.

Figure 2.11D. Selective bottom photograph showing the floor of the South Wall.

Figure 2.11E. Selective bottom photograph showing the floor of the South Wall.

Figure 2.11F. Selective bottom photograph showing the floor of the South Wall.

Figure 2.11G. Selective bottom photograph showing the floor of the South Wall.

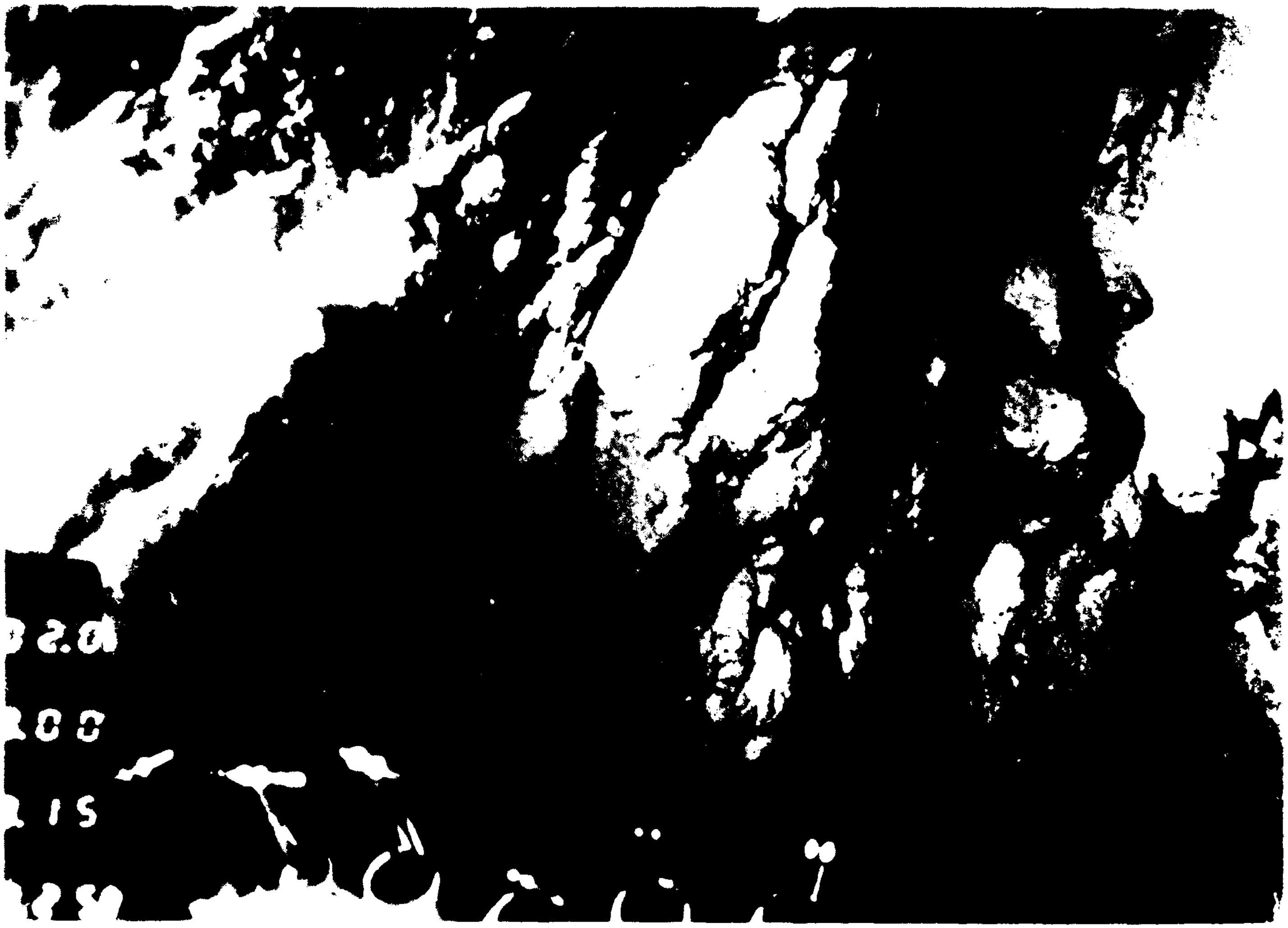

Figure 2.11H. Selective bottom photograph showing the floor of the South Wall.

2.4.5.4 Overview

The previous discussion highlights the major features observed at each dive site. Consequently, one can easily develop an exaggerated mental image of the slope environment. As a general overview and with the intent of establishing perspective, it is important to note that the visual impression of the bottom conveyed by the videotapes is that of a generally monotonous, subdued terrain covered by predominantly muddy, bioturbated sediment (similar in appearance to Fig. 2.11B.). This is true even off Christiansted Canyon where clay outcrops and gullied topography were most apparent. The most imposing topographic feature was the large outcrop off Cane Bay (Fig. 2.11H), although some of the clay outcrops off Christiansted Canyon were impressive. Most surprising, however, is that large outcrops were not encountered more frequently. It was difficult to distinguish in the videotapes coarse debris smaller than about 10 cm. Boulders and large cobble-size debris, however, appeared generally sparse and widely scattered.

2.4.6 Processes

It is apparent that a variety of sediment processes are, or have been, active in the survey area. The visual observations and sediment analyses clearly show that the steep south wall of the VIT is covered by a veneer of relatively fine-grained sediment (predominantly silt) as well as appreciable amounts of coarse debris consisting primarily of sand and gravel, and occasional large, massive blocks of material.

Pelagic deposition of fine-grained biogenic and terrigenous material can account for some of the sediment found in the deep basin and on the slopes. However, this mechanism does not account for the sands, gravels, and coarser materials which occur within the area. The nature of these materials, (coral, coralline algae fragments, rounded rock fragments, as well as sea grass) is convincing evidence of their shallow water origin. Hubbard et al. [2.22] indicate that the sands and gravels are transported off-shelf as bedload during storms. Gravitational settling dictates that these components deposit preferentially on the upper slope area although with time they could work downslope. Hubbard et al. [2.11] also suggest that transport of large blocks of material occurs only during major storms or perhaps were carried off during the low sea level stands of the Pleistocene. Once on the slope, however, it is not clear whether these larger materials roll or slide continuously down slope before coming to rest, undergo gradual downslope creep, or are carried down in slumps. It is reasonable to suspect all of these mechanisms.

Many of the larger blocks, perhaps most, are not necessarily derived from shallow water areas, but rather from submarine outcrops at various places on the face of the slope. Although outcropping clay ledges were observed on the lower slopes off Christiansted Canyon, outcrops of hard rock formations were conspicuously absent over the sea floor traversed by ALVIN (except for the single, large outcrop off Cane Bay). Outcrops would probably occur more frequently on the upper slopes, such as off Salt River Canyon, where gradients are steeper. The angularity of many of the rocks retrieved during dredging operations is more indicative of material having "calved" off the face of an outcrop (perhaps during seismicity) than material that resided in a shallow water area where it could undergo significant reworking before reaching the shelf edge. Indeed, it would be difficult to imagine some of the larger blocks of material being moved to the shelf edge even by large storms.

Slumping, together with turbidity currents, represent obvious and catastrophic mechanisms to distribute coarse as well as finer sediment downslope. Cracks observed in the slope sediments are highly indicative of slope failure or incipient slumping although, as noted in Part 2.4.2, evidence indicates that slumping is not a major process. Despite the steepness of the slope off St. Croix, the sediment thickness may not be great enough to develop sufficient shearing stress for large-scale, spontaneous slumping to occur. On the other hand, slumping may be a significant process on the north wall of the VIT, which is also steep, has a relatively thick sediment cover and is the locus of seismicity in the VIT. Indeed, the seismic reflection profiles of the north wall (Figs. 2.6 and 2.9) show terrace-like steps which may be slump scar features.

Turbidity currents and small-scale channelized flows may be an important sediment transport mechanism on the slope off St. Croix as indicated by the existence of gullies and canyons, and by the observation that the floor of the trough is a turbidite plain.

Despite the abundant evidence of downslope sediment transport, two facts suggest that sediment from St. Croix and its surrounding shelf area does not contribute as significantly to the basin sediment as one might expect. First, only a small depositional fan occurs at the base of the slope off Christiansted Canyon. Second, the tendency for the trough floor and subbottom reflectors to slope southward strongly implies north-to-south infilling of the trough. St. Croix clearly contributes some sediment to the VIT, however, the amount is probably vastly overwhelmed by material derived from the Virgin Islands Shelf to the north. The shallow water area of this shelf (200 m or less) provides an order of magnitude greater source area than the St. Croix shelf.

Much of the basin fill is probably a product of Pleistocene deposition. It is generally acknowledged that existing turbidite plains formed largely during the Pleistocene when erosion increased on a global scale. Since then, erosion (and turbidity current activity, slumping, etc.) has greatly diminished. In this regard, the gullied face of the St. Croix slope (and perhaps the canyons themselves) may be a relict of the Pleistocene as well.

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PART 3

GEOTECHNICAL INVESTIGATIONS

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PART 3.
GEOTECHNICAL INVESTIGATIONS

Geotechnical investigations were carried out in a selected area on the northern margin of St. Croix, Virgin Islands, integrating geology and geophysics (Part. 2) to provide fundamental data for offshore engineering applications on a carbonate island margin.

The general nature of the geotechnical properties of carbonate oozes and their variability are of interest in this investigation. Very limited geotechnical studies of carbonate sediments occur in the literature, particularly for deposits found on steep submarine slopes. Not only are these properties important to understanding the nature of the sediments, but this and the morphological setting of the sedimentary deposits are important aspects for virtually any offshore engineering activity utilizing the sea bed.

3.1 Earlier Investigations

Two earlier investigations addressed the geology and sedimentology of the north slope of St. Croix [3.1, 2]. Geotechnical measurements were reported [3.3] for sediments on the Frederiksted Plateau off the west end of the island, but such studies do not exist for the remaining offshore areas of the island or the VIT. This investigation is concerned with the engineering properties of the surficial sediments in relationship to the morphological characteristics and setting.

Figure 3.1 depicts the geological environments of interest including the outer shelf and slope off the north side of St. Croix Island and the adjacent VIT where bottom sampling and coring operations were conducted. Water depths range from a few tens of meters on the shelf to greater than 4000 m in the trough.

3.2 Area of Investigation

Station locations (Table 3.1) were chosen to collect representative sediment samples from the shelf, slope, trough, and "high" within the area of interest (Fig. 3.1). Limited ship time precluded a higher sampling density, which would be suggested for site specific areas of engineering concern.

3.3 Types of Sediment Sampling, Data Collected, and Limitations

Seven piston cores, 14 hydroplastic gravity cores, and 19 Shipek grab samples were recovered for geotechnical and sedimentological testing and study. The piston and hydroplastic corers used polyvinyl chloride (PVC) tubes (See Part 3.4.2.1). The PVC tubes were used as liners in a modified Ewing Piston Corer and were used as the coring sleeve (barrel) for the hydroplastic device [3.4, 5]. These coring tools recovered high quality sediment samples as revealed by x-radiographs made aboard ship. Details of the sedimentary structure and bioturbation can be observed readily in the radiographs. Soil testing procedures applicable to submarine sediments can be found in earlier reports [3.6, 7] and numerous textbooks on soil mechanics [3.8, 9]. Shipek grab samples were used at sites where core recovery was not possible because of thin sediment thickness or coarse sediment textures. These conditions often prevented corer penetration. Shipek grab sampling of muds often recovered relatively intact samples but disturbance prohibited testing of the mechanical properties such as shear strength. Of the 40 sample stations occupied (Table 3.1), the highest quality samples were tested in detail for mass physical and mechanical

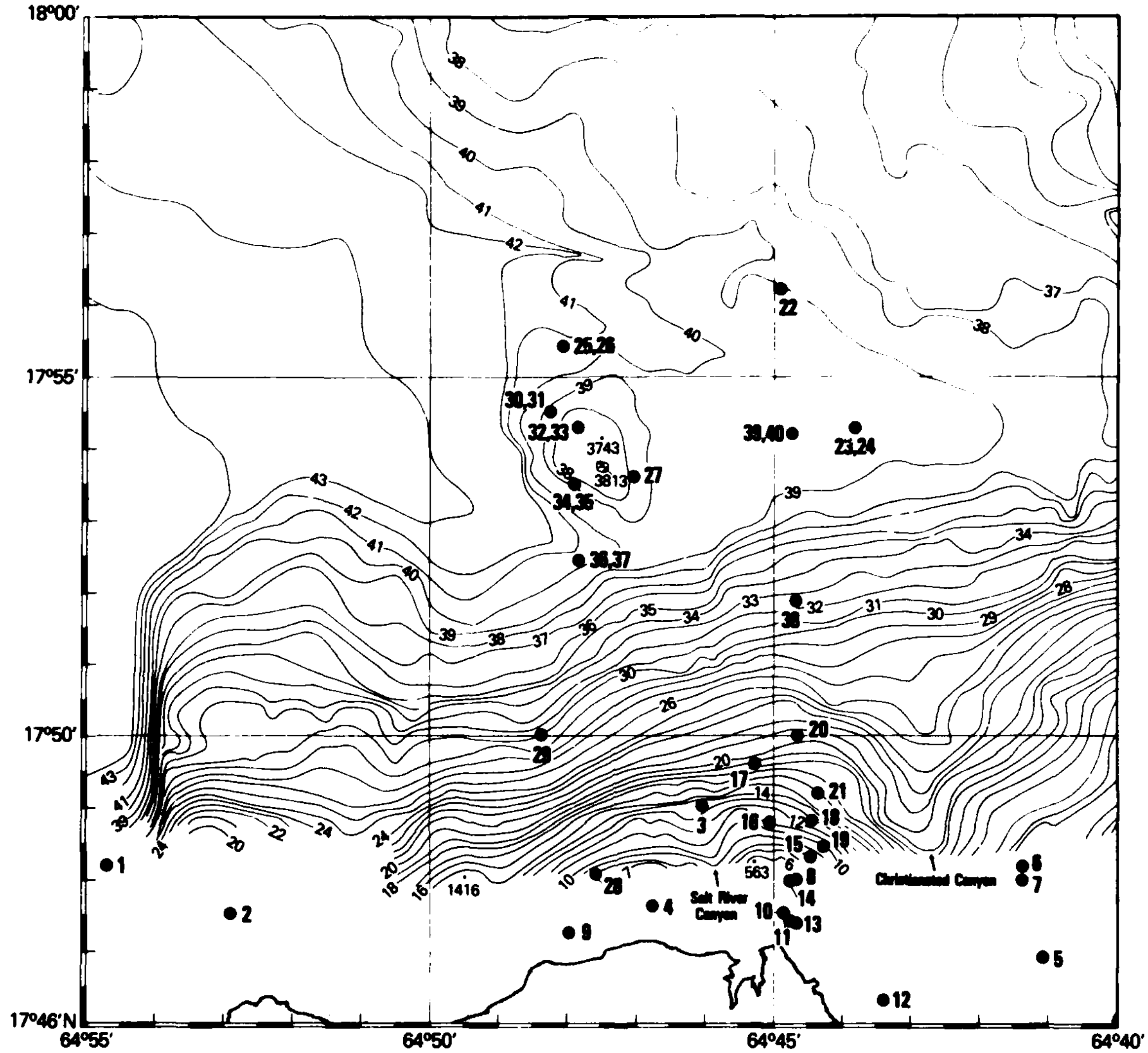


Figure 3.1. Bathymetric map of north slope, St. Croix Island and adjacent Virgin Islands Trough; contours are in uncorrected meters; contour interval is 100 m; bottom sample sites are indicated by solid dots and indexed by numbers.

properties as reflected in Table 3.2. Other samples having sufficient sediment volume, such as grabs and short hydroplastic core samples, were tested only for grain size and, in some cases, Atterberg limits were determined. The various figures throughout this report reflect the extent of the soil testing during this study. Miniature vane shear tests were made aboard ship and numerous subsamples were collected for shorebased testing. A limited number of direct shear (consolidated-drained) tests and one triaxial (consolidated-undrained) compression test were made on selected VIT sediment samples. Soil sensitivity was determined from natural and remolded vane shear tests for only the upper 1 to 2 m of core lengths. Water content, porosity, wet unit weight, grain specific gravity, and Atterberg limits analyses were performed on numerous samples with the greatest subsampling and testing also in the upper meter. Selected data

Table 3.1. Core locations.

Sample Number	Lat(N)/Long(W)	Sample Locations	Sample Device
1	17°48.2, 64°54.7	1885	Grab
2	17°47.5, 64°52.9	1389	Grab
3	17°49.0, 64°46.0	1441	Grab
4	17°47.6, 64°46.7	100	Grab
5	17°46.9, 64°41.0	42	Grab
6	17°48.2, 64°41.3	1262	Grab
7	17°48.0, 64°41.5	1071	Grab
8	17°48.0, 64°44.6	256	Grab
9	17°47.2, 64°47.9	81	Grab
10	17°47.5, 64°44.8	70	Grab
11	17°47.4, 64°44.7	57	Grab
12	17°46.3, 64°45.4	68	Grab
13	17°42.4, 64°44.6	44	Grab
14	17°48.0, 64°44.7	88	Grab
15	17°48.3, 64°44.4	760	Grab
16	17°48.8, 64°45.0	1006	Hydroplastic
17	17°49.6, 64°45.2	1745	Hydroplastic
18	17°48.8, 64°44.4	1293	Hydroplastic
19	17°48.4, 64°44.2	1289	Hydroplastic
20	17°50.0, 64°44.6	2651	Hydroplastic
21	17°49.2, 64°44.3	1568	Grab
22	17°56.2, 64°44.9	3819	Piston
23	17°54.3, 64°43.8	3859	Piston
24	17°54.3, 64°43.8	3859	Hydroplastic
25	17°55.4, 64°48.0	4005	Piston
26	17°55.4, 64°48.0	4005	Hydroplastic
27	17°53.6, 64°47.0	3724	Hydroplastic
28	17°48.0, 64°47.5	730	Grab
29	17°50.0, 64°48.3	3131	Grab
30	17°54.5, 64°48.2	4098	Piston
31	17°54.5, 64°48.2	4098	Hydroplastic
32	17°54.3, 64°47.8	3707	Piston
33	17°54.3, 64°47.8	3707	Hydroplastic

Table 3.1, continued. Core locations.

Sample Number	Lat(N)/Long(W)	Sample Locations	Sample Device
34	17°53.5, 64°47.9	3911	Hydroplastic
35	17°53.5, 64°47.9	3911	Piston
36	17°52.4, 64°47.8	3949	Hydroplastic
37	17°52.4, 64° 47.8	3800	Grab
38	17°51.9, 64° 44.7	3659	Hydroplastic
39	17°54.2, 64° 44.7	3868	Hydroplastic
40	17°54.2, 64° 44.7	3868	Piston
41	17°50.8, 65° 00.8	4354	Hydroplastic
42	17°50.8, 65° 00.8	4354	Piston
43	17°51.4, 64° 56.7	4371	Hydroplastic
44	17°51.4, 64° 56.7	4371	Piston
45	17°50.3, 64° 55.1	4334	Hydroplastic
46	17°50.6, 64° 55.3	1334	Piston
47	17°47.5, 65°01.0	900	Hydroplastic
48	17°47.5, 65°01.0	900	Piston
49	17°45.1, 65° 06.2	1150	Hydroplastic
50	17°45.1, 65° 06.2	1150	Piston
51	17°53.7, 65° 05.4	4350	Piston
52	17°48.1, 65° 05.3	3261	Hydroplastic
53	17°48.1, 65° 05.3	3261	Grab
54	17°48.6, 65° 03.6	3915	Hydroplastic
55	17°48.6, 65° 03.6	3915	Grab
56	17°48.6, 65° 02.4	2926	Hydroplastic
57	17°48.6, 65° 02.4	2926	Grab
58	17°49.0, 64° 59.9	2155	Hydroplastic
59	17°47.6, 64°58.4	1396	Grab
60	17°47.8, 64° 56.2	2495	Hydroplastic
61	17°58.2, 65° 53.9	20	Grab
62	17°58.2, 65° 53.9	20	Grab
63	17°58.2, 65° 53.9	17	Grab
64	17°57.7, 65°55.2	35	Grab
65	17°57.7, 65°55.2	28	Grab

Table 3.1, continued. Core locations.

Sample Number	Lat(N)/Long(W)	Sample Locations	Sample Dev.ce
66	$17^{o}54.2$, $65^{o}57.9$	45	Grab
67	$17^{o}57.9$, $65^{o}54.2$	91	Grab
68	$17^{o}58.0$, $65^{o}54.2$	34	Grab
69	$18^{o}00.5$, $65^{o}53.9$	417	Grab
70	$17^{o}57.6$, $65^{o}53.5$	825	Grab
71	$17^{o}57.4$, $65^{o}53.8$	822	Hydroplastic
72	$17^{o}57.2$, $65^{o}53.6$	1006	Hydroplastic
73	$17^{o}56.8$, $65^{o}52.8$	1354	Grab
74	$17^{o}56.8$, $65^{o}52.8$	1354	Hydroplastic
75	$17^{o}56.0$, $65^{o}51.9$	1750	Grab
76	$17^{o}55.9$, $65^{o}52.0$	1790	Hydroplastic
77	$17^{o}55.8$, $65^{o}54.2$	1500	Hydroplastic
78	$17^{o}56.3$, $65^{o}54.5$	1207	Hydroplastic
79	$17^{o}56.9$, $65^{o}53.1$	890	Hydroplastic
80	$17^{o}56.9$, $65^{o}53.6$	1200	Hydroplastic
81	$17^{o}52.2$, $65^{o}51.8$	1920	Hydroplastic
82	$17^{o}52.2$, $65^{o}51.8$	1920	Piston
83	$17^{o}53.9$, $65^{o}49.7$	1899	Hydroplastic
84	$17^{o}53.9$, $65^{o}49.7$	1899	Piston
85	$17^{o}56.3$, $65^{o}52.1$	1674	Piston
86	$17^{o}57.2$, $65^{o}53.9$	1100	Hydroplastic
87	$17^{o}57.2$, $65^{o}53.9$	1100	Piston

Footnote - Samples 41 through 60 were taken from the West St. Croix Margin. Samples 61 through 87 were taken from the south Puerto Rican Margin. Data from these samples are not included in this report.

Table 3.2. Geotechnical properties.

CORE	SHEAR STRENGTH (kPa) MIN	AVG	MAX	WATER CONTENT (w%) MIN	AVG	MAX	SENSITIVITY S_t MIN	AVG	MAX	WET UNIT WEIGHT Mg/m^3 MIN	AVG	MAX	POROSITY (n%) MIN	AVG	MAX	SPECIFIC GRAVITY OF SOLIDS G_s MIN	AVG	MAX	CORE LENGTH (m)
1+				85	101	118				1.43	1.48	1.52	70	73	75	2.73	2.74	2.74	
2+				73	77	84				1.54	1.56	1.58	67	68	70	2.73	2.75	2.81	
16	1.3	3.1	4.8	53	65	80	3.0	3.3	3.7	1.54	1.64	1.71	59	63.5	69	2.73	2.74	2.75	.66
17		5.4*		53	57	60		3.2*		1.66	1.69	1.71	59	60.6	62		2.73*		.20
18	3.4	5.9	8.3	52	59	71	3.1	3.8	4.4	1.59	1.67	1.72	59	61.8	66	2.73	2.75	2.76	.65
20		7.0*		55	59	65		4.8*		1.63	1.67	1.69	60	61.6	64		2.74*		.20
22	4.4	25.9	48.0	34	55	71		6.7*		1.59	1.71	1.90	48	59.0	66	2.70	2.73	2.76	4.96
25	6.6	35.8	55.1	39	60	80	4.7	7.5	12.2	1 54	1.66	1.84	52	62.0	69	2.73	2.74	2.75	5.54
30	11.2	23.4	44.1	55	64	85	8.7	12.1	14.0	1.52	1.62	1.69	60	64.5	70	2.72	2.74	2.75	5.13
31				61	64	72													.44
32	17.9	40.2	59.5	44	52	67	4.2	4.4	4.5	1.61	1.70	1.79	55	59.6	65	2.73	2.74	2.75	4.85
34				59	64	71				1.59	1.64	1.66	62	63.3	66	2.72	2.73	2.74	.70
35	10.7	39.4	69.1	33	55	80	3.4	4.8	6.1	1.54	1.66	1.91	48	61.9	69	2.73	2.74	2.75	5.33
36	3.5	5.8	8.2	54	57	68		4.4*		1.61	1.66	1.70	60	62.3	65	2.74	2.74	2.75	.24
37+					67*														
38	6.8	10.0	14.2	53	57	67	4.9	6.1	7.3	1.62	1.66	1.71	59	62.2	65	2.73	2.74	2.74	.60

\+ Grab samples
*= One value only

are reported for the upper 5.5 m of surficial sediments, however, greatest emphasis in this report is on the upper 1 m.

3.4 Technical Approach, Equipment, Procedures

Soil samples were collected aboard the NOAA Ship RESEARCHER in August 1981. Concurrently geophysical (narrow beam echo sounding and seismic reflection) profiling was completed and used for establishing sampling locations. (It is important to note that the narrowbeam data could not be incorporated into Figures 2.3 and 3.1. It is not believed, however, that its inclusion would have greatly altered the contours.) Samples were recovered from soil deposits representative of the major morphological features from the area of investigation on the northern margin of St. Croix, V.I.: the narrow shallow water carbonate shelf; the steep slope; and the deep-sea basin. Shallow water reef material and carbonate debris occurs along the shelf. A thin carbonate ooze overlies the steep slope where occasionally rock outcrops occur. The trough sediments are clayey silts and turbidite deposits.

3.4.1 Surveying and Sampling

A 210 nm^2 reconnaissance survey was conducted at approximately 500 m trackline spacings. This area selected for geotechnical investigation is part of a large geological study area discussed in Part II of this report. The high degree of precision (theoretically ± 1 m) of the Racal-Decca model 540 navigation system and the precision of the narrow beam (~2-2/3 half-angle beam) enabled the RESEARCHER to accurately relocate and position over seafloor features for bottom sampling.

The large sail area and overall size of the RESEARCHER made maneuvering difficult in shallow waters on the St. Croix shelf. This precluded the collection of large numbers of bottom samples and bathymetric profiling in very shallow water near shore (see Fig. 3.1 for sample locations).

Large diameter piston cores, 20- and 40-feet long, were handled using a 20,000 ton A-frame and 10,000 pound capacity crane on the aft boat deck. Piston cores were assembled, deployed, and recovered using a piston core cradle [3.10] mounted on the starboard side and aft area of the ship. Short PVC hydroplastic cores and ship grab samples were handled from the port oceanographic winch. Upon recovery, soil samples were numbered, sectioned, capped, sealed, and moved into the oceanographic laboratory aboard ship for further processing. Samples were kept in cold storage aboard ship (when not being processed) for shipment to the shore-based laboratory (NOAA, AOML) in Miami, Florida.

3.4.2 Equipment and Techniques

The following subsections provide specific information relating to the equipment and procedures used for this investigation.

3.4.2.1 Field Equipment and Shipboard Techniques

Sediment coring devices used during the field work consisted of two types: a large diameter gravity corer called the hydroplastic corer and a modified "Ewing-type" large diameter piston corer.

The hydroplastic corer was originally described by Richards and Keller [3.4] and later modified by Lambert and Merrill [3.5]. Figure 3.2 is a line drawing of this corer showing the weight stand with finned shroud and stackable weights, which allows the variability of driving force of up to 450 pounds by the addition of 50 pound lead weights. The core barrel is made of standard 160 psi rated 3 inch IPS PVC plastic pipe, which has a 3.25 inch ID and bolts onto the weight stand with two machine screws.

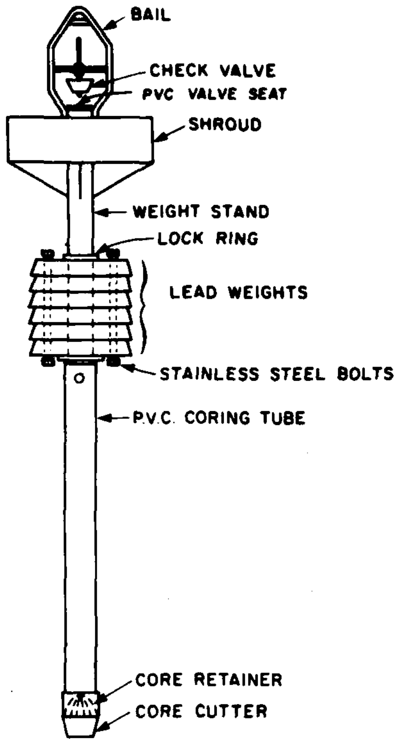


Figure 3.2. Hydroplastic corer.

High quality 10 foot cores can be collected easily with this corer in relatively soft sediment. The hydroplastic corer with a 5 ft barrel is also used routinely as a pilot (trigger) for the piston corer. The hydroplastic corer has been used successfully to collect high quality samples for trace metal analysis when fitted with plastic core cutters and retainers [3.5].

The large diameter piston corer (Fig. 3.3) is a modified version of the standard 2000 pound "Ewing-type" piston corer manufactured by Ocean/Seismic/Survey, Inc., and Eastern Instrument Corporation. The modified corer uses the standard core head and 3.5 inch IPS (4.0 inch OD, 3.55 inch ID) black water pipe with threaded ends as the core barrel and 125 psi, 3 inch IPS (3.5 inch OD, 3.25 inch ID) PVC plastic pipe as the core liner. The core barrels are shortened (in-house) to 19 ft, 4 inch lengths (from 21 ft standard lengths) and can be coupled

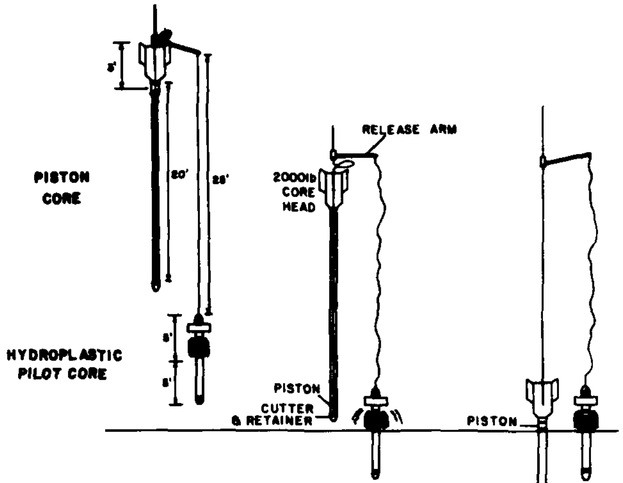


Figure 3.3. Operation of the free-fall method of coring using the modified "Ewing-type" large diameter piston corer with a hydroplastic corer used as the trip weight.

together with sleeved and threaded couplings for cores up to 58 ft long. The core cutters and retainers (Fig. 3.4) are produced from hardened steel and phosphor bronze, respectively. The piston (Fig. 3.5) is simply two 0.5 inch thick rubber discs compressed between a steel block and backing plates. The amount of suction created by the piston

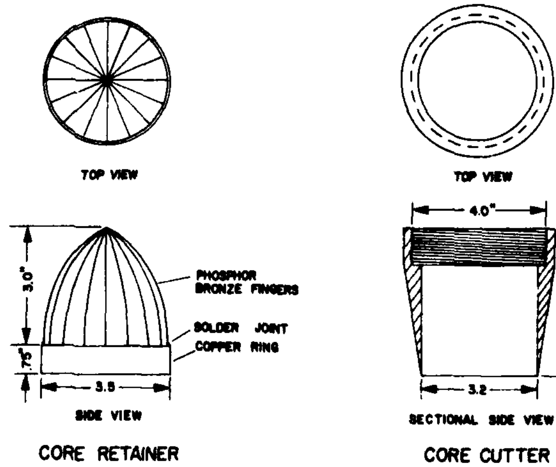


Figure 3.4. Core retainers and cutters used with the large diameter piston corer.

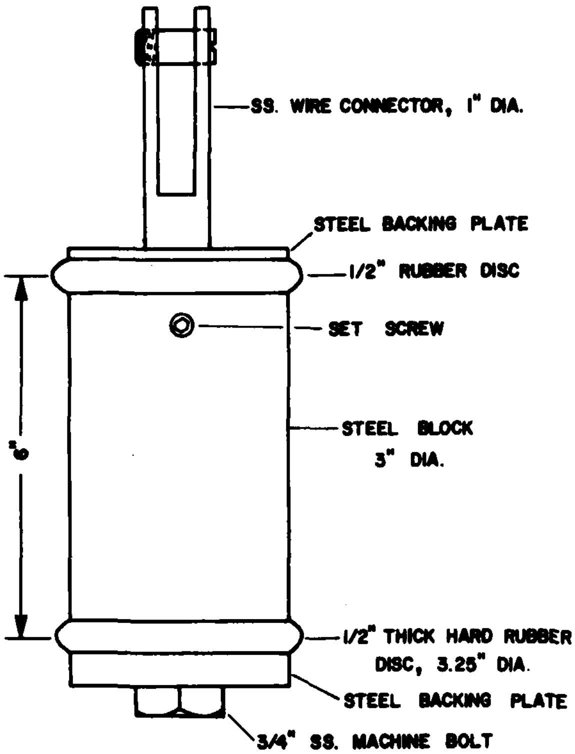


Figure 3.5. Modified piston used with the large diameter piston corer.

can be adjusted by compressing the rubber discs with the backing plates, thus enlarging the outside diameter of the discs and increasing the sidewall friction on the core liner. The piston corer is free-fallen approximately 15 ft by using a standard trigger release arm and a hydroplastic corer, with a 5 ft barrel used as the trigger weight (Fig. 3.3).

The grab sampler used in this project is the Model 860 Shipek sediment sampler manufactured by Hydro Products (Fig. 3.6). This spring loaded sampler collects approximately 0.5 ft by 4 inch deep samples of soft oozes or coarse sand. Samples collected with the Shipek grab are relatively undisturbed compared to other types of grab samples. Because of the horizontally oriented cylindrical shape after closure, this sampler is virtually immune to sample washout during retrieval.

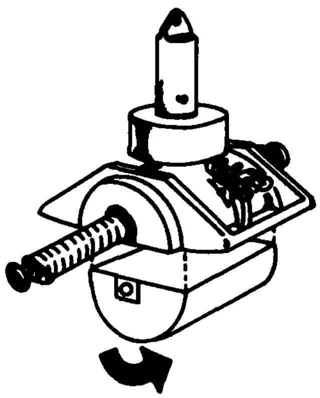


Figure 3.6. Shipek grab sampler.

Immediately after collection, all cores were cut into 12 inch sections and x-radiographed aboard ship, using a Hewlett-Packard Faxitron x-ray machine. This instrument is equipped with an automatic exposure control system for consistency of film exposure. Since the cores were exposed to x-radiation while in contact with the film, exposures are 1:1 and depth within the core was determined on the film by a lead scale lying beside the core section on the film. The radiographs of the cores were used to assess any disturbance that may have occurred during coring operations, to delineate the presence or absence of sedimentary structures, and to describe the cores initially, prior to laboratory analysis. Using the initial core descriptions, a general sampling pattern was established for geotechnical testing and subsampling before the cores were opened. This procedure permits the best selection of the core sections and intervals for geotechnical analyses.

Shipboard laboratory analyses included x-radiography, natural and remolded miniature vane shear, torvane, and core description. Subsamples were removed for water content, grain specific gravity, Atterberg limits, carbonate analysis, total organic carbon, size analysis, direct shear and triaxial shear. All subsamples removed for shorebased laboratory analyses were refrigerated at

4°C immediately after collection except for the organic carbon samples which were frozen. The water content samples were placed in pre-weighed glass vials, capped, and inserted into moisture tight polethylene bags along with moist paper towels to retain a high humidity environment around the vials until the water content analyses could be completed.

Torvane measurements were made on selected ends of core sections using an instrument manufactured by Soiltest, Inc. The torvane consists of a hand-held wheel with pointer, and a calibrated spring through which torque is transmitted to the multi-bladed vanes (Fig. 3.7). Basically, the vane is inserted into the sediment (a smooth surface is required), and torque is applied through the movable hand-held wheel until failure occurs. Numerous measurements can be carried out quickly. Unfortunately, the speed and consistency at which the torque is applied depends on the operator, with potentially varying results. During shipboard testing, if miniature vane measurements were made on the same core section end, the torvane measurement was completed first using either the standard vane (0 to 1.0 TSF) or the sensitive vane adapter (0 to 0.2 TSF). Torvane results are given in Appendix A, Table A-6.7.3.

Miniature vane shear tests were accomplished aboard ship using a Wykeham Farrance motorized laboratory vane apparatus (Fig. 3.8) using a 0.5 inch wide by 1 inch long vane rotated at 60°/min. Details of vane shear testing of soils can be found in Evans and Sherratt [3.11], Richards [3.6] and the American Society for Testing Materials [3.12]. "Natural" shear strength measurements were made on both ends of the 12 inch core sections by gently clamping the complete section in the instrument (Fig. 3.9) where sediment conditions and quality permitted. Samples for water content and grain specific gravity were removed from the immediate vicinity of the vane measurement. Remolded shear strength measurements were selectively made by scooping adequate material out of the core section ends after the natural "undisturbed" test was determined, remolding the sample and reconstituting the sample by placing it in a 1-1/4 inch by 2-3/4 inch long, thin-wall brass tube. The sample was then clamped in the vane apparatus and the remolded strength determined. The sample used for the remolded test was then containerized and later used for shore based Atterberg limits tests.

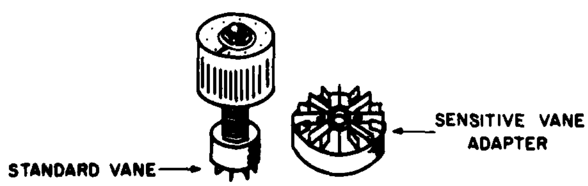


Figure 3.7. Torvane device and sensitive vane adapter.

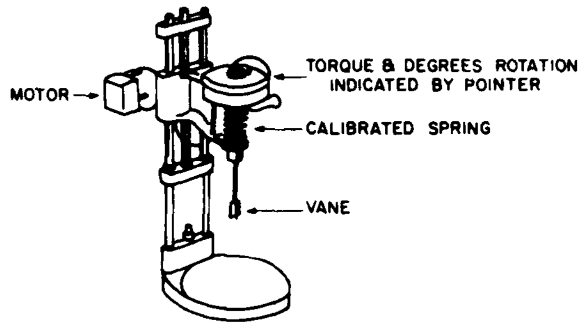


Figure 3.8. Minature vane shear apparatus.

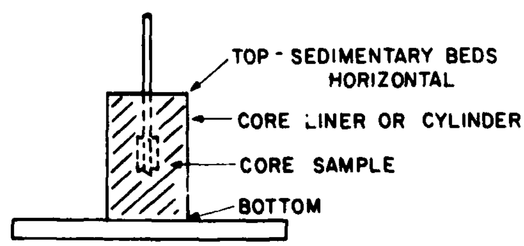


Figure 3.9. Typical arrangement for inserting mini-vane into short core section. Vane is parallel to core length.

Immediately after testing the ends of each core section for miniature vane shear, torvane, and removing samples for water content, grain specific gravity and Atterberg limits, each of the upper four core sections (upper 4 ft) were extruded and split using an osmotic knife [3.13]. Each split section was additionally sampled for water content at 2 inch intervals or where structural or textural changes occurred. One-half of the split core sections was described in detail and saved for archive purposes. Core sections below the first four were not extruded and split aboard ship but were sampled only at the ends of each section.

Special core sections or portions of sections were saved for direct shear and triaxial shear testing. The unextruded core sections were packed in padded containers and stored vertically in a refrigerated van until transferred to cold storage onshore.

3.4.2.2 Shore-Based Laboratory Testing and Techniques

Limited soil strength (consolidated-drained) testing was accomplished using a modified direct shear apparatus manufactured by Soiltest, Inc. The tests were performed using a lightweight acrylic plastic split ring soil sample retainer (Fig. 3.10). One-half of the sample retainer is held fixed (lower) while a shear stress is applied to the adjoining but slightly separated retainer (upper). The sample was confined above and below by porous stones for pore water drainage. Prior to applying the shear stress a normal load was applied to the sample and allowed to consolidate (load P, Figs. 3.10 and 3.11). When a sufficient magnitude of shear stress is applied to the movable retainer, the soil sample deforms and ultimately shears along a fixed surface (Fig. 3.11, see shear plane). Electronic monitoring devices (load cell and two linear displacement transducers), along with a data logger, were used continuously throughout the test to monitor shear stress applied, and horizontal and vertical movement. With the standard direct shear test, drained or undrained (consolidated or unconsolidated) testing can be carried out [3.14]. Details and well-documented discussions on the theory and testing can be found in numerous textbooks on soil mechanics.

Triaxial tests were performed on a very limited number of VIT samples (cores 22 and 35) using Wykeham Farrance equipment. The triaxial test is a more rigorous strength test than the direct shear test and is often referred to as the "cylindrical compression test" [3.14]. It utilizes a cylindrical specimen and chamber fluid which produces a stress in two principal planes (Figs. 3.12 and 3.13) when pressure is applied through the confining pressure unit. Thus, a confining stress is produced in which $\sigma_2 = \sigma_3$ and a uniaxial shearing stress is produced by a movable piston or ram.

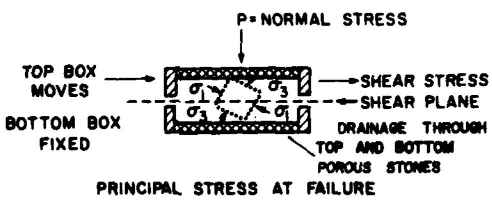


Figure 3.10. Sediment sample shown in a split ring soil sample retainer for use in the direct shear test. Principal stresses at failure shown (σ_1 and σ_3).

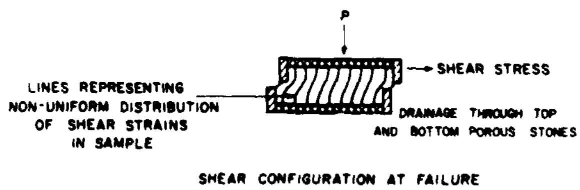


Figure 3.11. Example of shear configuration at failure in the direct shear test. Note direction of normal load, shear plane, and non-uniform distribution of shear strains.

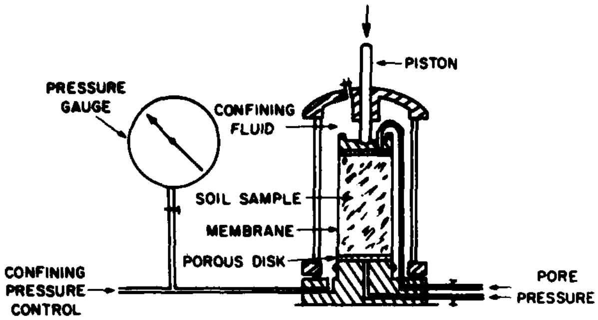


Figure 3.12. Typical configuration of triaxial test apparatus and cylindrical soil sample. From Bishop and Henkel, 1962.

The triaxial test is time consuming and requires considerably more sample preparation than the direct shear test. It has advantages because the complete state of stress is known at all stages of testing. Specimen volume changes are more accurate to determine, and pore pressure can be monitored and controlled. Readers with further interest in these tests are referred to a good review by Lambe [3.14, chapter XI] of the advantages of the triaxial and direct shear test. An excellent book on triaxial testing is available elsewhere [3.15]. A book giving further information regarding the shear strength of cohesive soils is available through the American Society of Civil Engineers [3.16]. Details of shear strength testing of soils can be found in Lambe and Whitman [3.9]. Further details of the concepts, theory, and practice of strength testing of soils is beyond the scope of this report and can be easily found in numerous textbooks on soil mechanics and in numerous papers.

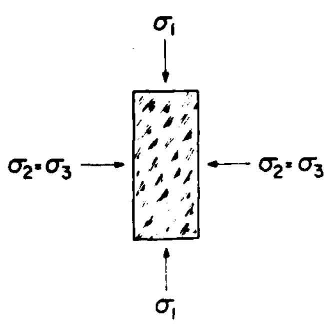


Figure 3.13. Typical example of principal stresses on cylindrical soil sample in triaxial test.

Atterberg limits tests were performed on the VIT samples generally following the ASTM standard methods for liquid limit (LL) (D 423-66, 1972) and plastic limit (PL) (D 424-59, 1971) with a minor exception. A representative portion of the entire sample, including all grain sizes, was used for the Atterberg limits tests. The ASTM method recommends removal of all grain sizes larger than silt. Removal of small percentages of sand size particles in fine-grained submarine sediments is considered unnecessary [3.7]; consequently, our techniques for the determination of Atterberg limits followed those prescribed by Richards, [3.7]. Samples containing large percentages of sand size material were not tested for Atterberg limits. Plasticity index was calculated from the liquid limit and plastic limit: PI = LL-PL. Liquidity index (LI) was calculated from the plastic limit, plasticity index, and water content (w); $LI = \frac{w - PL}{LL - PL}$. The liquid limit device used in these tests was a motorized type with automatic counter (Model CL-205) manufactured by Soiltest, Inc. Measurements of water content (w) followed ASTM standard procedures (D 2216-71) and values reported are uncorrected for salt content. Values of wet unit weight and porosity were determined using methods described by Bennett and Lambert [3.17]. Values of void ratio and dry unit weight were calculated using simple formulas that can be found in soils engineering textbooks.

Grain specific gravity values were determined using an in-house designed helium pycnometer (Fig. 3.14). The principle of this instrument is based on the ideal gas laws and uses a single cylinder piston to compress a relatively large and constant volume of dry gas into a small chamber containing the dry

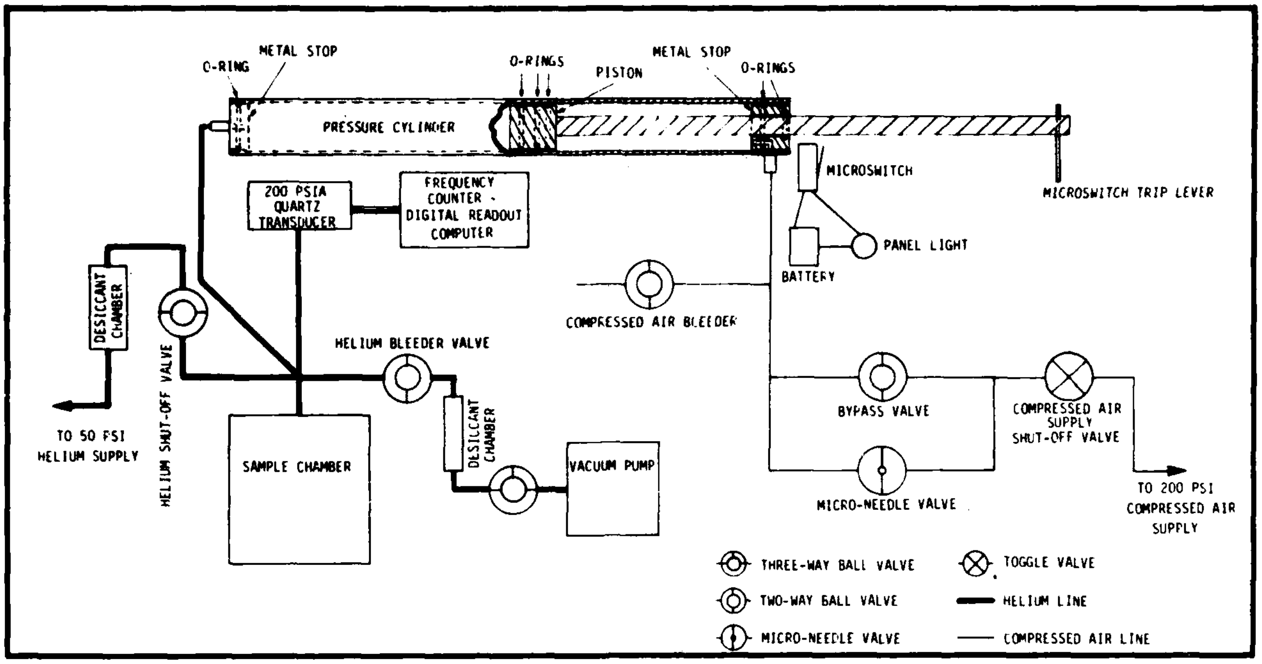


Figure 3.14. Schematic of single piston helium pycnometer.

powdered sediment. As the volume of sediment in the chamber increases, the final pressure registered after the compression of the gas also increases proportionately. Calibration of the instrument was accomplished by using a standard sediment of known grain density and varying the sample volume to determine a corresponding pressure. The instrument is sensitive to small changes in atmospheric pressures; however, this is easily compensated for by determining the pressure of a standard volume before each sediment sample is tested and normalizing its final pressure to a set standard determined in the instrument calibration. Once the volume of the sample is determined using the pycnometer, average grain density is easily calculated by the ratio of the weight of the sample, in grams, to the sample volume in cubic centimeters. Preliminary calculation of instrument precision (repeatability) is approximately 0.004 cc in volume or 0.01 g/cc in average grain density for a sample with a grain density of 2.70 g/cc. Reliability of this technique for determining grain density has been thoroughly checked against the ASTM standard method [3.18].

Size analysis was accomplished using a combination of sieving (particles >63 µm) and pipette analysis (particles <63 µm) following the Wentworth [3.19] size classification. The samples were first air dried then wet sieved to remove grains >63 µm. The silts and clays (<63 µm) were caught in a one liter graduated cylinder during wet seiving. The coarse fraction, after oven drying, was dry seived and components divided into 4.75 mm, 4.75 mm-2.0 mm, 2.0 mm-75 µm, 75 µm-63 µm. Any residue left in the sieve stack pan (<63 µm) was then added to the graduated cylinder for pipette analysis. The pipette analysis follows the method described by Krumbein and Pettijohn [3.20]. One gram of sodium hexametaphosphate was added to each cylinder as a dispersent prior to testing. Settling times for each pipette draw were calculated using the average grain specific gravity of sample and density of the demineralized water. Pipette draws were made corresponding to the 3.9 μm and 2.0 μm size boundaries.

3.4.5 Techniques and Data Quality

Equations used for the calculations of the mass physical properties are found in various textbooks on soil mechanics and other publications [3.8, 9, 17, 19, 20]. No corrections were made for salt content of the interstitial water with the exception of specific gravity determinations. The interested reader can use a value of 63.9 lb/ft^3 (1.024 Mg/m^3) for the density of seawater (@35 ppt, 4°C) and for most practical pur-purposes, a value of 1.2% of the volume of the water can be used for the calculation of the volume occupied by the salts in standard seawater having a salinity of 35 ppt [3.17].

The test procedures for the geotechnical properties closely followed the methods described by others [3.14, 23] and details of special techniques are discussed in Sections 3.4.2.1 and 3.4.2.2 in this report.

A detailed discussion of testing procedures and limits of reproducibility can be found elsewhere [3.26] but for convenience of the reader the limits of analytical precision are summarized in Table 3.3 as follows:

Table 3.3. Reported limits of reproducibility for selected geotechnical tests and analyses.

Type of Test/Analysis	Reported Reproducibility*	Reference
Atterberg Limits	±2-5%	3.24, 25
Vane Shear Tests	±0.01PSI(0.7 g/cm^2)	3.26
Vane-Triaxial Apparatus	±1%	3.27
Vane Shear Test	±.003-0.011PSI ±(0.2-0.8g/cm^2)	3.28
Grain Size	±2%-+4% ±1%-+2%	3.29 3.28
Water Content, and Wet Unit Weight	±1%	3.28
Grain Specific Gravity	±0.5%	3.28
Porosity	<±2%	3.28
Void Ratio	<±5%	3.28

*percent of observed value except where absolute value is given

3.5 Results and Interpretation

Tables and plots of the geotechnical properties for individual soil samples (cores and grabs) are found in Appendix A. Detailed discussion of each sample is beyond the scope and purpose of this report, but the interested reader can find detailed results by sample number and by depth in core (sample) in the appendix. The following discussion of the geotechnical properties analyses results is limited to the suite of data as a whole rather than as individual discussions of samples. Where necessary, individual samples are noted and the reader can quickly refer to the appendix as required.

3.5.1 Sediments

Sediments within the study area are calcareous oozes composed primarily of biogenic debris with terrigenous material usually forming a minor part of the constituents. The texture of these soils displayed in Figure 3.15 is highly variable over the shelf, slope and trough, although there is a general fining of the sediments with increased water depth.

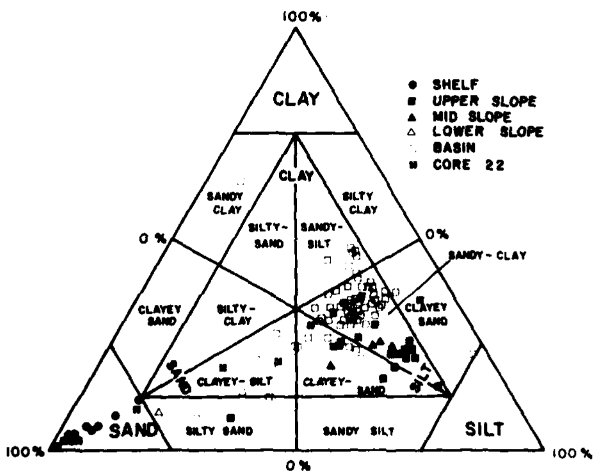


Figure 3.15. Textural classification of sediments from the northern margin of St. Croix using Link's (1966) method. Samples are shown according to their physiographic location on the shelf, upper, mid or lower slope and basin. Note the high variability in the texture classification of Core 22 (labeled) due to the presence of several turbidite sequences.

Shelf sediments are characterized by large sand fractions (2-0.075 mm) averaging 75% and gravel fraction (>2 mm) varying from 3-38%. Silts (0.075-0.002 mm) and clays (<0.002 mm) typically constitute only 2-18% of the sample. All of the shelf sediments classify as sands as indicated in Figure 3.15 [3.30].

A thin veneer of sediment occurs on the slope reaching only one to two meters in thickness near the base. Upper slope sediments have highly variable textures ranging from clayey silts to gravely sands and rock fragments. Silt content averages approximately 60% for the upper slope sediments, generally decreasing downslope while the amount of clay increases proportionally. Sample 22 in Figure 3.15 is an example of the high variability of sediment textures on the lower slope (3131 m) and contained 23% gravel, 50% sand, 18% silt and only 9% clay. Cores taken from the slope are generally structureless, which implies considerable reworking by benthic fauna. Figure 3.15 shows that overall slope sediments classify as sandy-clay silts.

Basin sediments generally classify as sandy-clay silts; however, high variability exists here due to the common presence of turbidity sequences as observed in several cores. Core 22 is a good example (see labeled samples on Fig. 3.15) with textures ranging from clayey silts to sands due to the grading of these sediments within the turbidite sequences. Graded turbidite sequences are evident in cores 22 (Fig. 3.16), 23, 24, and 25 and to a minor extent in cores 34 and 35. Cores revealing mottling, indicative of bioturbation or reworking of sediment due to burrowing organisms, include 30, 31, 32, 34, 35, 36, and 38. These cores were taken on, or in the vicinity of, the topographic "high" in the trough with the exception of core 38. One piston core cutter was

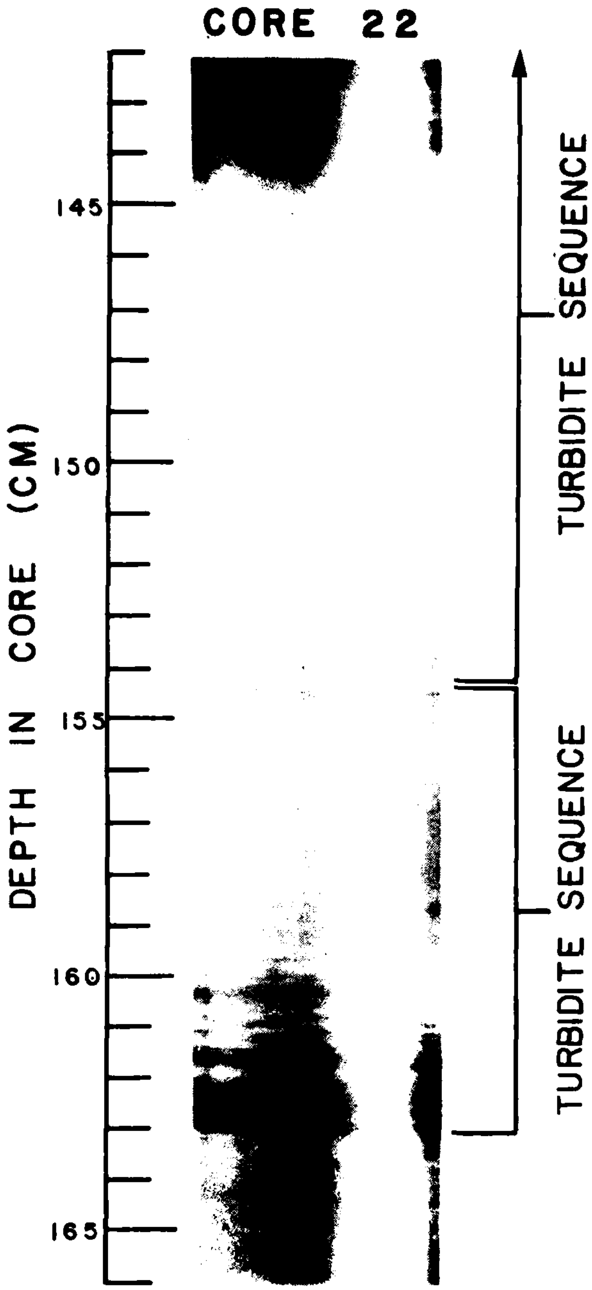


Figure 3.16. X-radiograph of a section of Core 22 showing one complete turbidity sequence and the lower portion of another.

badly damaged at site 40 and only recovered a few freshly broken rock fragments, indicating exposed bedrock or the existence of a displaced boulder.

3.5.2 Geotechnical Properties

The following subsections discuss the results of the measurements made for sediment mass physical and mechanical properties. These results are also summarized in Table 3.2.

3.5.2.1 Water Content, Porosity, Void Ratio

With few exceptions, average water contents range between 55-65 % (percent dry weight). The highest value was found for a grab sample in the upper 1-4 cm (average value-101%). The average porosity values are remarkably similar (59-65%) with the exception of two grab samples of surface sediments (samples No. 1 and 2; see Table 3.2). Although differences in average values for water content and porosity are not large among samples, maximum and minimum values vary significantly as shown in Table 3.2. Some of the highest values and greatest ranges of porosity, void ratio, and water content occur in sediment associated with the "high" in the VIT. This high variability probably is due largely to bioturbation and reworking of the sediments as noted in the previous section (3.5.1). The variability and general trends in porosity and void ratio, which decreases with depth below the sea floor, are clearly depicted in Figures 3.17 and 3.18 for all samples.

Detailed tabulations of water content, porosity, and void ratio as well as additional parameters pertaining to specific samples are given in Table A-6.7.2 of Appendix A. The corresponding plots are shown in Plot A-6.8.1 of Appendix A.

3.5.2.2 Wet Unit Weight

Wet unit weight (wet bulk density) displays significant variability due to

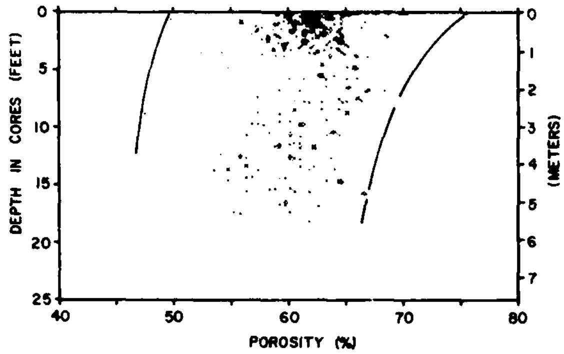


Figure 3.17. Plot of porosity (%) versus depth in core for all samples.

localized differences in grain size and degree of consolidation (Fig. 3.19). The average values shown in Table 3.2, however, are not remarkably different among cores. The grab samples display low values of wet unit weight and high water content due to negligible overburden. The large range in wet unit weight is revealed by the relatively large "envelope" encompassing the data of Figure 3.19. The relatively uniform nature and mineralogy of the solid grains comprising the sediment matrix is displayed by the consistent specific gravities for all samples in Table 3.2.

3.5.3 Shear Strength Parameters

Numerous miniature vane (undrained) shear tests were determined aboard ship on core samples shortly after recovery.

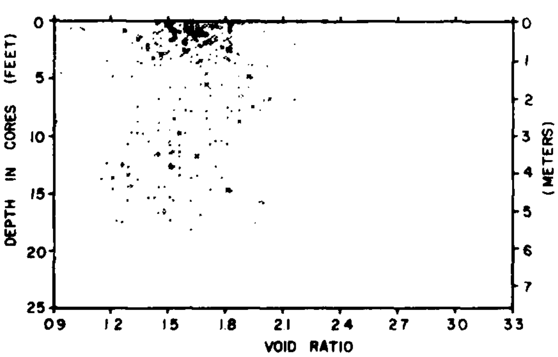


Figure 3.18. Plot of void ratio versus depth in core for all samples.

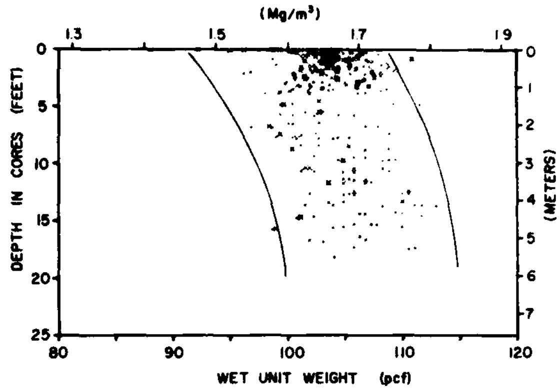


Figure 3.19. Plot of wet unit weight (pcf) versus depth in core for all samples.

These data (all "undisturbed" cores) are plotted as a function of depth in Figure 3.20. In addition, maximum, minimum, and average values of shear strength and sensitivity are reported and summarized for all available data in Table 3.2. A very wide range in shear strength is observed. Shear strength and variability increases significantly with depth below the sea floor. Over the 5 m depth interval, the minimum shear strength increase (vane data only) is approximately 0.7 psi (5 kPa) using the "envelope" of the minimum strength values in Figure 3.20. High variability of geotechnical properties is common in carbonate oozes [3.28].

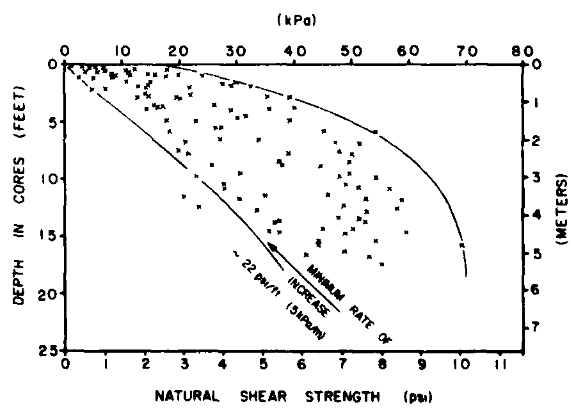


Figure 3.20. Plot of natural shear strength (psi) versus depth in core for all samples.

Sensitivity (ratio of natural to remolded shear strength determined by miniature vane shear tests) is also highly variable. The sensitivity is an indication of strength loss upon remolding or severe disturbance of the soil mass. Of significance is that sediments (generally clays) with high sensitivities may flow on gently slopes if severely disturbed [3.20]. Thus knowledge of the sensitivity is an aid in assessing the potential behavior of a deposit if subjected to disturbance or remolding in natural environments (i.e. sediments subjected to earthquakes). Shear strengths of remolded material are low in the upper 1 m. Values are generally less than 1.4 psi (10 kPa) with most values falling lower than 0.5 psi (3.5 kPa) as depicted in Figure 3.21. The sensitivity data shown in Table 3.2 and Figure 3.22 reveal that the sediments range from normal (sensitivities of 2.4) to extra-sensitive (sensitivities of 8-16).

In general, sensitivities appear to increase downslope with increasing water depth. Sediments collected from the St. Croix Island margin slope display sensitivities in the normal (2-4) to sensitive range (4-8). Those slope sediments in the sensitive range generally have values of only 4-5. The highest sensitivities (greater than 5) are associated with deposits on the sides and top of the topographic "high" and the deposits in the northern portions of the VIT (samples 22, 25, 30, 35, and 38). See Table 3.1 and Figure 3.1 for sample locations.

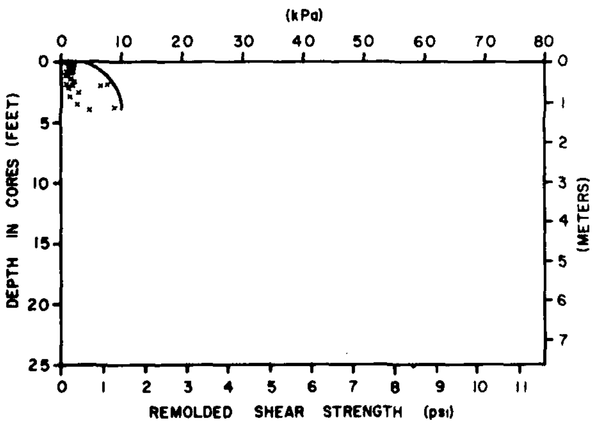


Figure 3.21. Plot of remolded shear strength (psi) versus depth in core for all samples.

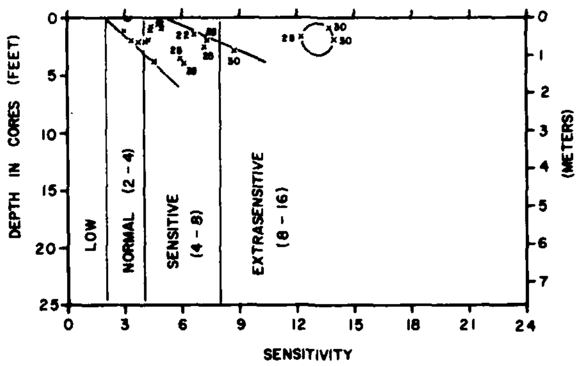


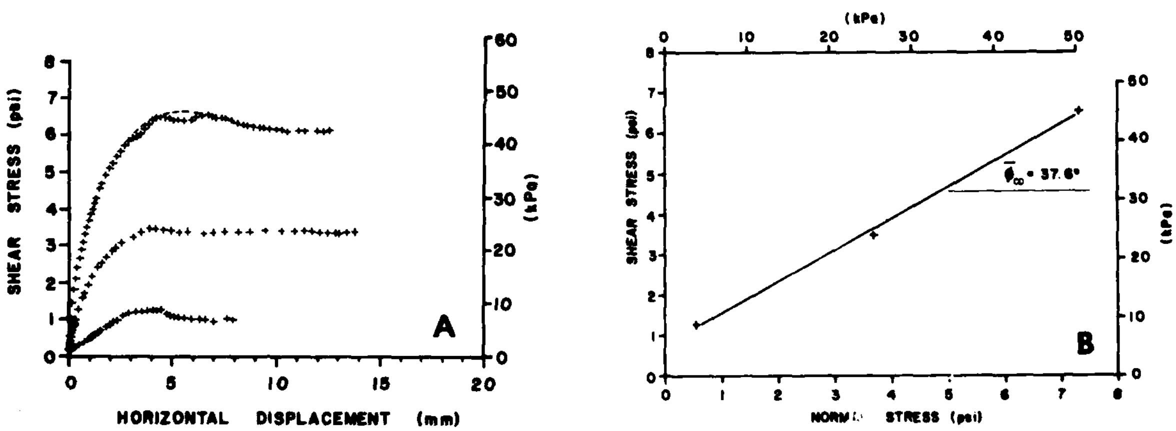
Figure 3.22. Plot of sensitivity versus depth in core for all samples.

Two sets of direct shear tests (consolidated drained: rate of shear = 1.78 x 10^{-4} inch/min or 4.52 x 10^{-3} mm/min) were completed for cores 22 and 35 recovered from the VIT. Core 22 was collected from the northern portion of the trough in approximately 3900 m of water. Core 35 was recovered from the southwest slope of the "high" in about 3800-3900 m water depth. Both samples show good stress-strain characteristics as depicted in Figures 3.23 and 3.24. Despite the differences in depositional environment (trough floor versus slope of the "high") the drained angles of internal friction agree within 0.3 (see Figs. 3.23 and 3.24, Sample 22, $\bar{\phi}_{CD}$=37.6°; Sample 35, $\bar{\phi}_{CD}$=37.9°). The rather large angles of internal friction probably are due to the high carbonate content of the samples. Table 3.4 gives the gasometric carbonate analyses of subsamples of each core and reveals carbonate contents of 82-83% (Core 22) and 63-76% (Core 35). Triaxial tests of deep-sea sediments reveal increasing angles of internal friction with increasing carbonate content, and those sediments having carbonate contents greater than 40% exhibit granular behavior [3.21]. Angles of internal friction of 31.3 were reported for sediments having greater than 60% calcium carbonate [3.31]. Angles of internal friction (undrained triaxial tests) of 37° for fine calcareous ooze and 33° for coarse calcareous ooze were reported earlier [3.32]. Note that in both tests performed in samples 22 and 35, a small cohesion intercept (c) was found to be approximately 5 kPa.

Triaxial data (one set) for sample 35 are shown in Figure 3.25. Angles of internal friction for total stress and effective stress were ϕ_{CU}=19.7° and $\bar{\phi}_{CU}$=37.5°, respectively. Note that the angle of internal friction for effective stress analysis compares well with angles of internal friction determined by direct shear drained testing ($\bar{\phi}_{CD}$= 37.6°; 37.9°).

3.5.4 Atterberg Limits and Indices

Liquid (LL) and plastic limits (PL) were determined on selected subsamples. Figure 3.26 gives the data from calculations of liquidity index, (LI=$\frac{w-PL}{LL-PL}$) where w = natural water content and indicates values of greater than one for most samples tested. Some of the highest values of Liquidity Index (LI=9, sample 16; LI=6, sample 38) are found for sediment samples from the slope off St. Croix. As noted earlier [3.8], remolding of natural sediments having water contents greater than their liquid limits (liquidity index greater than 1.0) transforms the deposit into a viscous slurry. Thus liquidity index is an important soil property for evaluating sediment behavior and seafloor stability.



CORE 22

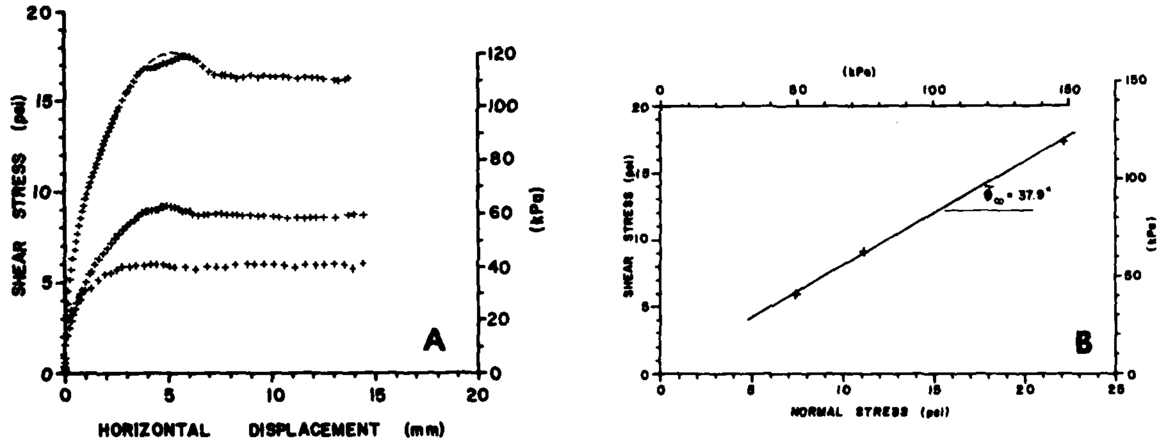
INTERVAL (in)	SHEAR LOAD (lbs)	SHEARING STRESS AT FAILURE τ_f (psi)	EFFECTIVE NORMAL STRESS $\bar{\sigma}_n$ (psi)	$\tau_f/\bar{\sigma}_n$	SHEAR DISPLACEMENT AT FAILURE ε (in)	WATER CONTENT W (%)	WET UNIT WEIGHT γ (pcf)
19.9-20.5	6.30	1.28	0.54	2.38	0.175	50.3	102.4
20.5-21.6	17.15	3.50	3.67	.953	0.153	53.5	108.0
21.6-23.6	32.01	6.52	7.28	.896	0.1743	51.2	108.0

Figure 3.23. A. Stress-strain plot from consolidated-drained direct shear tests--Core 22. B. Plot showing the drained angle of internal friction for Core 22.

Although the liquidity indices are high, the Atterberg limits (liquid and plastic limits) reveal that the sediments are inorganic silts of low plasticity. Using the plasticity chart of Figure 3.27, [3.33], these sediments are considered to behave as silts having medium compressibility. These St. Croix samples have considerably lower plasticity indices and liquid limits than the carbonate sediments described by others [3.31]. This can be attributed to the very high silt and carbonate contents for the St. Croix samples as seen in Figure 3.15 and Table 3.4, respectively.

3.5.5 Seafloor Gradients

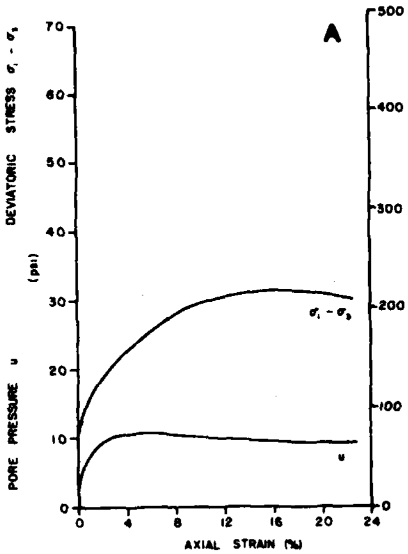
A bathymetric map (Fig. 3.1) was developed from earlier cruises aboard Navy survey vessels during geological and geophysical investigations off the northern margin of St. Croix (see Part 2 of this report). The bathymetric data were used to generate a bathymetric map at a scale of approximately 1:65,000 and is included in this report as a pocket insert. This bathymetric map was used to produce a slope map of the study area for the purpose of graphically depicting five slope zones, or gradients, showing major morphological features of the sea floor. Major seafloor features are readily apparent in the slope map. The steepest gradients (>35°) are found predominantly at water depths of 2500 m or less, with the exception of the very steep escarpment at the western edge of the study area (~latitude 64°54'W) where these steep gradients extend from 2200-4400 m water depth. The nature of these contours implies strong structural control on the bathymetry and slopes. In contrast to the steep gradients, the axial gradients of Christiansted Canyon range from ~5°-11°. Large portions of the slope, however, are characterized by

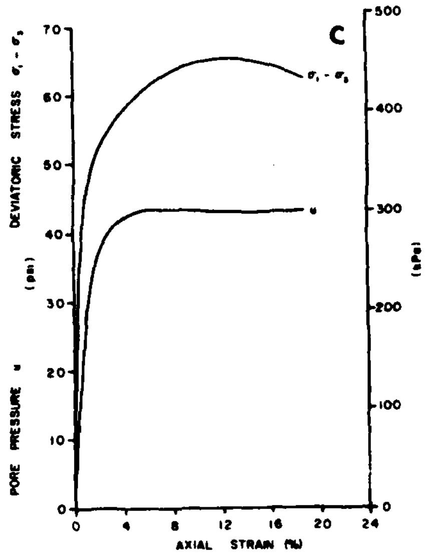


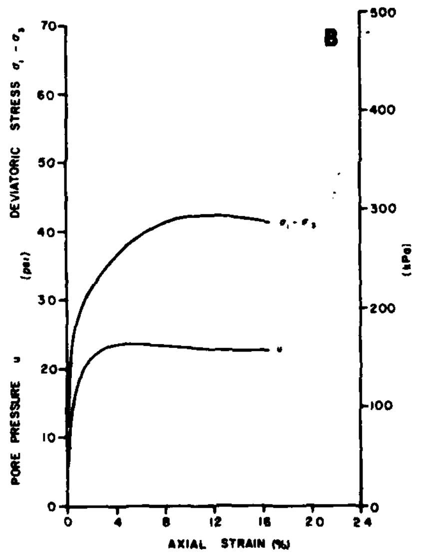
CORE 35

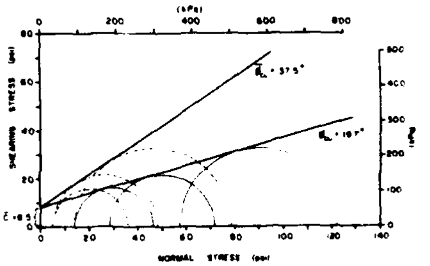
INTERVAL (in)	SHEAR LOAD (lbs)	SHEARING STRESS AT FAILURE τ_f (psi)	EFFECTIVE NORMAL STRESS $\bar{\sigma}_n$ (psi)	$\tau_f/\bar{\sigma}_n$	SHEAR DISPLACEMENT AT FAILURE ε (in)	WATER CONTENT w (%)	WET UNIT WEIGHT γ (pcf)
12.2-13.3	44.71	9.11	10.85	.839	0.194	58.8	104.9
13.6-14.8	84.9	17.29	21.58	.801	0.222	57.3	106.1
15.7-16.9	29.3	5.96	7.25	.822	0.176	55.6	105.5

Figure 3.24. A. Stress-strain plot from consolidated-drained direct shear tests--Core 35. B. Plot showing the drained angle of internal friction for Core 35.









	A	B	C
cell pressure, σ_c	85.7 psi	85.3 psi	85.3 psi
back pressure, bp	71.2 psi	56.9 psi	28.4 psi
axial strain, ε	17.0%	11.2%	11.2%
effective cell pressure, $\bar{\sigma}_c = \sigma_3$	14.5 psi	28.4 psi	56.9 psi
compression stress, $\sigma_d = \sigma_1 - \sigma_3$	31.5 psi	13.9 psi	8.2 psi
maximum principle total stress, σ_1	46.0 psi	42.3 psi	65.1 psi
excess pore water pressure, u	9.5 psi	22.9 psi	43.2 psi
maximum principle effective stress, $\bar{\sigma}_1$	36.5 psi	19.4 psi	21.9 psi
minimum principle effective stress, $\bar{\sigma}_3$	5.1 psi	5.5 psi	13.7 psi
pore pressure coefficient, A	0.30	1.65	6.23

effective angle of internal friction, $\bar{\phi}_{cu} = 37.5^0$
total angle of internal friction, $\phi_{cu} = 19.7^0$

Figure 3.25. Plots of triaxial shear tests results for Core 35.

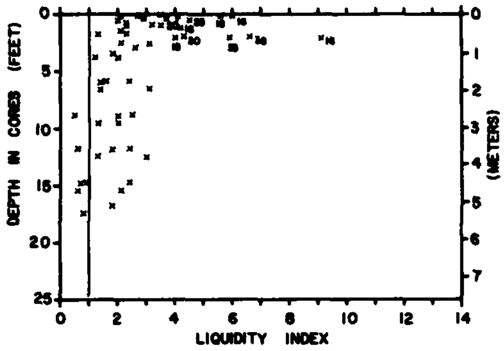


Figure 3.26. Plot of liquidity index versus depth in core.

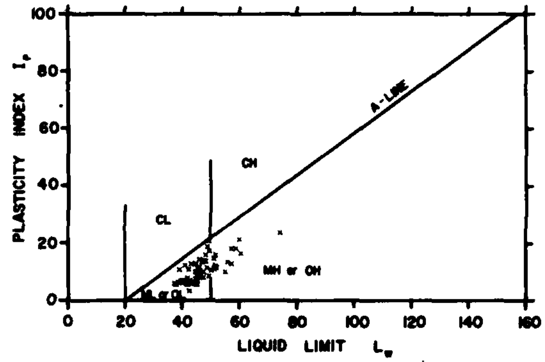


Figure 3.27. Plasticity chart for all samples tested.

gradients of 11°-20° and 20°-35°, which are substantial compared with other types of margins [3.36]. In contrast to the slope off St. Croix the VIT is characterized by gradients of only 5° and less. The topographic "high," however, displays areas of rather steep gradients extending up to 35° (see map insert). The "top" of the topographic "high" is essentially flat. A few patches of 5° to 10° gradients are found in the northern portion of the VIT. The steep slopes along the St. Croix Margin must be carefully considered in any offshore engineering construction or activities planned in the area.

Table 3.4. Calcium carbonate analyses.

Sample Number	Below Mud Line (cm)	Percent (dry weight) $CaCO_3$
16	(0-7)	81.8%
16	(33-38)	83.7%
16	(60-66)	83.5%
17	(0-6)	81.3%
18	(0-6)	83.1%
18	(26-32)	84.6%
18	(59-65)	84.7%
20	(0-7)	82.4%
22	(40-45)	81.7%
22	(75-80)	82.4%
25	(8-12)	78.5%
25	(48-52)	77.2%
25	(102-108)	63.6%
30	(55-61)	77.5%
30	(85-91)	77.2%
32	(0-5)	75.8%
32	(49-56)	75.7%
32	(112-116)	74.5%
35	(13-18)	76.3%
35	(58-65)	72.6%
35	(112-117)	63.2%
36	(18-24)	79.1%
38	(9-13)	59.7%
38	(56-62)	66.3%

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PART 3

APPENDIX A

Table A-6.7.1. Size classification.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm-74 μ	SAND (%) 74-62.5 μ	SILT (%) 62.5-3.9 μ	CLAY (%) 3.9-2.0 μ	CLAY (%) <2.0 μ
1	0.001 — 0.066	0.1	30.4	2.1	47.2	3.9	16.2

GRAB 1

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm-74 μ	SAND (%) 74-62.5 μ	SILT (%) 62.5-3.9 μ	CLAY (%) 3.9-2.0 μ	CLAY (%) <2.0 μ
1	0.001 — 0.066	0.4	23.4	5.3	45.8	3.0	22.1

GRAB 2

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm-74 μ	SAND (%) 74-62.5 μ	SILT (%) 62.5-3.9 μ	CLAY (%) 3.9-2.0 μ	CLAY (%) <2.0 μ
1	0.001 — 0.066	7.1	50.6	0.9	33.2	1.8	6.3

GRAB 6

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm-74 μ	SAND (%) 74-62.5 μ	SILT (%) 62.5-3.9 μ	CLAY (%) 3.9-2.0 μ	CLAY (%) <2.0 μ
1	0.001 — 0.066		14.1	0.2	70.9	2.7	12.1

GRAB 7

Table A-6.7.1, continued. Size classification.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm-74 µ	SAND (%) 74-62.5 µ	FINES (%) < 62.5 µ
1	0.001 — 0.066	14.3	77.4	0.8	7.5

GRAB 3

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm-74 µ	SAND (%) 74-62.5 µ	FINES (%) < 62.5 µ
1	0.001 — 0.066	3.7	80.6	2.3	13.4

GRAB 5

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm-74 µ	SAND (%) 74-62.5 µ	FINES (%) < 62.5 µ
1	0.001 — 0.066	16.3	76.0	1.2	6.4

GRAB 8

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm-74 µ	SAND (%) 74-62.5 µ	FINES (%) < 62.5 µ
1	0.001 — 0.066	5.0	86.7	2.5	5.8

GRAB 9

Table A-6.7.1, continued. Size classification.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm - 74 µ	SAND (%) 74-62.5 µ	FINES (%) < 62.5 µ
1	0.001 — 0.066	15.4	71.0	2.3	11.3

GRAB 10

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm - 74 µ	SAND (%) 74-62.5 µ	FINES (%) < 62.5 µ
1	0.001 — 0.066	37.7	50.3	1.3	10.7

GRAB 11

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm - 74 µ	SAND (%) 74-62.5 µ	FINES (%) < 62.5 µ
1	0.001 — 0.066	15.3	82.4	0.4	1.9

GRAB 12

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm - 74 µ	SAND (%) 74-62.5 µ	FINES (%) < 62.5 µ
1	0.001 — 0.066	31.6	61.0	0.9	6.5

GRAB 13

Table 6.7.1, continued. Size classification.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm-74 µ	SAND (%) 74-62.5 µ	FINES (%) < 62.5 µ
1	0.001 – 0.066	2.8	72.8	6.3	18.1

GRAB 14

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm-74 µ	SAND (%) 74-62.5 µ	FINES (%) < 62.5 µ
1	0.001 – 0.066	59.2	34.9	1.0	4.8

CORE 19

Table A-6.7.1, continued. Size classification.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm -74 μ	SAND (%) 74-62.5 μ	SILT (%) 62.5-3.9 μ	CLAY (%) 3.9-2.0 μ	CLAY (%) <2.0 μ
1	0.001 — 0.066	0.1	23.4	4.9	46.1	3.7	21.8

GRAB 15

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm -74 μ	SAND (%) 74-62.5 μ	SILT (%) 62.5-3.9 μ	CLAY (%) 3.9-2.0 μ	CLAY (%) <2.0 μ
1	0.001 — 0.098	0.1	14.2	3.1	60.8	3.9	17.9
2	0.460 — 0.558	0.1	14.8	3.0	59.3	3.6	19.2
3	1.080 — 1.180		12.8	1.9	62.9	3.0	19.4
4	2.070 — 2.170		15.0	2.1	58.4	3.6	20.9

CORE 16

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm -74 μ	SAND (%) 74-62.5 μ	SILT (%) 62.5-3.9 μ	CLAY (%) 3.9-2.0 μ	CLAY (%) <2.0 μ
1	0.001 — 0.066	0.2	18.1	1.6	54.1	4.4	21.6

CORE 17

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm -74 μ	SAND (%) 74-62.5 μ	SILT (%) 62.5-3.9 μ	CLAY (%) 3.9-2.0 μ	CLAY (%) <2.0 μ
1	0.001 — 0.066		13.0	1.8	61.0	4.1	20.1
2	0.853 — 1.050	0.1	13.1	2.2	60.2	3.5	20.9
3	1.940 — 2.130	0.1	12.7	1.5	59.6	3.1	23.0

CORE 18

Table A-6.7.1, continued. Size classification.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0mm	SAND (%) 2.0mm-74µ	SAND (%) 74-62.5µ	SILT (%) 62.5-3.9µ	CLAY (%) 3.9-2.0µ	CLAY (%) <2.0µ
1	0.001 — 0.098		18.7	2.8	53.1	3.4	22.0
2	0.591 — 0.660		16.0	2.0	57.1	3.4	21.5

CORE 20

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0mm	SAND (%) 2.0mm-74µ	SAND (%) 74-62.5µ	SILT (%) 62.5-3.9µ	CLAY (%) 3.9-2.0µ	CLAY (%) <2.0µ
1	0.001 — 0.066		17.3	2.5	59.7	4.8	15.7

GRAB 21

Table A-6.7.1, continued. Size classification.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm-74 μ	SAND (%) 74-62.5 μ	SILT (%) 62.5-3.9 μ	CLAY (%) 3.9-2.0 μ	CLAY (%) <2.0 μ
1	0.098 — 0.197		27.[illegible]	2.1	45.5	4.1	21.2
2	0.460 — 0.560	0.1	40.6	1.4	36.7	3.1	18.0
3	1.480 — 1.570		16.0	2.5	51.4	5.0	25.1
4	2.030 — 2.070		5.7	1.6	57.3	4.3	31.1
5	2.230 — 2.260	0.9	74.7	1.7	12.7	1.3	8.7
6	2.660 — 2.690		21.7	2.0	49.0	3.3	24.0
7	3.380 — 3.410	0.1	53.1	2.1	25.1	2.6	17.0
8	6.430 — 6.500	0.1	19.9	2.3	42.4	5.0	30.3
9	9.380 — 9.450		16.2	2.8	45.0	5.1	30.9
10	12.340 — 12.430	0.2	27.3	3.9	38.2	3.6	26.8
11	15.290 — 15.350	0.1	22.3	3.9	41.0	5.3	27.4

CORE 22

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm -74 μ	SAND (%) 74-62.5 μ	SILT (%) 62.5-3.9 μ	CLAY (%) 3.9-2.0 μ	CLAY (%) <2.0 μ
1	0.001 — 0.066	0.5	49.2	4.0	32.2	1.9	12.2
2	0.098 — 0.131		23.2	2.9	51.7	1.9	20.2
3	0.623 — 0.656		47.0	2.5	37.8	1.7	10.9

CORE 24

Table A-6.7.1, continued. Size classification.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm - 74 μ	SAND (%) 74-62.5 μ	SILT (%) 62.5-3.9 μ	CLAY (%) 3.9-2.0 μ	CLAY (%) <2.0 μ
1	0.001 — 0.098		27.6	2.5	41.9	4.7	23.3
2	0.460 — 0.558		47.0	0.5	31.0	2.0	19.5
3	0.591 — 0.660		2.6	0.3	74.0	3.8	19.3
4	0.984 — 1.080		62.4	2.8	27.0	0.5	7.3
5	1.570 — 1.640		14.8	1.0	47.8	5.3	31.1
6	2.490 — 2.560		13.7	2.4	45.0	5.0	33.9
7	6.500 — 6.560		12.9	2.5	36.8	7.5	40.3
8	9.450 — 9.510		16.0	3.8	43.9	4.1	32.2
9	12.400 — 12.470		16.2	5.4	48.5	3.4	26.5
10	15.350 — 15.420		11.9	4.0	49.8	5.1	29.2
11	17.320 — 17.390		9.6	2.4	43.8	8.4	35.8

CORE 25

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm - 74 μ	SAND (%) 74-62.5 μ	SILT (%) 62.5-3.9 μ	CLAY (%) 3.9-2.0 μ	CLAY (%) <2.0 μ
1	0.001 — 0.066		12.0	1.4	48.7	5.6	32.3

CORE 26

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm - 74 μ	SAND (%) 74-62.5 μ	SILT (%) 62.5-3.9 μ	CLAY (%) 3.9-2.0 μ	CLAY (%) <2.0 μ
1	0.001 — 0.066		31.5	3.3	38.7	4.4	22.1

CORE 27

Table A-6.7.1, continued. Size classification.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm-74 µ	SAND (%) 74-62.5 µ	SILT (%) 62.5-3.9 µ	CLAY (%) 3.9-2.0 µ	CLAY (%) <2.0 µ
1	0.001 — 0.066		21.8	2.5	58.9	4.0	12.8

GRAB 28

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm-74 µ	SAND (%) 74-62.5 µ	SILT (%) 62.5-3.9 µ	CLAY (%) 3.9-2.0 µ	CLAY (%) <2.0 µ
1	0.001 — 0.066	23.4	48.7	1.5	17.8	0.9	7.6

GRAB 29

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm-74 µ	SAND (%) 74-62.5 µ	SILT (%) 62.5-3.9 µ	CLAY (%) 3.9-2.0 µ	CLAY (%) <2.0 µ
1	0.001 — 0.098		39.8	1.5	33.4	3.1	22.2
2	0.328 — 0.394	0.2	26.1	2.3	40.5	3.9	27.0
3	0.820 — 0.919	0.4	23.9	1.8	43.9	4.8	25.2
4	1.800 — 1.940		21.2	1.4	44.8	3.8	28.8
5	2.790 — 2.850	0.9	17.4	2.1	43.2	6.3	30.1
6	3.710 — 3.740		20.0	2.4	44.3	4.4	28.8
7	5.740 — 5.810		16.1	3.3	44.8	5.5	30.3
8	8.690 — 8.760		10.7	3.6	45.3	5.4	35.0
9	11.650 — 11.710	0.3	14.8	4.0	44.8	3.7	32.4
10	14.600 — 14.670		23.4	2.9	40.2	4.6	28.9

CORE 30

Table A-6.7.1, continued. Size classification.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm -74 µ	SAND (%) 74-62.5 µ	SILT (%) 62.5-3.9 µ	CLAY (%) 3.9-2.0 µ	CLAY (%) <2.0 µ
1	0.001 — 0.066		16.6	2.5	46.6	4.4	29.9
2	0.361 — 0.427		15.8	1.6	38.5	7.1	37.0
3	0.853 — 0.920		13.7	1.9	38.8	7.3	38.3
4	1.770 — 1.840		25.6	3.5	6.9	9.2	54.8
5	2.760 — 2.820	0.1	24.8	3.2	37.6	6.3	28.0
6	3.740 — 3.810	0.1	15.1	2.2	42.0	6.5	34.1
7	5.770 — 5.870	0.2	24.3	3.5	39.1	5.6	27.3
8	8.730 — 8.830		17.8	2.8	34.1	8.6	36.7
9	11.650 —11.750		13.0	1.6	38.0	7.6	39.8
10	14.600 —14.700		17.1	2.6	41.2	6.6	32.5

CORE 32

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm -74 µ	SAND (%) 74-62.5 µ	SILT (%) 62.5-3.9 µ	CLAY (%) 3.9-2.0 µ	CLAY (%) <2.0 µ
1	0.001 — 0.066	0.1	15.8	1.5	46.0	5.7	30.8

GRAB 33

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm -74 µ	SAND (%) 74-62.5 µ	SILT (%) 62.5-3.9 µ	CLAY (%) 3.9-2.0 µ	CLAY (%) <2.0 µ
1	0.001 — 0.033		26.2	1.6	47.6	6.8	17.8
2	0.459 — 0.492		36.1	2.4	36.6	3.7	21.2
3	1.120 — 1.150		18.5	3.2	46.9	5.0	26.4
4	1.610 — 1.640		23.4	1.5	43.9	3.9	27.3
5	2.260 — 2.300	0.1	14.5	2.0	48.0	4.9	30.5

CORE 34

Table A-6.7.1, continued. Size classification.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0mm	SAND (%) 2.0mm-74µ	SAND (%) 74-62.5µ	SILT (%) 62.5-3.9µ	CLAY (%) 3.9-2.0µ	CLAY (%) <2.0µ
1	0.001 — 0.066		27.9	2.1	43.2	4.0	22.8
2	0.426 — 0.492		12.8	2.9	50.0	5.2	29.1
3	0.560 — 0.591		22.4	1.8	46.1	4.2	25.4
4	1.840 — 1.870		20.9	0.1	46.3	3.1	29.6
5	1.900 — 1.970		20.6	1.9	45.5	3.9	28.0
6	2.850 — 2.890		14.8	2.8	43.6	5.4	33.4
7	2.920 — 2.950	0.1	13.1	1.4	46.5	4.3	34.6
8	3.770 — 3.840		22.1	2.2	38.4	5.6	31.7
9	3.840 — 3.870		19.6	1.7	44.3	4.7	29.7
10	5.840 — 5.910		13.9	2.2	46.8	7.4	29.7
11	8.790 — 8.860	0.1	27.2	2.4	38.9	4.2	27.2
12	11.750 — 11.810		14.1	2.9	41.3	6.5	35.2
13	14.700 — 14.760	0.1	13.2	1.8	37.6	10.3	37.0
14	16.670 — 16.730		20.0	3.7	42.2	3.1	31.0

CORE 35

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0mm	SAND (%) 2.0mm-74µ	SAND (%) 74-62.5µ	SILT (%) 62.5-3.9µ	CLAY (%) 3.9-2.0µ	CLAY (%) <2.0µ
1	0.001 — 0.066		26.8	3.2	39.2	4.7	26.1
2	0.722 — 0.787		21.3	1.5	46.3	3.5	27.4

CORE 36

AD-A137 665 SEAFLOOR ENVIRONMENTS NORTH ST CROIX MARGIN AND VIRGIN ISLANDS TROUGH PAR..(U) NAVAL OCEAN RESEARCH AND DEVELOPMENT ACTIVITY NSTL STATION MS.. 2/2

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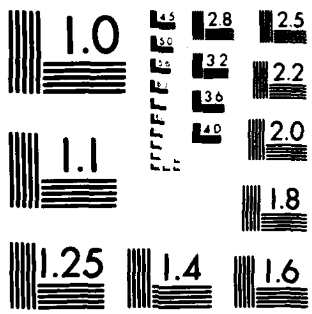

MICROCOPY RESOLUTION TEST CHART
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Table A-6.7.1, continued. Size classification.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm-74 µ	SAND (%) 74-62.5 µ	SILT (%) 62.5-3.9 µ	CLAY (%) 3.9-2.0 µ	CLAY (%) <2.0 µ
1	0.001 — 0.066		43.9	1.7	34.7	3.7	16.0

GRAB 37

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm-74 µ	SAND (%) 74-62.5 µ	SILT (%) 62.5-3.9 µ	CLAY (%) 3.9-2.0 µ	CLAY (%) <2.0 µ
1	0.001 — 0.066		12.0	1.9	50.3	5.0	30.8
2	0.098 — 0.131	0.1	9.2	1.5	51.1	5.3	32.8
3	0.853 — 0.919		18.6	4.1	42.6	5.4	29.3
4	1.900 — 1.970		16.8	1.8	49.7	4.0	27.7

CORE 38

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	GRAVEL (%) >2.0 mm	SAND (%) 2.0 mm-74 µ	SAND (%) 74-62.5 µ	SILT (%) 62.5-3.9 µ	CLAY (%) 3.9-2.0 µ	CLAY (%) <2.0 µ
1	0.001 — 0.066	0.8	23.0	2.4	50.0	3.0	20.7

CORE 40

Table A-6.7.2. Soil properties.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	WATER CONTENT (% DRY WT)	WET UNIT WT γ_t (PCF)	SPECIFIC GRAVITY G_s	VOID RATIO e	POROSITY n (%)	DRY UNIT WT γ_d (PCF)
1	0.001 — 0.033	84.6	94.95	2.73	2.31	69.8	51.44
2	0.001 — 0.033	117.6	88.02	2.74	3.06	75.3	78.76

GRAB 1

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	WATER CONTENT (% DRY WT)	WET UNIT WT γ_t (PCF)	SPECIFIC GRAVITY G_s	VOID RATIO e	POROSITY n (%)	DRY UNIT WT γ_d (PCF)
1	0.001 — 0.131	75.0	98.20	2.76	2.07	67.4	56.12
2	0.001 — 0.131	73.1	98.76	2.75	2.01	66.8	57.04
3	0.001 — 0.131	77.1	97.45	2.73	2.10	67.8	55.03
4	0.001 — 0.131	84.0	96.14	2.82	2.37	70.3	52.26

GRAB 2

Table A-6.7.2, continued. Soil properties.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	WATER CONTENT (% DRY WT)	WET UNIT WT γ_t (PCF)	SPECIFIC GRAVITY G_s	VOID RATIO e	POROSITY n (%)	DRY UNIT WT γ_d (PCF)
1	0.001 — 0.033	80.0	92.14	2.73	2.18	68.6	51.77
2	0.164 — 0.197	64.0	101.88	*2.74	1.75	63.7	62.13
3	0.328 — 0.361	62.9	102.26	*2.74	1.72	63.3	62.76
4	0.492 — 0.525	63.9	101.76	2.75	1.76	63.7	62.10
5	0.660 — 0.690	60.5	103.07	*2.74	1.67	62.6	64.20
6	0.820 — 0.853	72.9	98.64	*2.74	2.00	66.7	57.05
7	0.984 — 1.020	56.1	105.32	*2.74	1.53	60.5	67.48
8	1.080 — 1.120	60.3	103.63	2.75	1.66	62.4	64.66
9	1.310 — 1.350	64.1	101.88	*2.74	1.75	63.7	62.07
10	1.480 — 1.510	66.0	101.13	*2.74	1.81	64.4	60.92
11	1.640 — 1.670	59.6	103.51	*2.74	1.65	62.2	64.85
12	1.800 — 1.840	62.0	102.69	*2.74	1.70	62.9	63.38
13	1.970 — 2.000	79.4	96.76	*2.74	2.16	68.4	53.93
14	2.130 — 2.170	53.2	106.75	2.74	1.46	59.3	69.68

CORE 16

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	WATER CONTENT (% DRY WT)	WET UNIT WT γ_t (PCF)	SPECIFIC GRAVITY G_s	VOID RATIO e	POROSITY n (%)	DRY UNIT WT γ_d (PCF)
1	0.001 — 0.033	60.0	103.63	2.73	1.64	62.1	64.78
2	0.098 — 0.131	53.0	106.75	*2.74	1.45	59.2	69.76

CORE 17

* inferred value

Table A-6.7.2, continued. Soil properties.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	WATER CONTENT (% DRY WT)	WET UNIT WT γ_t (PCF)	SPECIFIC GRAVITY G_s	VOID RATIO e	POROSITY n (%)	DRY UNIT WT γ_d (PCF)
1	0.001 — 0.033	70.6	99.26	2.73	1.93	65.8	58.19
2	0.164 — 0.197	60.0	103.50	*2.74	1.65	62.2	64.68
3	0.328 — 0.361	63.0	102.26	*2.74	1.72	63.3	62.74
4	0.492 — 0.525	59.8	103.50	*2.74	1.65	62.2	64.75
5	0.558 — 0.591	58.6	103.94	*2.74	1.62	61.8	65.52
6	0.772 — 0.755	61.3	103.07	*2.74	1.67	62.6	63.91
7	0.886 — 0.919	58.7	103.94	*2.74	1.62	61.8	65.48
8	1.020 — 1.050	52.2	107.38	2.75	1.44	59.0	70.54
9	1.050 — 1.080	61.0	103.26	*2.75	1.68	62.7	64.12
10	1.210 — 1.250	62.0	102.82	*2.75	1.70	63.0	63.49
11	1.380 — 1.410	56.2	105.44	*2.75	1.54	60.6	67.51
12	1.540 — 1.570	55.0	105.94	*2.75	1.51	60.2	68.37
13	1.710 — 1.740	55.3	105.94	*2.75	1.51	60.2	68.19
14	1.870 — 1.900	51.7	107.38	*2.75	1.43	58.8	70.81
15	2.070 — 2.100	55.9	105.50	2.76	1.54	60.7	67.65

CORE 18

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	WATER CONTENT (% DRY WT)	WET UNIT WT γ_t (PCF)	SPECIFIC GRAVITY G_s	VOID RATIO e	POROSITY n (%)	DRY UNIT WT γ_d (PCF)
1	0.001 — 0.033	65.1	101.76	2.74	1.78	64.1	61.65
2	0.098 — 0.131	55.7	105.50	*2.74	1.53	60.4	67.76
3	0.196 — 0.230	55.2	105.50	*2.74	1.51	60.2	67.99

CORE 20

*** inferred value**

Table A-6.7.2, continued. Soil properties.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	WATER CONTENT (% DRY WT)	WET UNIT WT γ_t (PCF)	SPECIFIC GRAVITY G_s	VOID RATIO e	POROSITY n (%)	DRY UNIT WT γ_d (PCF)
1	0.098 — 0.131	66.8	100.51	2.74	1.83	64.7	60.27
2	0.262 — 0.295	53.8	106.38	*2.75	1.49	59.8	69.16
3	0.394 — 0.427	50.5	107.88	*2.75	1.40	58.4	71.68
4	0.525 — 0.560	37.8	116.12	2.76	1.04	51.1	84.24
5	0.591 — 0.623	36.5	117.55	*2.76	0.99	49.8	86.13
6	0.755 — 0.787	45.9	110.81	*2.76	1.27	55.9	75.94
7	0.853 — 0.886	45.9	110.81	*2.76	1.27	55.9	75.93
8	0.951 — 0.984	65.8	101.38	*2.76	1.82	64.6	61.15
9	1.120 — 1.150	60.5	103.38	*2.76	1.68	62.7	64.40
10	1.280 — 1.310	59.3	103.82	*2.76	1.63	62.0	65.16
11	1.440 — 1.480	53.3	106.56	*2.76	1.46	59.4	69.52
12	2.000 — 2.030	52.2	107.38	2.76	1.44	59.0	70.56
13	2.170 — 2.200	66.0	100.51	2.70	1.78	64.1	60.53
14	2.300 — 2.330	66.5	100.63	*2.73	1.83	64.7	60.43
15	2.430 — 2.460	50.5	107.56	*2.73	1.39	58.2	71.45
16	2.460 — 2.490	59.1	103.82	*2.73	1.61	61.7	65.25
17	2.590 — 2.620	54.2	106.75	2.76	1.50	59.9	69.23
18	2.760 — 2.790	53.4	106.38	*2.75	1.49	59.8	69.33
19	2.920 — 2.950	56.6	105.00	*2.75	1.57	61.1	67.05
20	3.080 — 3.120	59.4	103.63	*2.75	1.62	61.9	65.00
21	3.250 — 3.280	55.2	105.94	*2.75	1.51	60.2	68.28
22	3.440 — 3.480	43.3	112.50	*2.75	1.18	54.2	78.52
23	3.480 — 3.510	40.0	114.43	*2.75	1.10	52.4	81.74
24	4.460 — 4.490	34.3	118.61	2.74	0.94	48.5	88.29
25	5.410 — 5.450	62.0	102.69	*2.74	1.70	62.9	63.40
26	5.450 — 5.480	60.7	103.07	*2.74	1.67	62.6	64.13
27	6.430 — 6.460	62.2	102.69	*2.74	1.72	63.3	63.31
28	7.380 — 7.420	70.6	99.32	*2.74	1.94	66.0	58.20
29	7.420 — 7.450	71.0	99.26	2.74	1.94	66.0	58.06
30	8.370 — 8.400	65.6	101.13	*2.74	1.81	64.4	61.07

CORE 22

* inferred value

Table A-6.7.2, continued. Soil properties.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	WATER CONTENT (% DRY WT)	WET UNIT WT γ_t (PCF)	SPECIFIC GRAVITY G_s	VOID RATIO e	POROSITY n (%)	DRY UNIT WT γ_d (PCF)
31	8.400 — 8.430	61.8	102.69	*2.74	1.70	62.9	63.46
32	9.350 — 9.380	62.5	102.26	*2.74	1.72	63.3	62.93
33	10.330 —10.370	65.1	101.51	*2.74	1.78	64.0	61.47
34	10.370 —10.400	64.0	101.88	*2.74	1.75	63.7	62.11
35	11.320 —11.350	55.6	105.32	*2.74	1.53	60.5	67.68
36	11.350 —11.380	56.9	104.82	*2.74	1.56	61.0	66.79
37	12.300 —12.340	42.8	112.31	*2.74	1.18	54.1	78.66
38	12.340 —12.370	46.0	110.50	*2.74	1.26	55.8	75.70
39	13.290 —13.320	47.2	109.94	*2.74	1.29	56.3	74.67
40	13.320 —13.350	46.9	109.94	*2.74	1.29	56.3	74.82
41	14.270 —14.300	47.9	109.37	*2.74	1.31	56.8	73.95
42	14.300 —14.340	47.1	109.94	*2.74	1.29	56.3	74.75
43	15.260 —15.290	54.9	105.75	*2.74	1.51	60.1	68.29
44	15.290 —15.320	51.7	107.25	*2.74	1.43	58.8	70.69

CORE 22 (CONT'D)

* inferred value

Table A-6.7.2, continued. Soil properties.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	WATER CONTENT (% DRY WT)	WET UNIT WT γ_t (PCF)	SPECIFIC GRAVITY G_s	VOID RATIO e	POROSITY n (%)	DRY UNIT WT γ_d (PCF)
1	0.001 — 0.033	80.5	96.14	2.74	2.21	68.8	53.27
2	0.164 — 0.197	69.2	100.00	*2.74	1.89	65.4	59.09
3	0.328 — 0.361	62.2	102.69	*2.74	1.70	62.9	63.30
4	0.492 — 0.525	59.9	103.50	*2.74	1.65	62.2	64.73
5	0.558 — 0.590	66.3	101.13	2.75	1.82	64.6	60.80
6	0.590 — 0.623	63.1	102.38	2.74	1.73	63.3	62.79
7	0.722 — 0.755	38.8	114.86	2.74	1.06	51.5	82.77
8	0.919 — 0.951	55.8	105.13	*2.73	1.53	60.5	67.49
9	1.020 — 1.050	59.0	103.63	2.73	1.61	61.7	65.18
10	1.080 — 1.120	59.1	103.82	*2.73	1.61	61.7	65.25
11	1.540 — 1.570	60.2	103.38	*2.73	1.64	62.1	64.54
12	1.570 — 1.610	62.8	102.38	2.73	1.71	63.2	86.01
13	1.740 — 1.770	58.1	104.25	*2.73	1.58	61.3	65.92
14	1.900 — 1.940	58.4	104.25	*2.73	1.58	61.3	65.92
15	2.070 — 2.100	60.8	102.94	*2.73	1.66	62.5	64.00
16	2.230 — 2.260	60.4	103.38	*2.73	1.64	62.1	64.44
17	2.390 — 2.430	57.6	104.25	*2.73	1.58	61.3	65.92
18	2.530 — 2.560	57.9	104.25	2.73	1.58	61.2	66.04
19	2.560 — 2.590	58.1	104.38	*2.74	1.59	61.4	66.02
20	2.660 — 2.690	58.5	104.38	*2.74	1.59	61.4	66.02
21	2.820 — 2.850	63.0	102.26	*2.74	1.72	63.3	62.72
22	3.020 — 3.050	64.2	101.88	*2.74	1.75	63.7	62.03
23	3.180 — 3.220	66.3	101.13	*2.74	1.81	64.4	60.81
24	3.350 — 3.380	60.9	103.07	*2.74	1.67	62.6	64.04
25	3.510 — 3.540	59.4	103.94	*2.74	1.62	61.8	65.22
26	3.540 — 3.580	60.4	103.51	*2.74	1.65	62.2	64.53
27	4.490 — 4.530	62.2	102.69	*2.74	1.70	62.9	63.23
28	4.530 — 4.560	62.0	102.69	*2.74	1.70	62.9	63.23
29	5.480 — 5.510	65.1	101.51	*2.74	1.78	64.0	61.47
30	5.510 — 5.540	62.4	102.70	*2.74	1.70	62.9	63.25

CORE 25

*** inferred value**

Table A-6.7.2, continued. Soil properties.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	WATER CONTENT (% DRY WT)	WET UNIT WT γ_t (PCF)	SPECIFIC GRAVITY G_s	VOID RATIO e	POROSITY n (%)	DRY UNIT WT γ_d (PCF)
31	6.460 — 6.500	68.5	100.00	*2.74	1.89	65.4	59.34
32	6.500 — 6.530	68.1	100.38	*2.74	1.87	65.1	59.73
33	7.480 — 7.510	66.1	101.13	*2.74	1.81	64.4	60.90
34	7.780 — 7.810	66.7	100.76	*2.74	1.83	64.7	60.45
35	8.430 — 8.460	56.2	105.32	*2.74	1.53	60.5	67.42
36	8.460 — 8.490	55.8	105.32	*2.74	1.53	60.5	67.42
37	9.420 — 9.450	55.1	105.75	*2.74	1.51	60.1	68.20
38	9.450 — 9.480	53.5	106.75	*2.74	1.45	59.2	69.56
39	10.400 — 10.430	54.7	105.75	*2.74	1.51	60.1	68.35
40	10.430 — 10.460	50.6	108.25	*2.74	1.40	58.3	71.88
41	11.380 — 11.420	52.7	106.75	*2.74	1.45	59.2	69.90
42	11.420 — 11.450	54.9	105.75	*2.74	1.51	60.1	68.27
43	12.400 — 12.430	55.3	105.75	*2.74	1.51	60.1	68.11
44	13.350 — 13.390	56.6	104.82	*2.74	1.56	61.0	66.92
45	13.390 — 13.420	60.4	103.51	*2.74	1.65	62.2	64.54
46	14.340 — 14.370	54.1	106.25	*2.74	1.48	59.7	68.96
47	14.370 — 14.400	52.9	106.75	*2.74	1.45	59.2	69.84
48	15.320 — 15.350	50.6	107.75	*2.74	1.40	58.3	71.56
49	16.340 — 16.370	54.4	106.25	*2.74	1.48	59.7	68.80
50	17.280 — 17.320	55.1	105.75	*2.74	1.51	60.1	68.18
51	17.320 — 17.360	45.2	111.06	*2.74	1.23	55.2	76.47
52	18.140 — 18.180	58.7	104.03	*2.74	1.62	61.8	65.57

CORE 25 (CONT'D)

*** inferred value**

Table A-6.7.2, continued. Soil properties.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	WATER CONTENT (% DRY WT)	WET UNIT WT γ_t (PCF)	SPECIFIC GRAVITY G_s	VOID RATIO e	POROSITY n (%)	DRY UNIT WT γ_d (PCF)
1	0.001 — 0.033	85.0	94.89	2.73	2.32	69.9	51.30
2	0.131 — 0.164	68.1	100.38	*2.74	1.87	65.1	59.71
3	0.262 — 0.295	67.0	100.76	*2.74	1.83	64.7	60.34
4	0.394 — 0.427	63.2	102.38	2.75	1.74	63.5	62.72
5	0.787 — 0.820	55.0	105.75	*2.74	1.51	60.1	68.23
6	0.820 — 0.853	55.0	105.50	2.74	1.51	60.1	68.05
7	0.984 — 1.020	58.5	103.94	*2.74	1.62	61.8	65.57
8	1.150 — 1.180	59.9	103.51	*2.74	1.65	62.2	64.75
9	1.310 — 1.350	56.3	105.32	*2.74	1.53	60.5	67.39
10	1.480 — 1.510	58.2	104.38	*2.74	1.59	61.4	65.99
11	1.640 — 1.670	59.2	103.94	*2.74	1.62	61.8	63.31
12	1.770 — 1.800	58.3	104.38	*2.74	1.59	61.4	65.93
13	1.800 — 1.840	61.7	103.01	2.74	1.69	62.8	63.72
14	1.970 — 2.000	63.1	102.13	*2.73	1.72	63.2	62.61
15	2.130 — 2.170	61.2	102.94	*2.73	1.67	62.5	63.86
16	2.300 — 2.330	65.2	101.38	*2.73	1.78	64.0	61.35
17	2.460 — 2.490	64.2	101.76	*2.73	1.75	63.6	61.98
18	2.620 — 2.660	67.1	100.63	*2.73	1.83	64.7	60.21
19	2.790 — 2.820	68.3	99.88	2.72	1.86	65.0	59.35
20	2.950 — 2.990	68.9	99.76	*2.72	1.87	65.2	59.08
21	3.120 — 3.150	65.9	100.82	*2.72	1.79	64.2	60.76
22	3.280 — 3.310	63.0	102.01	*2.72	1.71	63.1	62.60
23	3.440 — 3.480	67.2	100.45	*2.72	1.82	64.6	60.07
24	3.610 — 3.640	67.6	100.13	*2.72	1.85	64.9	59.73
25	3.740 — 3.770	70.6	99.26	2.72	1.92	65.8	58.17
26	3.770 — 3.840	71.5	99.32	*2.74	1.94	66.0	57.92
27	4.720 — 4.760	69.8	99.64	*2.74	1.92	65.7	58.67
28	4.760 — 4.790	67.5	100.38	*2.74	1.87	65.1	59.91
29	5.710 — 5.740	70.5	99.32	*2.74	1.92	66.0	58.24
30	5.740 — 5.770	68.1	100.38	*2.74	1.87	65.1	59.72

CORE 30

*inferred value

Table A-6.7.2, continued. Soil properties.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	WATER CONTENT (% DRY WT)	WET UNIT WT γ_t (PCF)	SPECIFIC GRAVITY G_s	VOID RATIO e	POROSITY n (%)	DRY UNIT WT γ_d (PCF)
31	6.690 — 6.730	74.0	98.32	*2.74	2.03	67.0	56.51
32	6.720 — 6.760	73.8	98.32	*2.74	2.03	67.0	56.58
33	7.680 — 7.710	71.6	98.95	*2.74	1.98	66.4	57.65
34	7.710 — 7.740	68.0	100.38	*2.74	1.87	65.1	59.74
35	8.660 — 8.690	67.5	100.38	*2.74	1.87	65.1	59.92
36	8.690 — 8.760	67.8	100.38	*2.74	1.87	65.1	59.82
37	9.650 — 9.680	56.9	104.82	*2.74	1.56	61.0	66.82
38	9.680 — 9.710	57.8	104.38	*2.74	1.59	61.4	66.16
39	10.630 —10.660	66.1	101.13	*2.74	1.81	64.4	60.89
40	10.660 —10.700	62.9	102.26	*2.74	1.72	63.3	62.80
41	11.610 —11.650	59.7	103.51	*2.74	1.65	62.2	64.82
42	11.650 —11.680	60.0	103.51	*2.74	1.65	62.2	64.70
43	12.600 —12.630	64.4	101.88	*2.74	1.75	63.7	61.99
44	12.630 —12.660	55.6	105.32	*2.74	1.53	60.5	67.68
45	13.580 —13.610	65.2	101.51	*2.74	1.78	64.0	61.44
46	13.610 —13.650	58.6	103.94	*2.74	1.62	61.8	65.55
47	14.570 —14.600	66.1	101.13	*2.74	1.81	64.4	60.87
48	14.600 —14.630	62.9	102.26	*2.74	1.72	63.3	62.77
49	15.550 —15.580	56.6	104.82	*2.74	1.53	60.5	66.95
50	15.580 —15.620	58.9	103.94	*2.74	1.62	61.8	65.41
51	16.800 —16.830	60.9	103.07	*2.74	1.67	62.6	64.07

CORE 30 (CONT'D)

* inferred value

Table A-6.7.2, continued. Soil properties.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	WATER CONTENT (% DRY WT)	WET UNIT WT γ_t (PCF)	SPECIFIC GRAVITY G_s	VOID RATIO e	POROSITY n (%)	DRY UNIT WT γ_d (PCF)
1	0.066 — 0.098	61.1	103.07	*2.74	1.82	62.6	63.98
2	0.328 — 0.361	61.3	103.07	*2.74	1.82	62.6	63.98
3	0.660 — 0.690	61.2	103.07	*2.74	1.82	62.6	63.98
4	0.984 — 1.020	65.1	101.51	*2.74	1.78	64.0	61.48
5	1.310 — 1.350	71.9	98.95	*2.74	1.98	66.4	57.54

CORE 31

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	WATER CONTENT (% DRY WT)	WET UNIT WT γ_t (PCF)	SPECIFIC GRAVITY G_s	VOID RATIO e	POROSITY n (%)	DRY UNIT WT γ_d (PCF)
1	0.001 — 0.033	59.4	103.63	2.72	1.62	61.8	65.02
2	0.001 — 0.098	70.9	99.26	2.72	1.93	65.9	58.08
3	0.328 — 0.361	61.4	103.01	2.73	1.68	62.6	63.83
4	0.660 — 0.690	59.2	103.82	*2.73	1.61	61.7	65.21
5	0.984 — 1.020	59.3	103.63	2.74	1.63	61.9	65.05
6	1.310 — 1.350	66.7	100.63	*2.73	1.83	64.7	60.37
7	1.640 — 1.670	65.7	101.13	2.73	1.79	64.3	61.04
8	1.970 — 2.000	67.3	100.51	2.72	1.83	64.7	60.08

CORE 34

*** inferred value**

Table A-6.7.2, continued. Soil properties.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	WATER CONTENT (% DRY WT)	WET UNIT WT γ_t (PCF)	SPECIFIC GRAVITY G_s	VOID RATIO e	POROSITY n (%)	DRY UNIT WT γ_d (PCF)
1	0.001 — 0.033	67.3	100.51	2.75	1.85	64.9	60.07
2	0.394 — 0.427	58.1	104.25	2.73	1.59	61.3	65.94
3	0.820 — 0.853	59.1	103.82	*2.73	1.61	61.7	65.26
4	0.853 — 0.886	56.6	104.88	2.74	1.55	60.8	66.97
5	0.984 — 1.020	52.5	107.06	*2.73	1.42	58.7	70.23
6	1.150 — 1.180	49.5	108.62	*2.73	1.34	57.2	72.67
7	1.310 — 1.350	49.5	108.13	*2.73	1.36	57.7	72.30
8	1.480 — 1.510	51.6	107.06	*2.73	1.42	58.7	70.63
9	1.640 — 1.670	48.9	108.62	*2.73	1.34	57.2	72.93
10	1.840 — 1.870	48.1	109.25	2.73	1.31	56.8	73.75
11	1.970 — 2.000	50.7	108.13	*2.73	1.39	58.2	71.75
12	2.130 — 2.160	51.3	107.56	*2.73	1.39	58.2	71.07
13	2.300 — 2.330	49.7	108.13	*2.73	1.36	57.7	72.23
14	2.460 — 2.490	51.1	107.56	*2.73	1.39	58.2	71.17
15	2.620 — 2.660	52.7	106.56	*2.73	1.44	59.1	69.78
16	2.790 — 2.820	53.7	106.13	2.73	1.47	59.5	69.05
17	2.820 — 2.850	53.5	106.07	*2.73	1.46	59.6	69.10
18	2.950 — 2.990	54.2	106.07	*2.73	1.46	59.6	68.77
19	3.120 — 3.150	52.0	107.06	*2.73	1.42	58.7	70.42
20	3.280 — 3.310	54.1	106.07	*2.73	1.46	59.6	68.85
21	3.440 — 3.480	49.2	108.62	*2.73	1.34	57.2	72.81
22	3.610 — 3.640	49.9	108.13	*2.73	1.36	57.7	72.13
23	3.770 — 3.810	52.5	106.75	2.73	1.43	58.9	70.01
24	3.810 — 3.840	53.8	106.07	*2.73	1.46	59.6	68.96
25	4.750 — 4.790	48.2	109.19	*2.73	1.31	56.7	73.70
26	4.790 — 4.820	44.4	111.50	*2.74	1.21	54.7	77.23
27	5.740 — 5.770	55.3	105.75	*2.74	1.51	60.1	68.08
28	5.770 — 5.810	58.2	104.38	*2.74	1.59	61.4	65.98
29	6.730 — 6.760	53.5	106.75	*2.74	1.45	59.2	69.56
30	6.760 — 6.790	56.7	107.82	*2.74	1.56	61.0	68.82

CORE 32

*** inferred value**

Table A-6.7.2, continued. Soil properties.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	WATER CONTENT (% DRY WT)	WET UNIT WT γ_t (PCF)	SPECIFIC GRAVITY G_s	VOID RATIO e	POROSITY n (%)	DRY UNIT WT γ_d (PCF)
31	7.380 — 7.410	48.8	108.81	*2.74	1.34	57.3	73.11
32	7.710 — 7.740	55.6	105.32	*2.74	1.53	60.5	67.68
33	7.740 — 7.760	57.6	104.37	*2.74	1.59	61.4	66.22
34	8.690 — 8.730	49.1	108.81	*2.74	1.34	57.3	72.97
35	9.650 — 9.680	47.5	109.37	*2.74	1.31	56.8	74.14
36	9.680 — 9.710	48.9	108.81	*2.74	1.34	57.3	73.06
37	10.630 — 10.660	47.2	108.81	*2.74	1.29	56.3	73.90
38	11.610 — 11.650	52.2	107.25	*2.74	1.43	58.8	70.49
39	11.650 — 11.680	53.2	106.75	*2.74	1.45	59.2	69.66
40	12.600 — 12.630	46.4	110.50	*2.74	1.26	55.8	75.49
41	12.630 — 12.660	46.5	109.94	*2.74	1.29	56.3	75.02
42	13.580 — 13.620	44.1	111.68	*2.74	1.21	54.7	77.51
43	13.620 — 13.650	44.2	111.06	*2.74	1.21	54.7	77.00
44	14.570 — 14.590	43.8	111.68	*2.74	1.21	54.7	77.65
45	15.520 — 15.550	47.1	109.94	*2.74	1.29	56.3	74.76

CORE 32 (CONT'D)

* inferred value

Table A-6.7.2, continued. Soil properties.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	WATER CONTENT (% DRY WT)	WET UNIT WT γ_t (PCF)	SPECIFIC GRAVITY G_s	VOID RATIO e	POROSITY n (%)	DRY UNIT WT γ_d (PCF)
1	0.001 — 0.033	72.0	98.64	2.72	1.96	66.2	57.35
2	0.164 — 0.197	57.8	104.38	*2.74	1.59	61.4	66.13
3	0.328 — 0.361	56.8	104.82	*2.74	1.56	61.0	66.87
4	0.423 — 0.459	54.6	106.13	2.75	1.50	60.0	68.63
5	0.591 — 0.623	59.2	103.63	2.73	1.62	61.8	65.09
6	0.722 — 0.755	60.1	103.51	*2.74	1.65	62.2	64.65
7	0.886 — 0.919	53.0	106.75	*2.74	1.45	59.2	69.79
8	0.919 — 0.951	56.6	104.82	*2.74	1.56	61.0	66.95
9	1.480 — 1.510	48.6	108.81	*2.74	1.34	57.3	73.21
10	1.640 — 1.670	55.8	105.32	*2.74	1.53	60.5	67.60
11	1.800 — 1.840	63.1	102.38	2.74	1.73	63.3	62.78
12	1.900 — 1.970	61.6	103.01	2.75	1.69	62.9	63.73
13	2.100 — 2.130	80.0	96.14	2.74	2.19	68.7	53.40
14	2.260 — 2.300	65.4	101.51	*2.74	1.81	64.4	61.36
15	2.430 — 2.460	65.4	101.51	*2.74	1.81	64.4	61.36
16	2.590 — 2.620	65.1	101.51	*2.74	1.81	64.4	61.36
17	2.850 — 2.890	60.3	103.01	2.73	1.65	62.2	64.25
18	3.080 — 3.120	56.9	105.13	*2.73	1.56	60.9	67.01
19	3.250 — 3.280	51.8	107.06	*2.73	1.42	58.7	70.50
20	3.410 — 3.440	61.0	102.94	*2.73	1.67	62.5	63.95
21	3.580 — 3.610	63.8	101.76	*2.73	1.75	63.6	62.12
22	3.840 — 3.870	73.9	98.01	2.73	2.02	66.9	56.36
23	3.870 — 3.900	63.9	101.88	*2.74	1.67	63.6	62.15
24	4.820 — 4.860	70.4	99.64	*2.74	1.92	65.7	58.48
25	4.860 — 4.880	70.6	99.32	*2.74	1.94	66.0	58.20
26	5.800 — 5.840	63.4	102.26	*2.74	1.72	63.3	62.57
27	6.790 — 6.820	78.7	96.76	*2.74	2.16	68.4	54.16
28	6.820 — 6.860	73.3	98.64	*2.74	2.00	66.7	56.91
29	7.760 — 7.810	62.0	102.69	*2.74	1.70	62.9	63.40
30	7.810 — 7.840	59.1	103.94	*2.74	1.62	61.8	65.31

CORE 35

*** inferred value**

Table A-6.7.2, continued. Soil properties.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	WATER CONTENT (% DRY WT)	WET UNIT WT γ_t (PCF)	SPECIFIC GRAVITY G_s	VOID RATIO e	POROSITY n (%)	DRY UNIT WT γ_d (PCF)
31	8.760 — 8.790	33.0	119.24	2.74	0.91	47.5	89.62
32	8.790 — 8.830	52.8	106.75	*2.74	1.45	59.2	69.85
33	9.740 — 9.780	50.0	108.25	*2.74	1.37	57.8	72.16
34	9.780 — 9.810	57.5	104.82	*2.74	1.56	61.0	66.57
35	10.730 —10.760	54.6	105.75	*2.74	1.51	60.1	68.40
36	10.760 —10.790	57.2	104.82	*2.74	1.56	61.0	66.67
37	11.710 —11.740	59.9	103.51	*2.74	1.65	62.2	64.73
38	11.740 —11.780	57.4	104.82	*2.74	1.56	61.0	66.59
39	12.700 —12.730	55.2	105.75	*2.74	1.51	60.1	68.13
40	12.730 —12.760	57.1	104.82	*2.74	1.56	61.0	66.73
41	13.680 —13.711	42.1	112.93	*2.74	1.15	53.5	79.45
42	13.710 —13.740	49.4	108.25	*2.74	1.34	57.3	72.44
43	14.670 —14.700	66.3	101.13	*2.74	1.81	64.4	60.80
44	14.700 —14.730	67.1	100.76	*2.74	1.83	64.7	60.31
45	15.680 —15.720	72.4	98.95	*2.74	1.98	66.4	57.38
46	15.720 —15.757	72.9	98.64	*2.74	2.00	66.7	57.06
47	16.630 —16.670	53.0	106.75	*2.74	1.45	59.2	69.77
48	16.670 —16.700	53.9	101.88	*2.74	1.48	59.7	66.22
49	17.450 —17.490	45.8	110.50	*2.74	1.26	55.8	75.76

CORE 35 (CONT'D)

* inferred value

Table A-6.7.2, continued. Soil properties.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	WATER CONTENT (% DRY WT)	WET UNIT WT γ_t (PCF)	SPECIFIC GRAVITY G_s	VOID RATIO e	POROSITY n (%)	DRY UNIT WT γ_d (PCF)
1	0.001 — 0.033	67.8	100.51	2.75	1.86	65.1	59.90
2	0.164 — 0.197	54.1	106.38	*2.75	1.49	59.8	69.03
3	0.328 — 0.361	54.2	106.38	*2.75	1.49	59.8	69.00
4	0.492 — 0.525	55.4	105.94	*2.75	1.51	60.2	68.17
5	0.656 — 0.689	55.5	105.32	*2.75	1.53	60.6	67.72
6	0.755 — 0.787	53.8	106.13	2.74	1.47	59.6	69.00

CORE 36

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	WATER CONTENT (% DRY WT)	WET UNIT WT γ_t (PCF)	SPECIFIC GRAVITY G_s	VOID RATIO e	POROSITY n (%)	DRY UNIT WT γ_d (PCF)
1	0.001 — 0.033	58.3	104.25	2.74	1.60	61.5	65.86
2	0.001 — 0.033	66.4	101.13	2.74	1.82	64.5	60.76
3	0.164 — 0.197	52.5	106.75	2.74	1.44	59.0	70.00
4	0.328 — 0.361	58.7	103.94	*2.74	1.62	61.8	65.50
5	0.492 — 0.525	64.7	101.50	*2.74	1.78	64.0	61.62
6	0.660 — 0.690	57.8	104.38	*2.74	1.59	61.4	66.16
7	0.820 — 0.853	58.2	104.38	*2.74	1.59	61.4	66.16
8	0.853 — 0.886	58.2	104.25	2.73	1.59	61.4	65.90
9	0.984 — 1.020	62.1	102.69	*2.74	1.70	62.9	63.34
10	1.150 — 1.180	60.9	103.07	*2.74	1.67	62.6	64.06
11	1.310 — 1.350	63.4	102.26	*2.74	1.73	63.3	62.59
12	1.480 — 1.510	58.0	104.38	*2.74	1.59	61.4	66.06
13	1.640 — 1.670	63.8	101.88	*2.74	1.75	63.7	62.18
14	1.800 — 1.840	66.6	101.13	2.74	1.82	64.6	60.70
15	1.970 — 2.000	58.4	104.38	*2.74	1.59	61.4	65.90

CORE 38

* inferred value

Table A-6.7.3. Strength measurements

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	SHEAR STRENGTH (PSI) NAT.	SHEAR STRENGTH (PSI) REM.	SENSITIVITY	TORVANE (TSF)
1	0.033 — 0.098	0.19			
2	0.460 — 0.560	0.54			
3	1.080 — 1.120	0.40	0.13	3.0	
4	2.070 — 2.170	0.69	0.19	3.7	

CORE 16

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	SHEAR STRENGTH (PSI) NAT.	SHEAR STRENGTH (PSI) REM.	SENSITIVITY	TORVANE (TSF)
1	0.001 — 0.098	0.79	0.25	3.2	

CORE 17

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	SHEAR STRENGTH (PSI) NAT.	SHEAR STRENGTH (PSI) REM.	SENSITIVITY	TORVANE (TSF)
1	0.001 — 0.098	0.49	0.16	3.1	
2	0.525 — 0.623	0.84			
3	0.951 — 1.050	1.20	0.28	4.3	
4	1.080 — 1.180	0.74			
5	2.000 — 2.100	1.02	0.25	4.1	

CORE 18

Table A-6.7.3, continued. Strength measurements.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	SHEAR STRENGTH (PSI) NAT.	SHEAR STRENGTH (PSI) REM.	SENSITIVITY	TORVANE (TSF)
1	0.098 — 0.197	0.64			
2	0.459 — 0.560	1.01			
3	1.380 — 1.480	1.56	0.23	6.6	
4	1.480 — 1.570	2.16			
5	2.460 — 2.560	2.04			
6	3.440 — 3.480				8.25
7	3.480 — 3.580	3.77			
8	4.430 — 4.490				3.20
9	5.410 — 5.450				6.70
10	5.450 — 5.540	3.93			
11	6.400 — 6.430				3.50
12	6.430 — 6.530	3.93			
13	7.380 — 7.420				2.80
14	7.420 — 7.510	2.89			
15	8.410 — 8.430	5.45			
16	9.350 — 9.380				3.80
17	9.380 — 9.480	4.45			
18	10.330 — 10.370				4.25
19	10.370 — 10.470	4.03			
20	11.320 — 11.350				4.00
21	11.350 — 11.450	5.08			
22	12.300 — 12.340				5.00
23	12.340 — 12.430	3.38			
24	13.290 — 13.320				5.60
25	13.320 — 13.420	6.92			
26	14.270 — 14.300				8.75
27	14.300 — 14.400	6.52			
28	15.260 — 15.290				4.70
29	15.290 — 15.390	6.12			

CORE 22

Table A-6.7.3, continued. Strength measurements.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	SHEAR STRENGTH (PSI) NAT.	SHEAR STRENGTH (PSI) REM.	SENSITIVITY	TORVANE (TSF)
1	0.492 — 0.590	0.96	0.20	4.7	
2	0.590 — 0.689	1.61			
3	1.480 — 1.570	4.32			
4	1.570 — 1.670	4.01	0.33	12.2	
5	2.460 — 2.560	3.01	0.42	7.2	
6	2.560 — 2.660	3.19			
7	3.440 — 3.540	2.26	0.38	5.9	
8	3.540 — 3.640	2.46			
9	4.430 — 4.530	4.58			
10	4.490 — 4.530				3.50
11	4.530 — 4.630	4.38			
12	5.480 — 5.510				3.15
13	5.510 — 5.610	3.81			
14	6.460 — 6.500				3.70
15	6.500 — 6.590	4.90			
16	7.450 — 7.480				4.00
17	7.480 — 7.580	6.94			
18	8.430 — 8.460				4.20
19	8.460 — 8.560	7.19			
20	9.450 — 9.550	7.19			
21	10.400 —10.430				4.90
22	10.430 —10.530	7.09			
23	11.320 —11.420	6.64			
24	11.380 —11.420				5.40
25	12.300 —12.400	7.04			
26	12.370 —12.400				6.80
27	13.350 --13.390				5.70
28	13.390 —13.480	7.44			
29	14.270 —14.370	7.28			
30	14.340 —14.370				5.90

CORE 25

Table A-6.7.3, continued. Strength measurements.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	SHEAR STRENGTH (PSI) NAT.	SHEAR STRENGTH (PSI) REM.	SENSITIVITY	TORVANE (TSF)
31	15.250 — 15.350	7.87			
32	15.320 — 15.350				5.40
33	16.230 — 16.340	7.04			
34	16.310 — 16.340				5.50
35	17.280 — 17.330				7.20
36	17.320 — 17.420	7.99			
37	18.140 — 18.180				5.70

CORE 25 (CONT'D)

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	SHEAR STRENGTH (PSI) NAT.	SHEAR STRENGTH (PSI) REM.	SENSITIVITY	TORVANE (TSF)
1	0.001 — 0.098	1.01	0.21	4.8	

CORE 20

Table A-6.7.3, continued. Strength measurements.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	SHEAR STRENGTH (PSI) NAT.	SHEAR STRENGTH (PSI) REM.	SENSITIVITY	TORVANE (TSF)
1	0.394 — 0.492	1.72			
2	0.722 — 0.820	1.63			
3	0.820 — 0.853	2.10	0.15	13.7	
4	1.710 — 1.800	2.11			
5	1.800 — 1.900	1.86	0.13	14.0	
6	2.690 — 2.790	2.11			
7	2.790 — 2.890	1.85	0.21	8.7	
8	3.670 — 3.770	2.33			
9	3.770 — 3.870	2.07			
10	4.720 — 4.760				2.20
11	4.760 — 4.860	2.57			
12	5.710 — 5.740				2.40
13	5.740 — 5.840	2.63			
14	6.690 — 6.730				2.20
15	6.720 — 6.820	3.06			
16	7.680 — 7.710				2.10
17	7.710 — 7.800	3.12			
18	8.660 — 8.690				2.90
19	8.690 — 8.790	3.72			
20	9.650 — 9.680				2.90
21	9.680 — 9.780	3.32			
22	10.660 —10.760	4.01			
23	11.610 —11.650				3.90
24	11.650 —11.750	4.42			
25	12.600 —12.630				4.10
26	12.630 —12.730	4.88			
27	13.580 —13.610				4.00
28	13.610 —13.720	5.40			
29	14.500 —14.600	5.18			
30	14.600 —14.700	5.42			

CORE 30

Table A-6.7.3, continued. Strength measurements.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	SHEAR STRENGTH (PSI) NAT.	SHEAR STRENGTH (PSI) REM.	SENSITIVITY	TORVANE (TSF)
31	15.550 —15.580				4.80
32	15.580 —15.680	6.39			
33	16.500 —16.600	6.10			

CORE 30 (CONT'D)

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	SHEAR STRENGTH (PSI) NAT.	SHEAR STRENGTH (PSI) REM.	SENSITIVITY	TORVANE (TSF)
1	0.066 — 0.098				1.50
2	0.660 — 0.690				1.50
3	1.310 — 1.350				1.00

CORE 31

Table A-6.7.3, continued. Strength measurements.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	SHEAR STRENGTH (PSI) NAT.	SHEAR STRENGTH (PSI) REM.	SENSITIVITY	TORVANE (TSF)
1	0.001 — 0.098		0.30		
2	0.328 — 0.427	2.59			
3	0.755 — 0.853	2.88			
4	0.853 — 0.951	3.50			
5	1.740 — 1.840	4.22			
6	1.840 — 1.900	4.70	1.10	4.2	
7	2.720 — 2.820	5.13			
8	2.820 — 2.920	5.67			
9	3.710 — 3.810	5.80	1.28	4.5	
10	3.810 — 3.900	5.18			
11	4.760 — 4.790				5.20
12	4.790 — 4.890	5.67			
13	5.740 — 5.770				5.60
14	5.770 — 5.870	6.54			
15	6.730 — 6.760				4.50
16	6.760 — 6.860	6.84			
17	7.380 — 7.410				5.10
18	7.640 — 7.740	5.67			
19	7.710 — 7.740				6.20
20	8.730 — 8.830	5.50			
21	9.680 — 9.710				4.90
22	9.680 — 9.780	6.94			
23	10.630 — 10.660				6.70
24	10.660 — 10.760	7.42			
25	11.610 — 11.650				6.90
26	11.650 — 11.750	7.60			
27	12.600 — 12.630				7.10
28	12.630 — 12.730	8.39			
29	13.620 — 13.710	7.60			
30	14.570 — 14.590				7.20

CORE 32

Table A-6.7.3, continued. Strength measurements.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	SHEAR STRENGTH (PSI) NAT.	SHEAR STRENGTH (PSI) REM.	SENSITIVITY	TORVANE (TSF)
31	14.590 — 14.700	8.63			
32	15.520 — 15.550				3.80

CORE 32 (CONT'D)

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	SHEAR STRENGTH (PSI) NAT.	SHEAR STRENGTH (PSI) REM.	SENSITIVITY	TORVANE (TSF)
1	0.001 — 0.033				1.40
2	1.150 — 1.180				2.30
3	2.260 — 2.300				3.00

CORE 34

Table A-6.7.3, continued. Strength measurements.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	SHEAR STRENGTH (PSI) NAT.	SHEAR STRENGTH (PSI) REM.	SENSITIVITY	TORVANE (TSF)
1	0.423 — 0.525	1.55	0.32	4.9	
2	0.820 — 0.919	2.28			
3	0.919 — 1.020	2.55			
4	1.900 — 2.000	3.17	0.94	3.3	
5	2.790 — 2.890	2.82			
6	2.890 — 2.990	2.91			
7	3.840 — 3.870				3.00
8	3.870 — 3.970	4.20	0.69	6.1	
9	4.820 — 4.860				2.30
10	4.860 — 4.950	3.30			
11	5.800 — 5.840				4.30
12	5.840 — 5.910	7.83			
13	6.790 — 6.820				3.70
14	6.820 — 6.920	8.91			
15	7.760 — 7.781				3.70
16	7.810 — 7.910	7.27			
17	8.760 — 8.790				4.40
18	8.790 — 8.890	6.47			
19	9.740 — 9.780				5.80
20	9.780 — 9.880	7.86			
21	10.730 —10.760				5.60
22	10.760 —10.860	8.19			
23	11.710 —11.740				4.60
24	11.740 —11.840	8.51			
25	12.700 —12.730				4.50
26	12.730 —12.830	7.64			
27	13.680 —13.710				2.80
28	13.710 —13.810	5.33			
29	14.670 —14.700				4.60
30	14.700 —14.800	7.08			

CORE 35

Table A-6.7.3, continued. Strength measurements.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	SHEAR STRENGTH (PSI) NAT.	SHEAR STRENGTH (PSI) REM.	SENSITIVITY	TORVANE (TSF)
31	15.720 — 15.750				5.20
32	15.680 — 15.780	10.02			
33	16.630 — 16.670				5.30
34	16.670 — 16.760	7.68			
35	17.450 — 17.490				4.20

CORE 35 (CONT'D)

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	SHEAR STRENGTH (PSI) NAT.	SHEAR STRENGTH (PSI) REM.	SENSITIVITY	TORVANE (TSF)
1	0.001 — 0.098	0.50			
2	0.689 — 0.787	1.18	0.27	4.4	

CORE 36

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	SHEAR STRENGTH (PSI) NAT.	SHEAR STRENGTH (PSI) REM.	SENSITIVITY	TORVANE (TSF)
1	0.001 — 0.098	0.98			
2	0.853 — 0.951	1.28	0.26	4.9	
3	1.870 — 1.970	2.06	0.28	7.3	

CORE 38

Table A-6.7.4. Atterberg limits.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	LIQUID LIMIT (%) LL	PLASTIC LIMIT (%) PL	PLASTICITY INDEX (%) PI	LIQUIDITY INDEX LI
1	0.001 -- 0.033	45.4	36.2	9.2	3.5

GRAB 2

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	LIQUID LIMIT (%) LL	PLASTIC LIMIT (%) PL	PLASTICITY INDEX (%) PI	LIQUIDITY INDEX LI
1	0.001 -- 0.164	43.9	34.3	9.6	

GRAB 7

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	LIQUID LIMIT (%) LL	PLASTIC LIMIT (%) PL	PLASTICITY INDEX (%) PI	LIQUIDITY INDEX LI
1	0.001 -- 0.033	45.3	34.1	11.2	

GRAB 15

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	LIQUID LIMIT (%) LL	PLASTIC LIMIT (%) PL	PLASTICITY INDEX (%) PI	LIQUIDITY INDEX LI
1	0.001 -- 0.230	40.5	34.2	6.3	6.0
2	1.080 -- 1.250	39.6	33.2	6.4	4.2
3	1.970 -- 2.160	37.1	31.9	5.2	9.1

CORE 16

Table A-6.7.4, continued. Atterberg limits.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	LIQUID LIMIT (%) LL	PLASTIC LIMIT (%) PL	PLASTICITY INDEX (%) PI	LIQUIDITY INDEX LI
1	0.001 – 0.197	38.3	27.9	10.4	2.8

CORE 17

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	LIQUID LIMIT (%) LL	PLASTIC LIMIT (%) PL	PLASTICITY INDEX (%) PI	LIQUIDITY INDEX LI
1	0.001 – 0.197	41.0	35.7	5.3	5.6
2	0.853 – 1.050	39.4	33.0	6.4	3.5
3	1.940 – 2.130	37.8	31.7	6.1	4.0

CORE 18

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	LIQUID LIMIT (%) LL	PLASTIC LIMIT (%) PL	PLASTICITY INDEX (%) PI	LIQUIDITY INDEX LI
1	0.001 – 0.230	38.8	32.4	6.4	4.1

CORE 20

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	LIQUID LIMIT (%) LL	PLASTIC LIMIT (%) PL	PLASTICITY INDEX (%) PI	LIQUIDITY INDEX LI
1	0.001 – 0.164	39.6	33.5	6.1	

GRAB 21

Table A-6.7.4, continued. Atterberg limits.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	LIQUID LIMIT (%) LL	PLASTIC LIMIT (%) PL	PLASTICITY INDEX (%) PI	LIQUIDITY INDEX LI
1	1.310 -- 1.480	40.3	28.4	11.9	[illegible]
2	2.460 -- 2.620	41.1	33.7	7.4	[illegible]
3	6.430 — 6.594	45.4	37.3	8.1	[illegible]
4	9.383 — 9.547	50.9	39.6	11.3	2.0
5	12.336 —12.500	44.0	36.9	[illegible]	1.3
6	15.289 —15.453	44.5	38.0	6.5	2.1

CORE 22

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	LIQUID LIMIT (%) LL	PLASTIC LIMIT (%) PL	PLASTICITY INDEX (%) PI	LIQUIDITY INDEX LI
1	0.262 — 0.394	45.5	36.9	8.6	2.9
2	0.394 — 0.560	40.6	34.7	5.9	4.5
3	1.570 -- 1.710	49.4	39.3	10.1	2.3
4	2.390 — 2.560	48.6	40.5	8.1	2.1
5	3.340 -- 3.540	[illegible]	39.0	11.8	1.8
6	6.496 -- 6.660	59.3	38.5	20.8	1.4
7	9.449 — 9.612	50.4	39.7	10.7	1.3
8	12.401 --12.565	41.9	35.3	6.6	3.0
9	15 354 --15.518	58.1	40.4	17.7	0.6
10	17.322 —17.486	48.8	28.6	20.2	0.8

CORE 25

Table A-6.7.4, continued. Atterberg limits.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	LIQUID LIMIT (%) LL	PLASTIC LIMIT (%) PL	PLASTICITY INDEX (%) PI	LIQUIDITY INDEX LI
1	0.001 — 0.033	47.5	32.1	15.4	

CORE 26

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	LIQUID LIMIT (%) LL	PLASTIC LIMIT (%) PL	PLASTICITY INDEX (%) PI	LIQUIDITY INDEX LI
1	0.001 — 0.164	41.2	35.2	6.0	

GRAB 28

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	LIQUID LIMIT (%) LL	PLASTIC LIMIT (%) PL	PLASTICITY INDEX (%) PI	LIQUIDITY INDEX LI
1	0.820 — 0.984	42.2	36.3	5.9	3.2
2	1.800 — 2.000	43.1	37.3	5.8	4.3
3	2.790 — 2.990	47.5	34.3	13.2	2.6
4	5.741 — 5.905	54.3	44.6	9.7	2.4
5	8.694 — 8.858	51.2	40.1	11.1	2.5
6	11.646 —11.811	46.6	37.0	9.6	2.4
7	14.600 —14.764	48.0	37.0	11.0	2.4

CORE 30

Table A-6.7.4, continued. Atterberg limits.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	LIQUID LIMIT (%) LL	PLASTIC LIMIT (%) PL	PLASTICITY INDEX (%) PI	LIQUIDITY INDEX LI
1	0.001 — 0.164	48.9	32.1	16.8	2.1
2	1.610 — 1.840	45.3	31.4	13.9	1.3
3	3.670 — 3.810	48.2	29.9	18.3	1.2
4	5.774 — 5.938	50.4	36.2	14.2	1.6
5	8.727 — 8.891	55.1	42.0	13.1	0.5
6	11.646 — 11.844	59.8	43.8	16.0	0.6
7	14.600 — 14.797	46.2	33.1	13.1	0.9

CORE 32

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	LIQUID LIMIT (%) LL	PLASTIC LIMIT (%) PL	PLASTICITY INDEX (%) PI	LIQUIDITY INDEX LI
1	0.001 — 0.164	51.0	35.5	15.5	

CORE 33

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	LIQUID LIMIT (%) LL	PLASTIC LIMIT (%) PL	PLASTICITY INDEX (%) PI	LIQUIDITY INDEX LI
1	0.001 — 0.164	46.6	39.1	7.6	2.7

CORE 34

Table A-6.7.4, continued. Atterberg limits.

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	LIQUID LIMIT (%) LL	PLASTIC LIMIT (%) PL	PLASTICITY INDEX (%) PI	LIQUIDITY INDEX LI
1	0.427 — 0.591	42.5	30.1	12.4	2.0
2	1.900 — 2.130	43.7	38.2	5.5	5.9
3	3.670 — 3.840	56.5	44.0	12.5	2.0
4	5.839 — 6.003	56.5	38.8	17.7	1.4
5	8.792 — 8.956	44.6	36.2	8.4	2.0
6	11.745 — 11.909	46.9	33.4	13.5	1.8
7	14.697 — 14.862	73.6	50.5	23.1	0.7
8	16.666 — 16.830	44.8	33.9	10.9	1.8

CORE 35

SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	LIQUID LIMIT (%) LL	PLASTIC LIMIT (%) PL	PLASTICITY INDEX (%) PI	LIQUIDITY INDEX LI
1	0.591 — 0.787	41.5	31.0	10.5	2.3

CORE 36

Table A-6.7.4, continued. Atterberg limits.

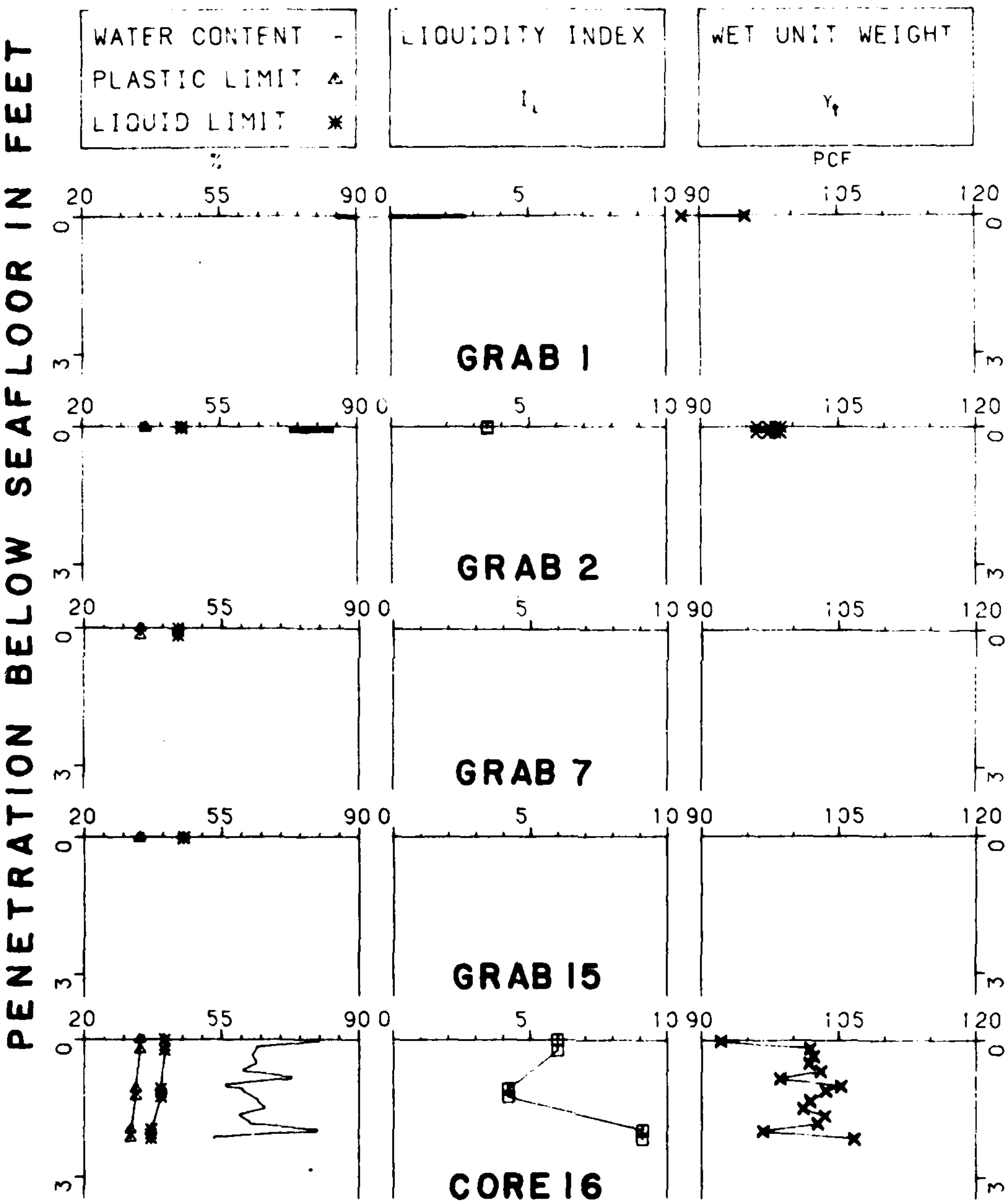
SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	LIQUID LIMIT (%) LL	PLASTIC LIMIT (%) PL	PLASTICITY INDEX (%) PI	LIQUIDITY INDEX LI
1	0.295 — 0.427	44.5	39.3	5.2	3.7
2	0.853 — 1.050	44.1	31.7	12.4	2.3
3	1.840 — 2.030	41.7	38.7	3.0	6.6

CORE 38

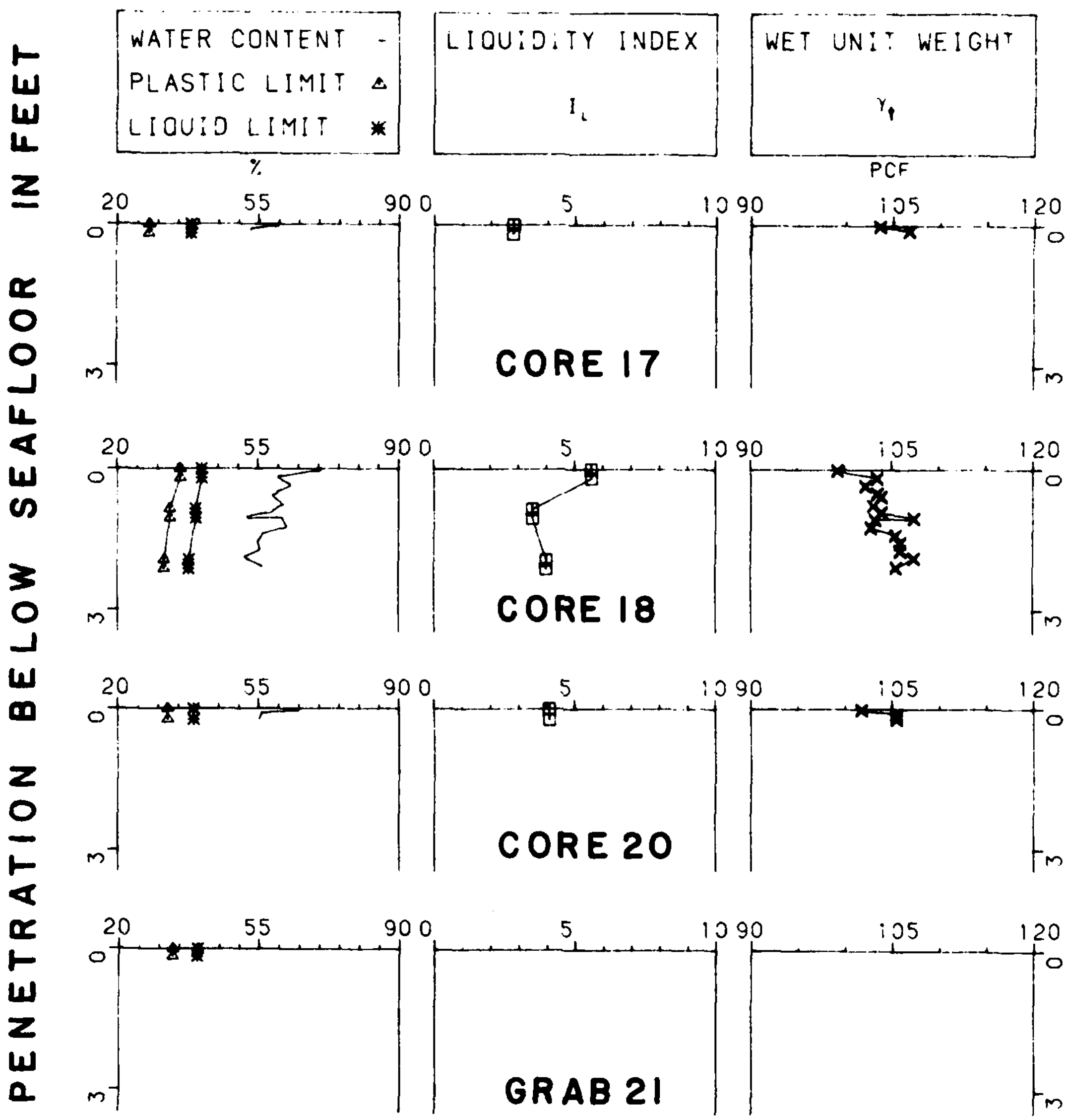
SAMPLE NUMBER	SAMPLE INTERVAL (FEET)	LIQUID LIMIT (%) LL	PLASTIC LIMIT (%) PL	PLASTICITY INDEX (%) PI	LIQUIDITY INDEX LI
1	0.001 -- 0.164	36.6	31.0	5.6	

CORE 40

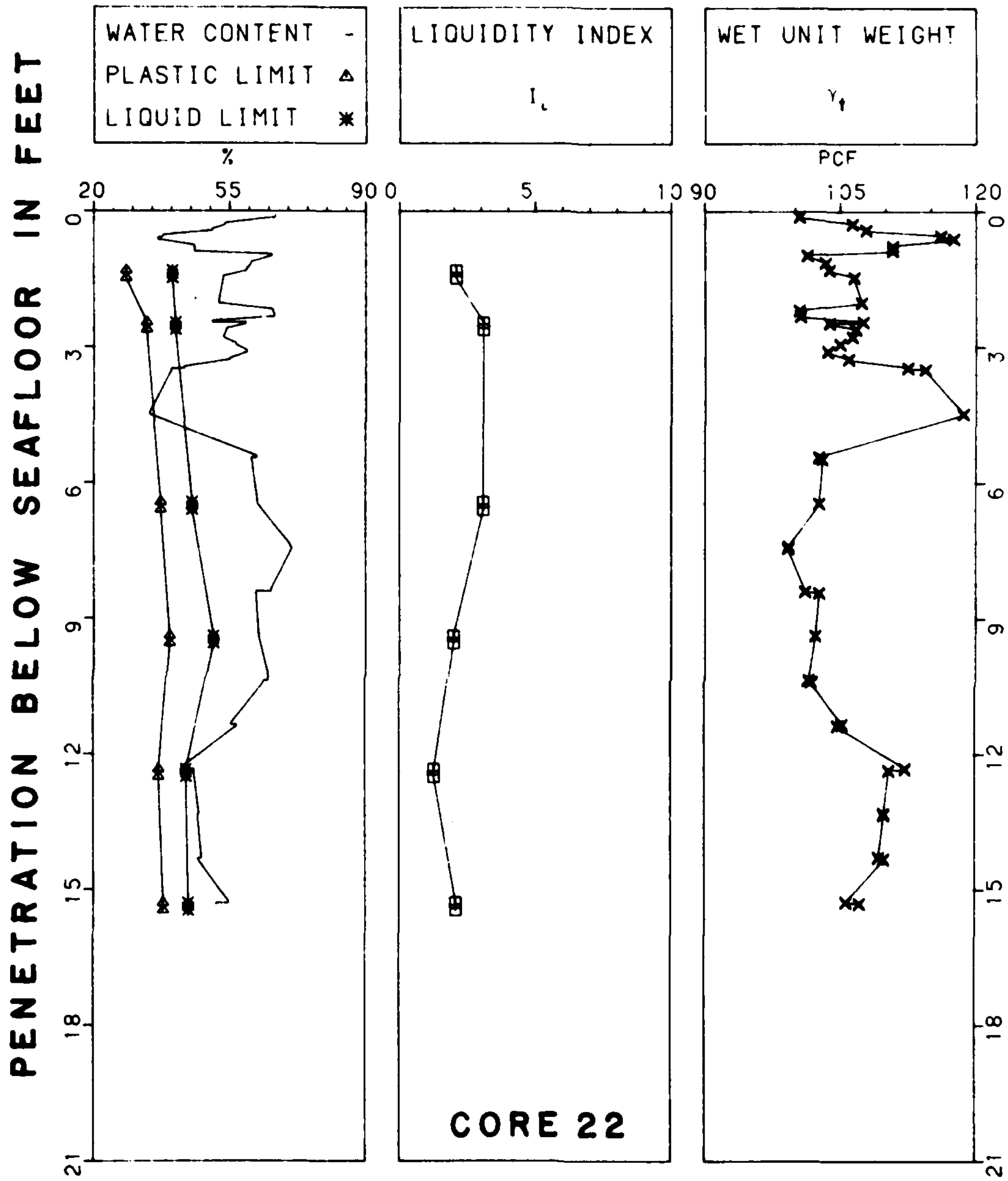
Plot A-6.8.1. Soil properties



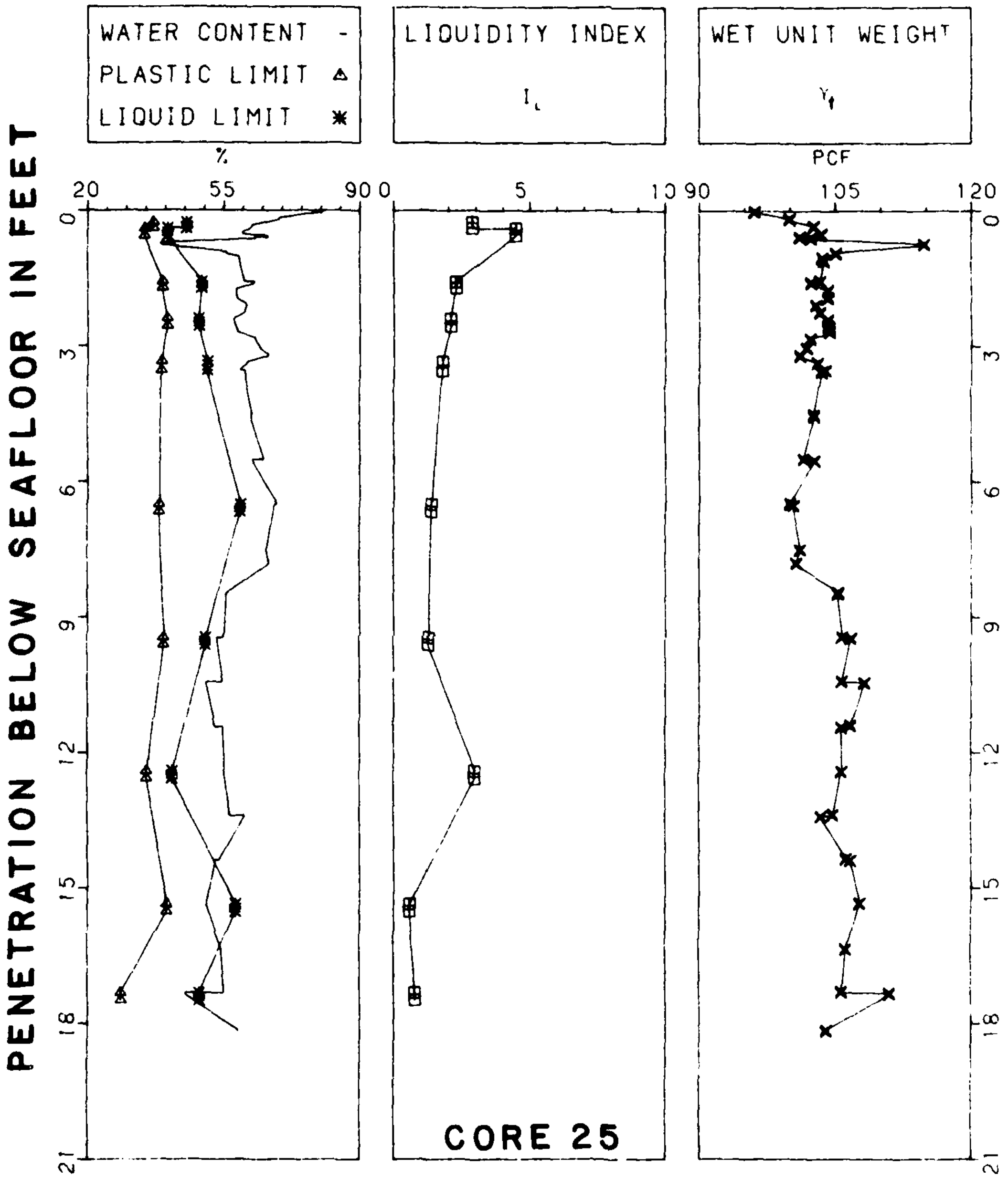
Plot A-6.8.1, continued. Soil properties.



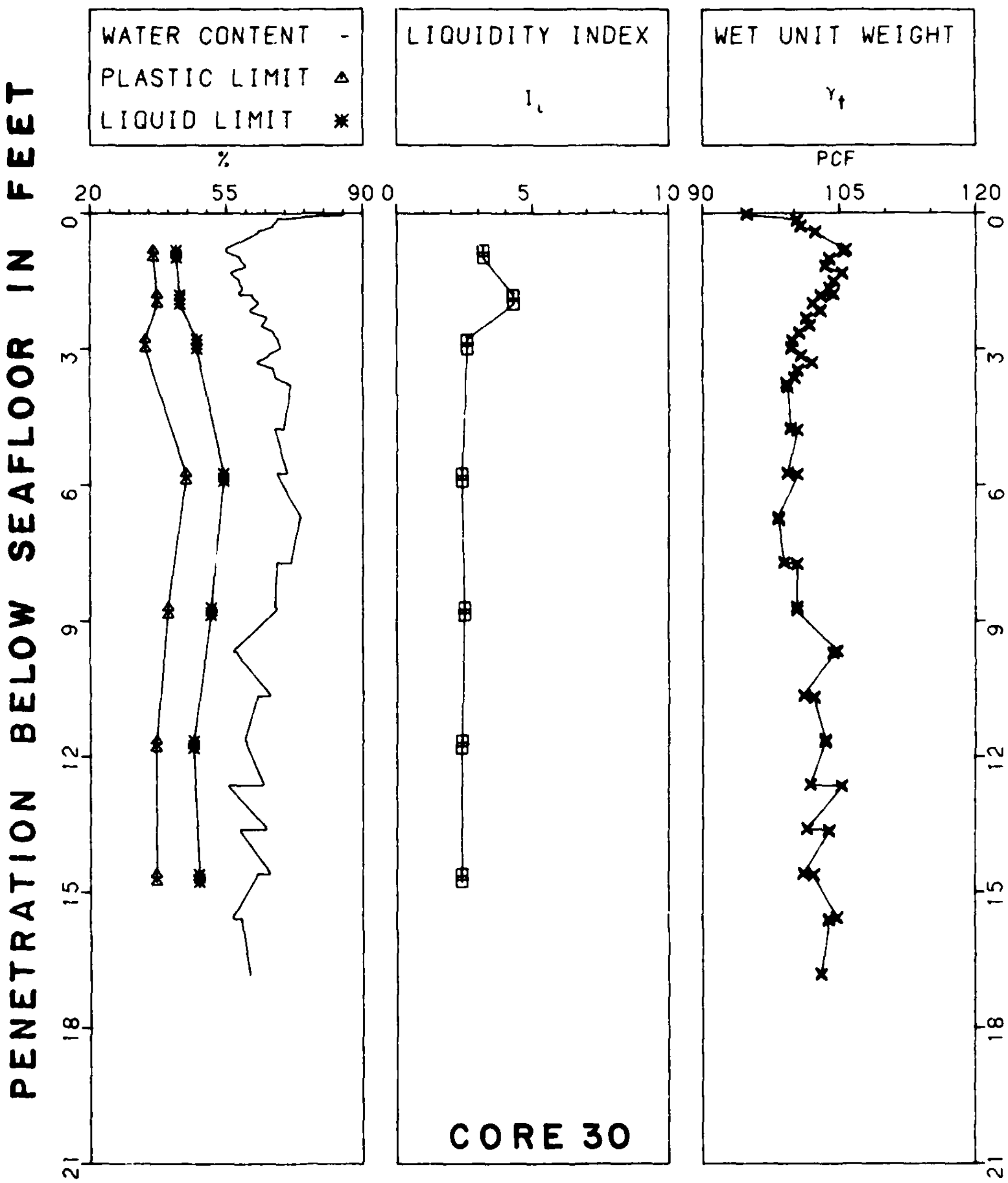
Plot A-6.8.1, continued. Soil properties.



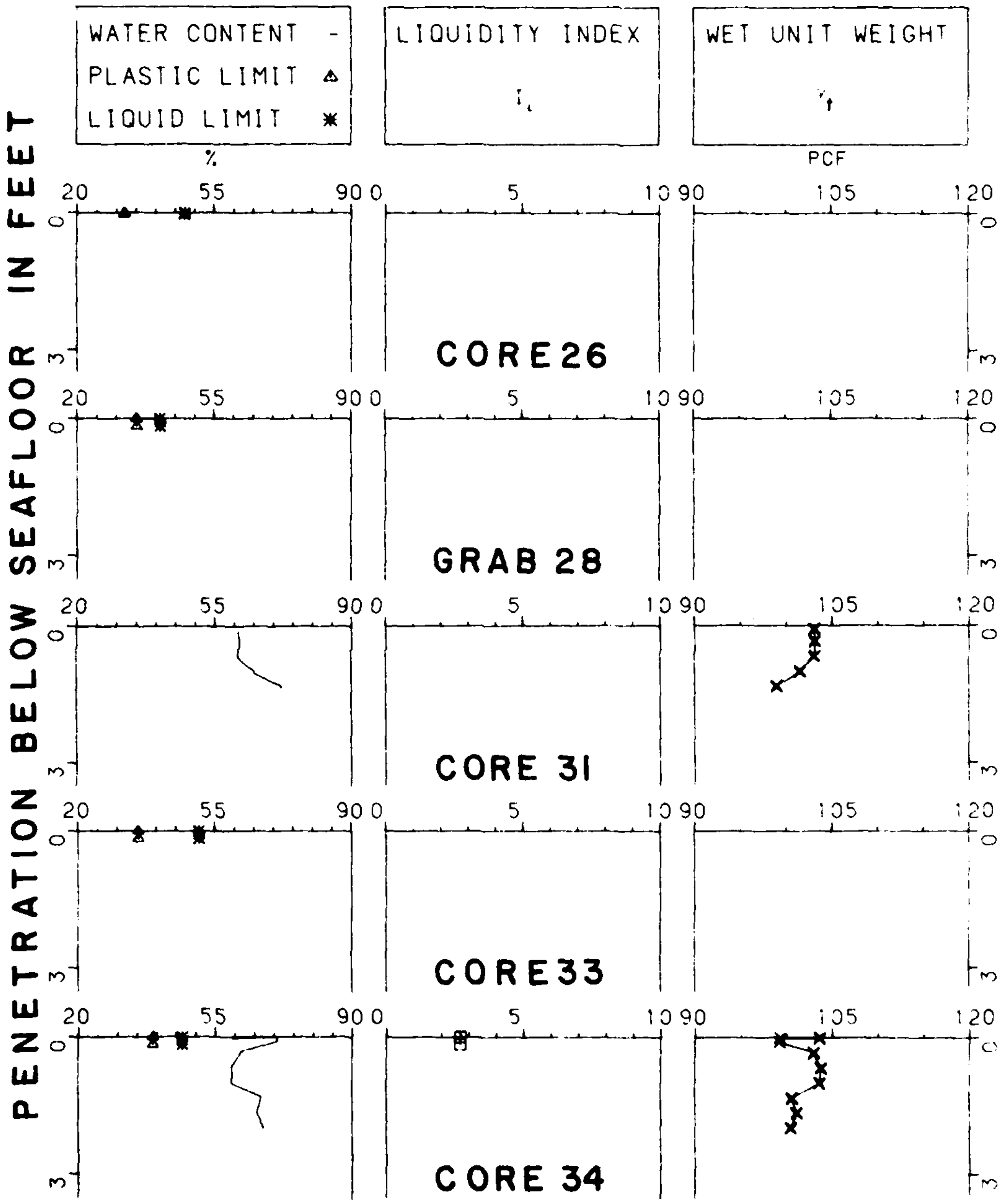
Plot A-6.8.1, continued. Soil properties.



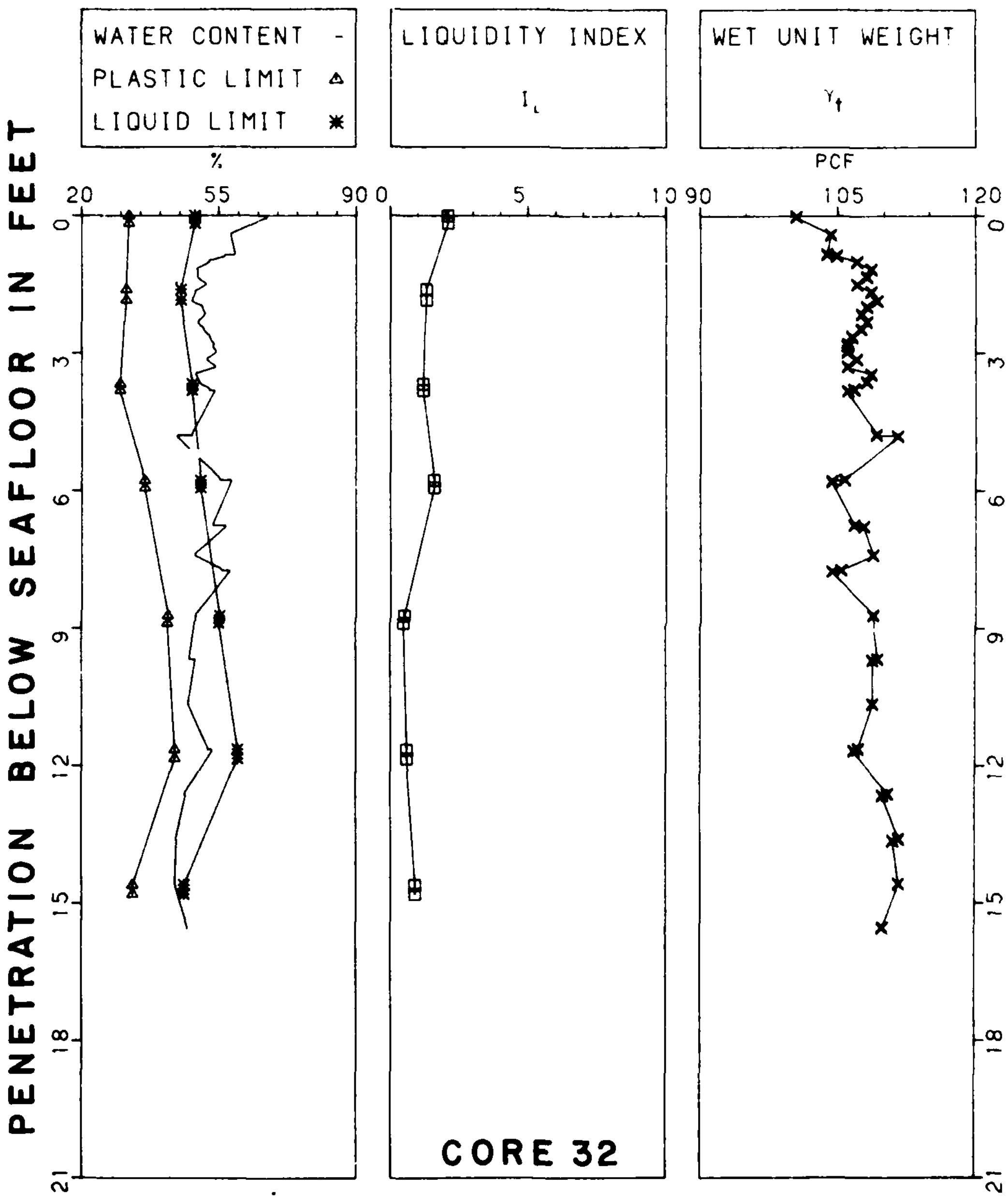
Plot A-6.8.1, continued. Soil properties.



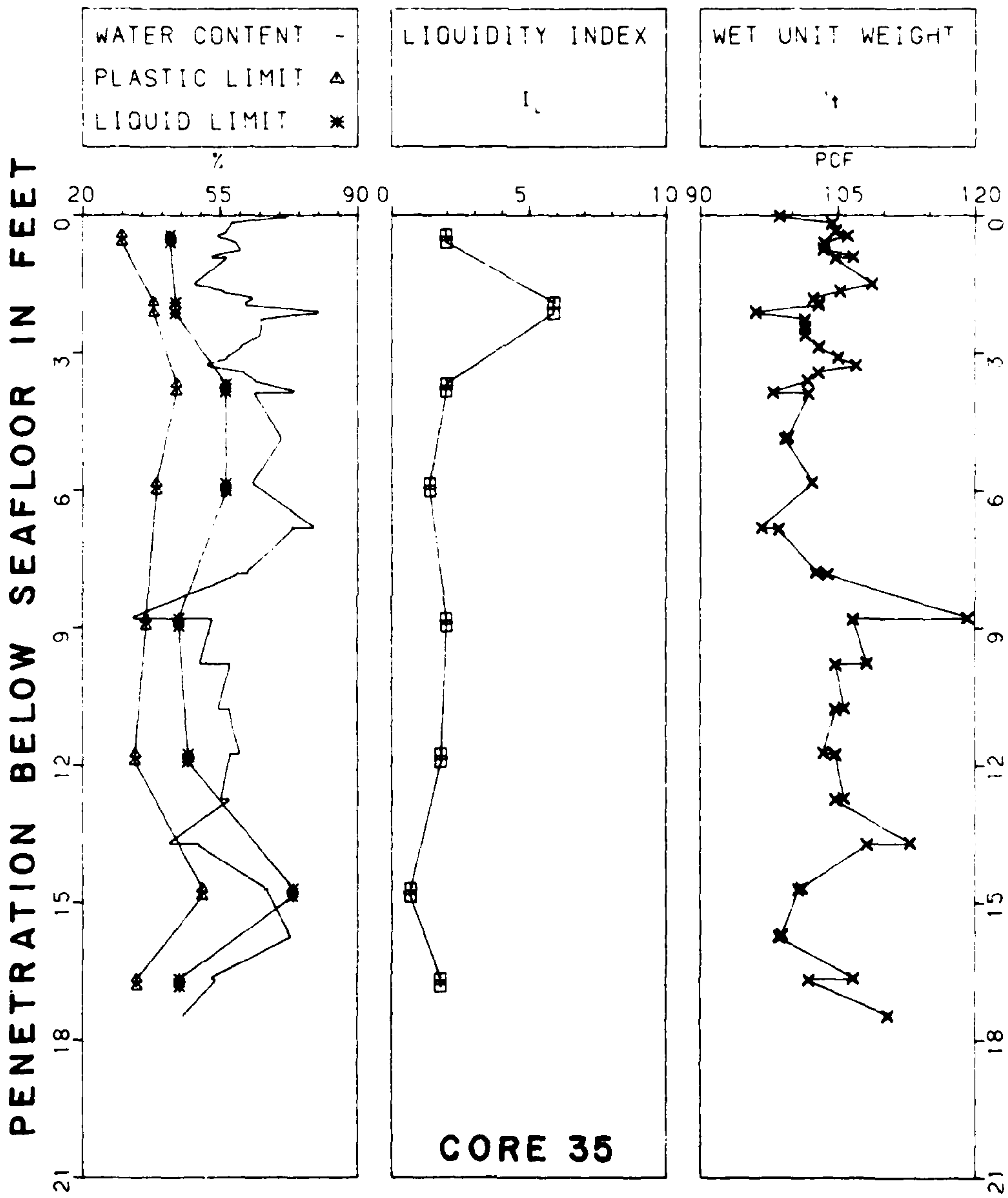
Plot A-6.8.1, continued. Soil properties.



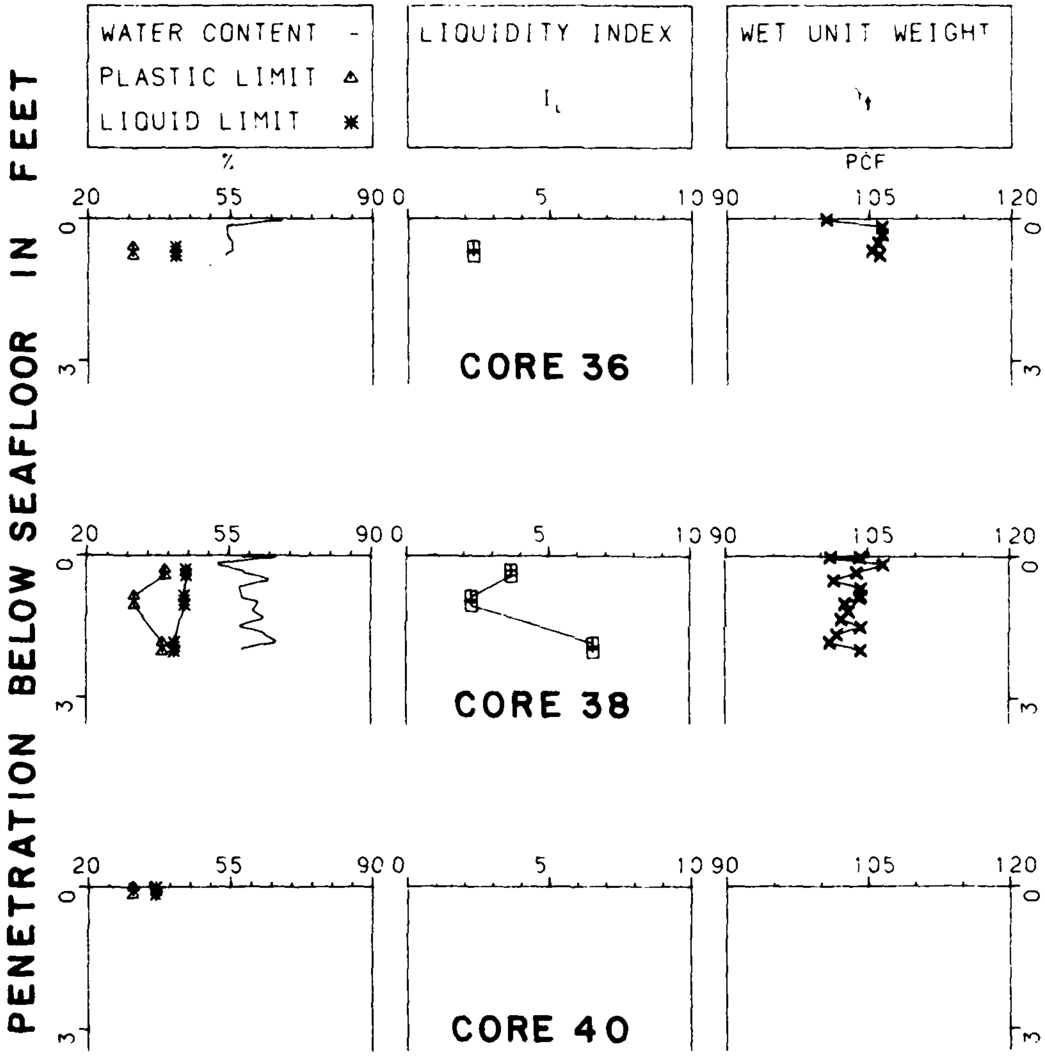
Plot A-6.8.1, continued. Soil properties.



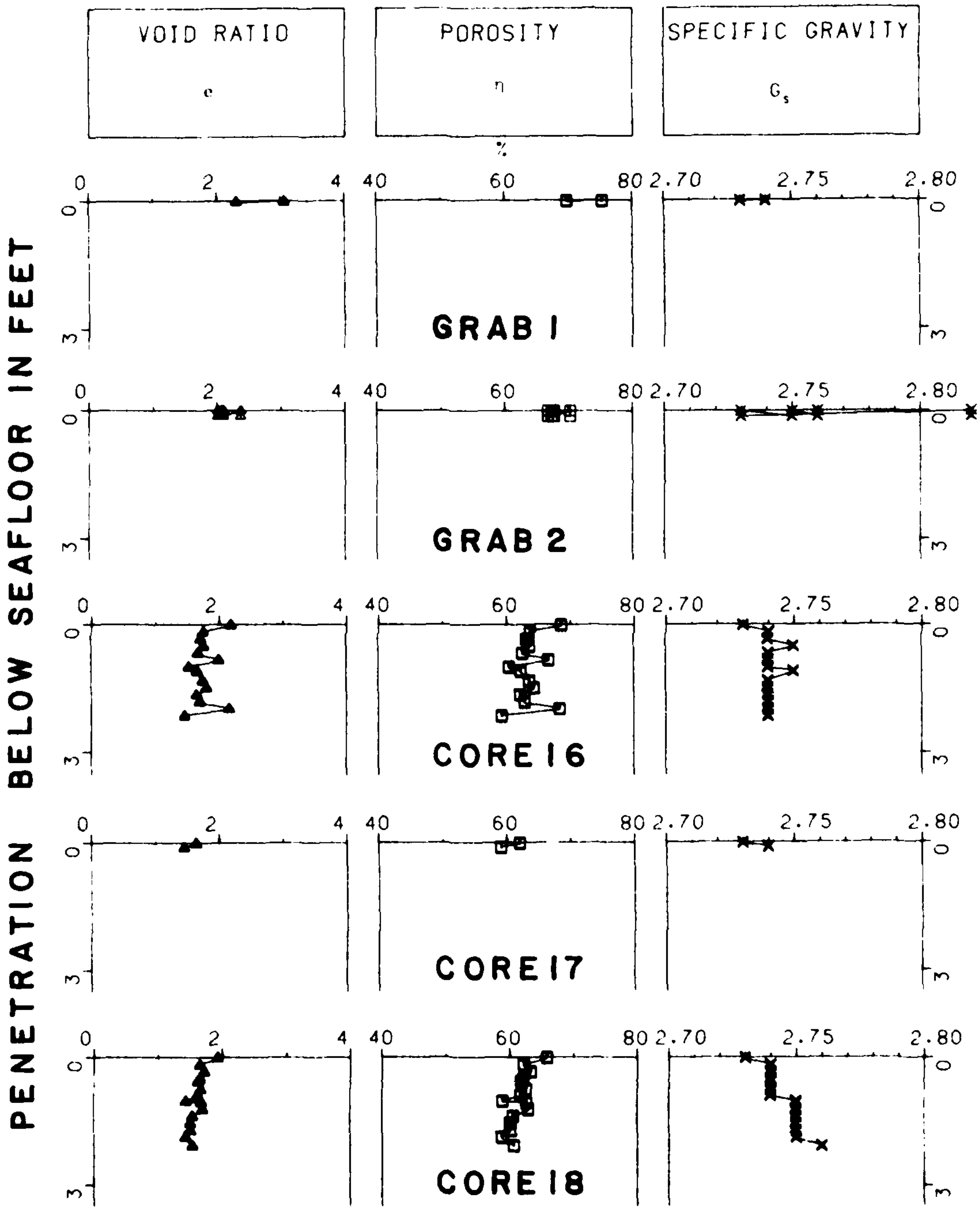
Plot A-6.8.1, continued. Soil properties.



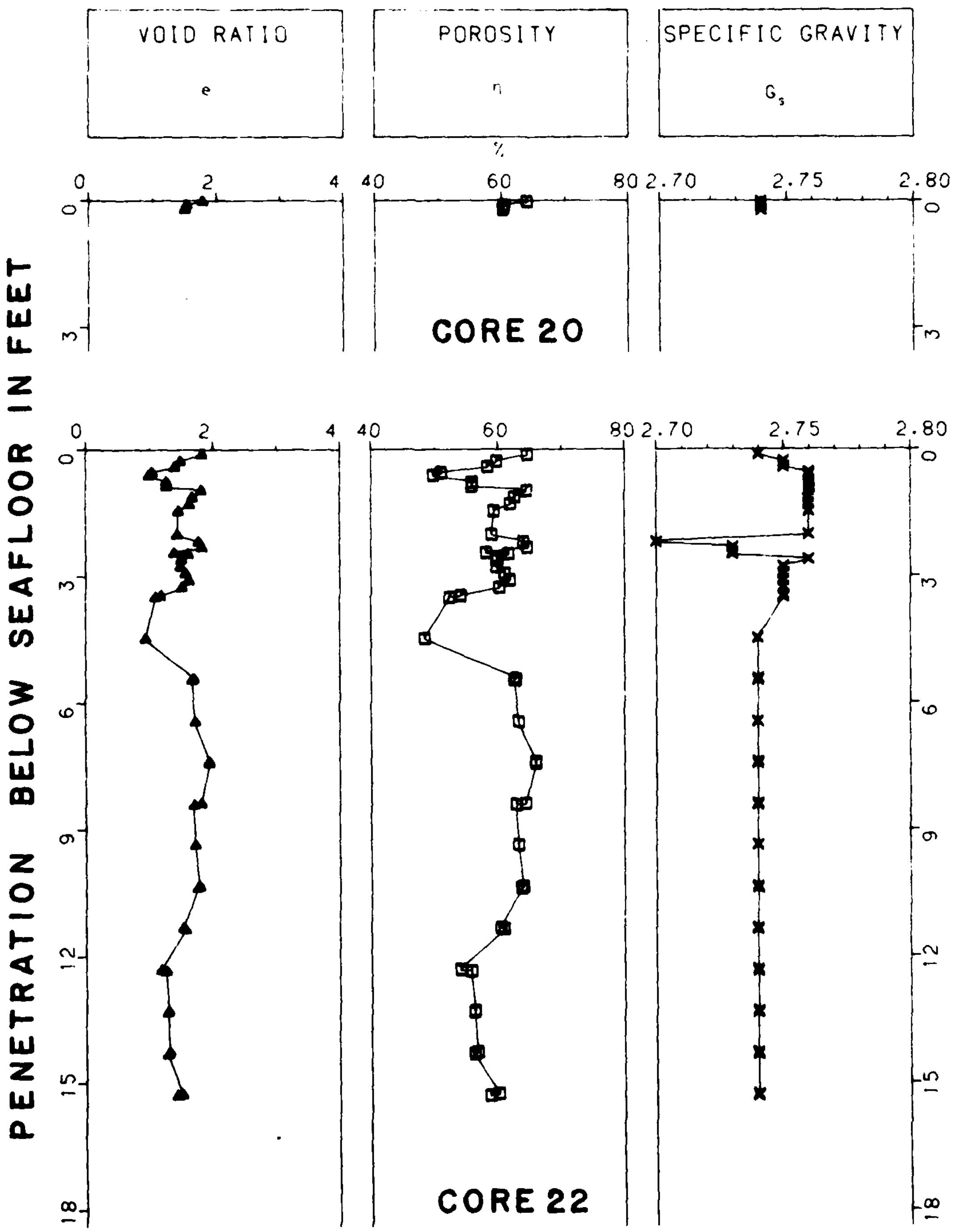
Plot A-6.8.1, continued. Soil properties.



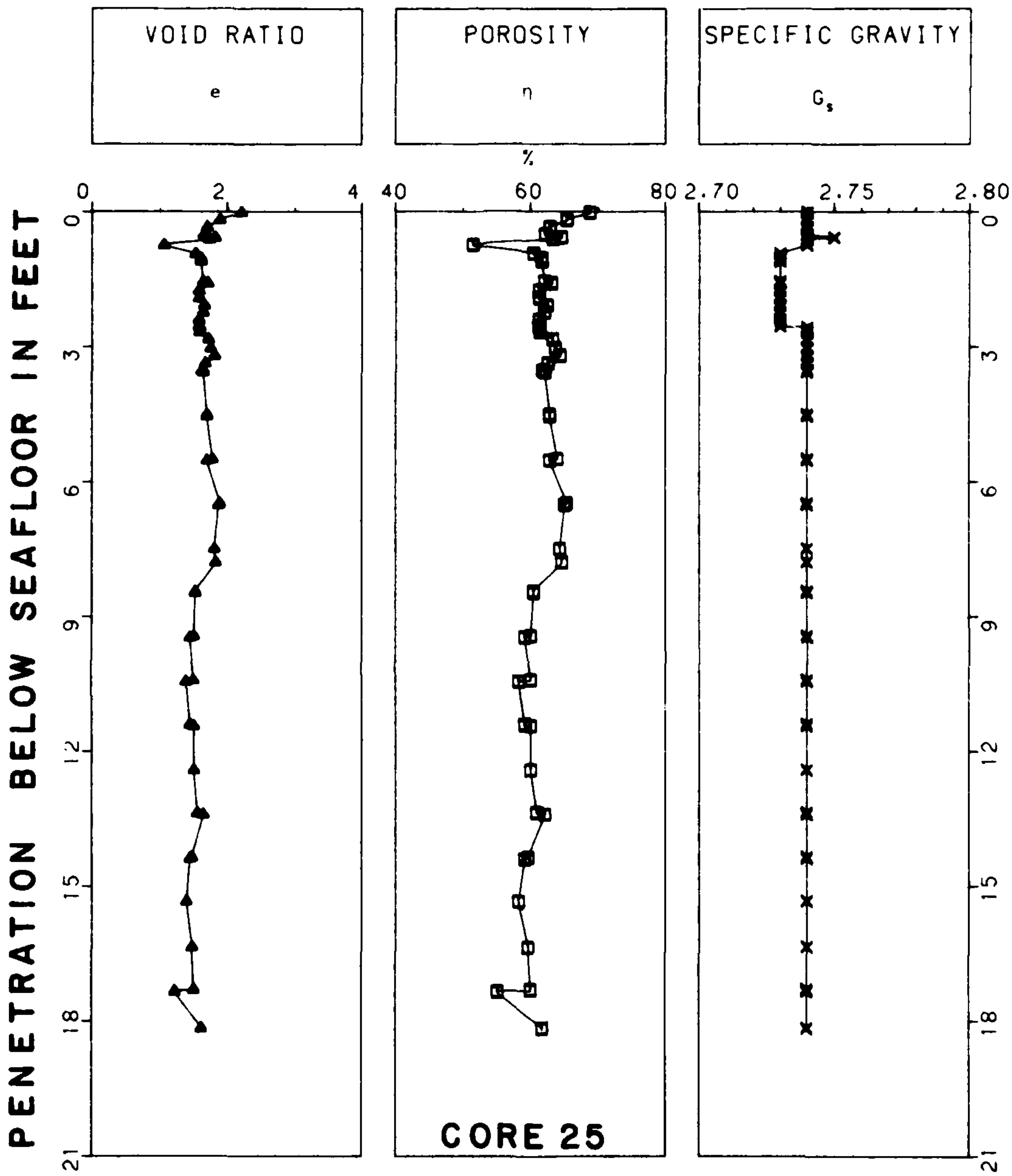
Plot A-6.8.1, continued. Soil properties.



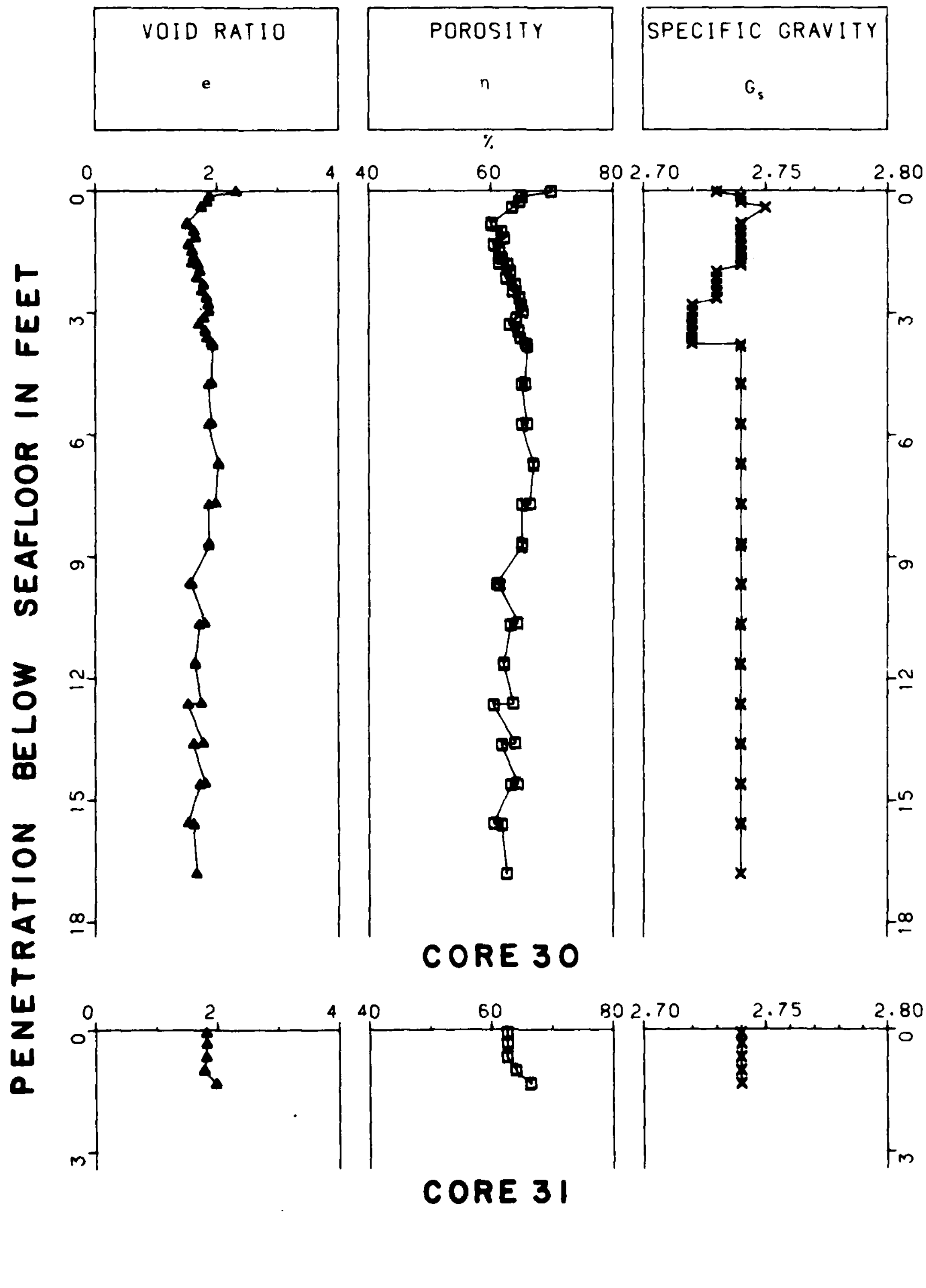
Plot A-6.8.1, continued. Soil properties.



Plot A-6.8.1, continued. Soil properties.



Plot A-6.8.1, continued. Soil properties.



Plot A-6.8.1, continued. Soil properties.

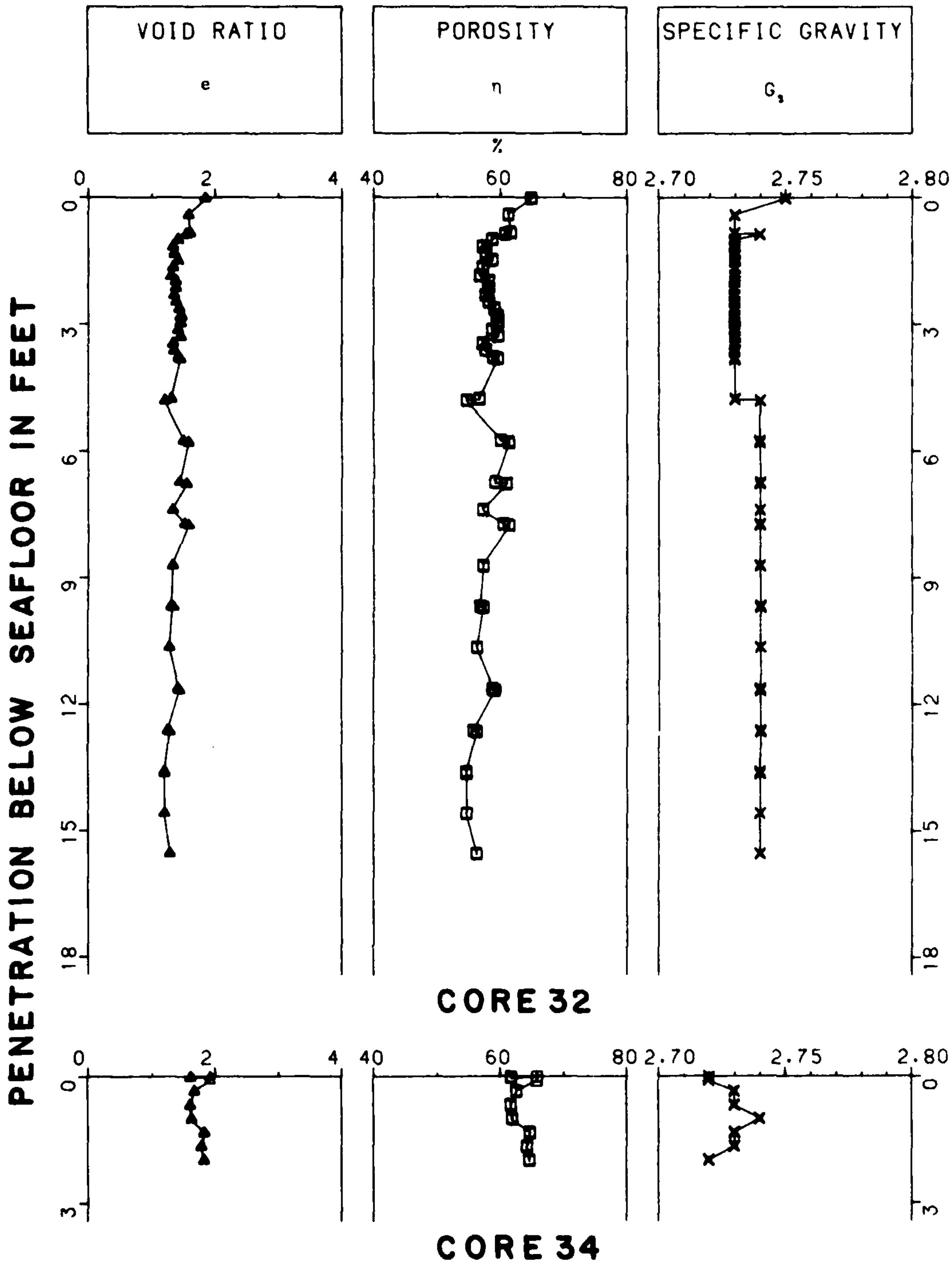
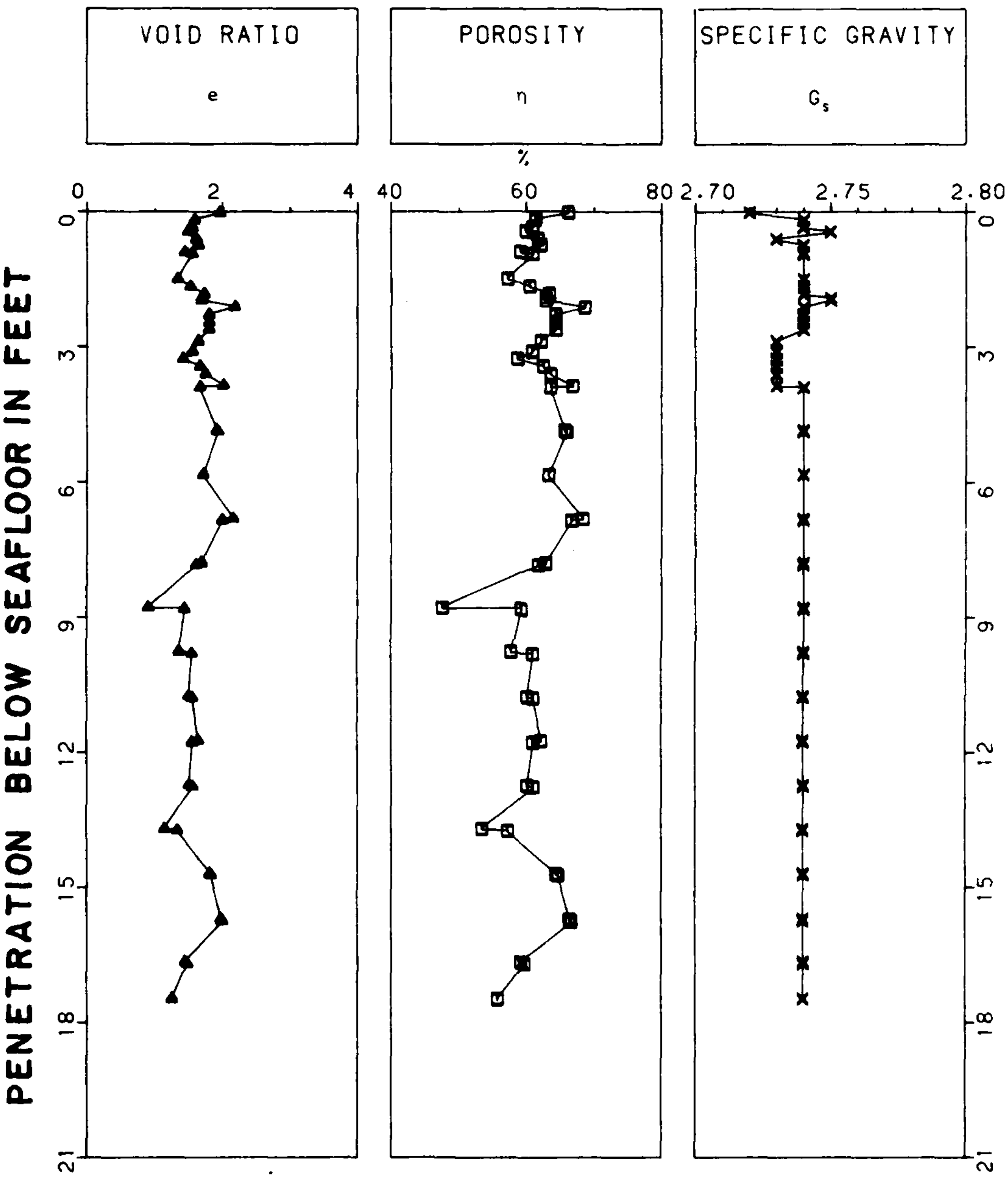
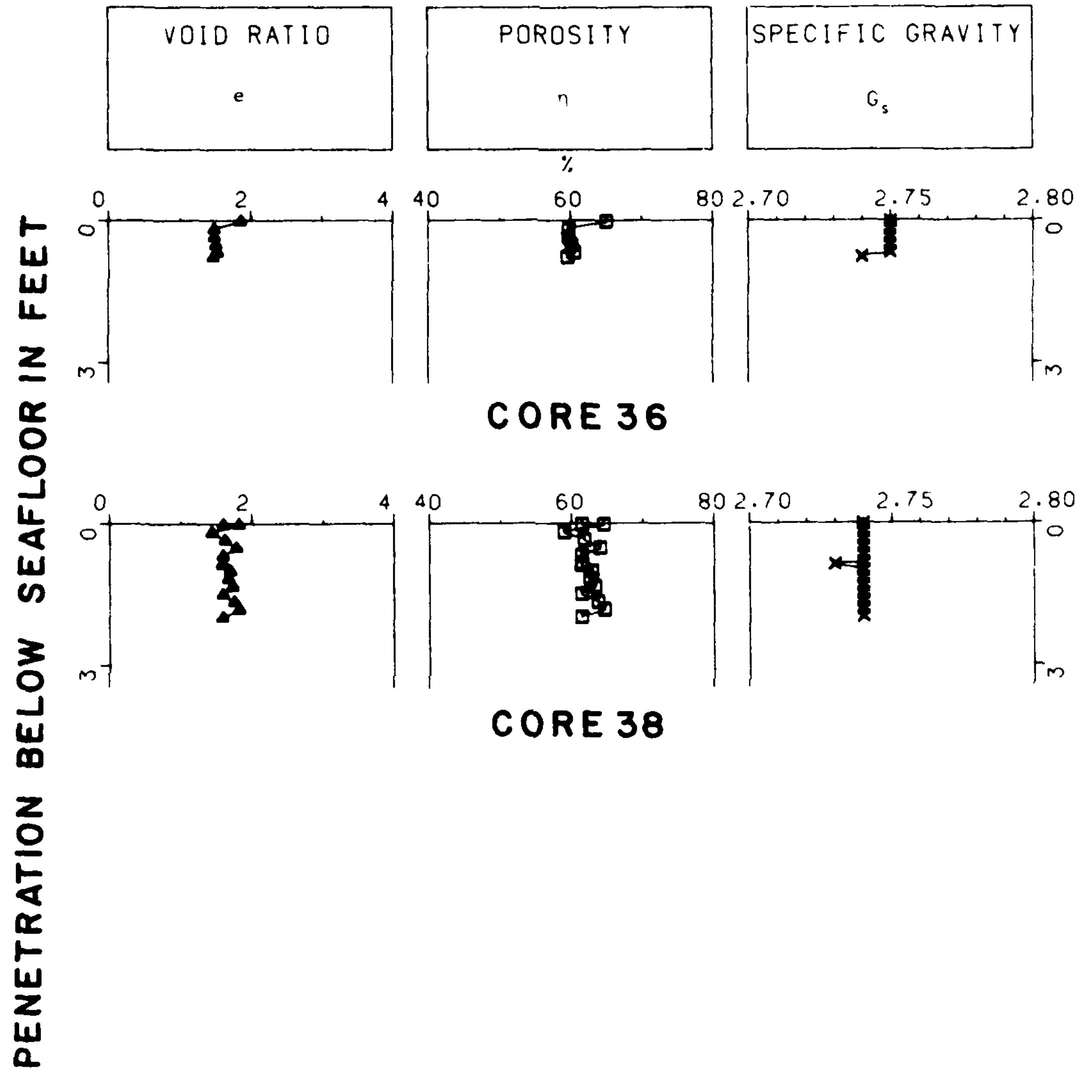


Table A-6.8.1, continued. Plot of soil properties.

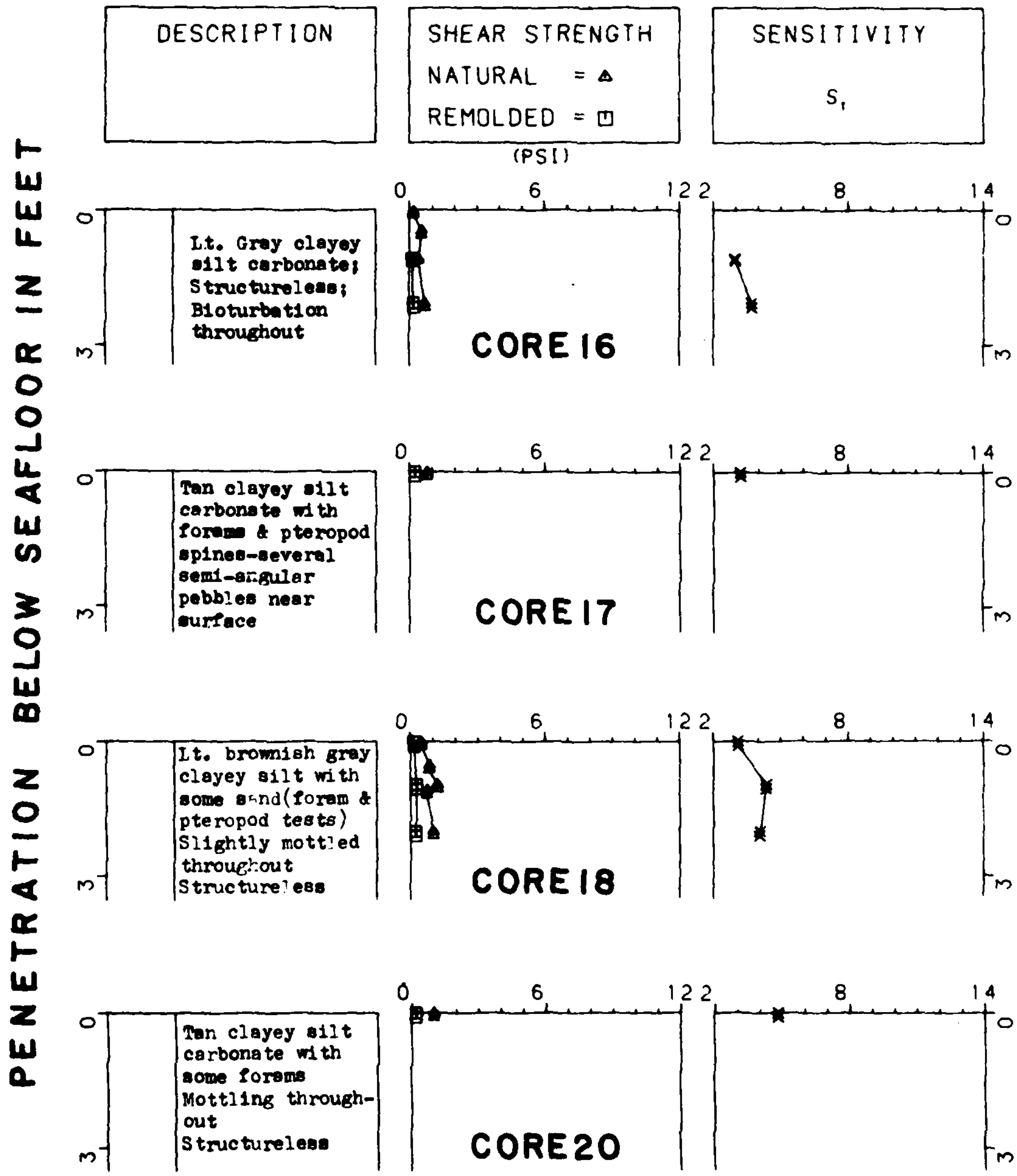


CORE 35

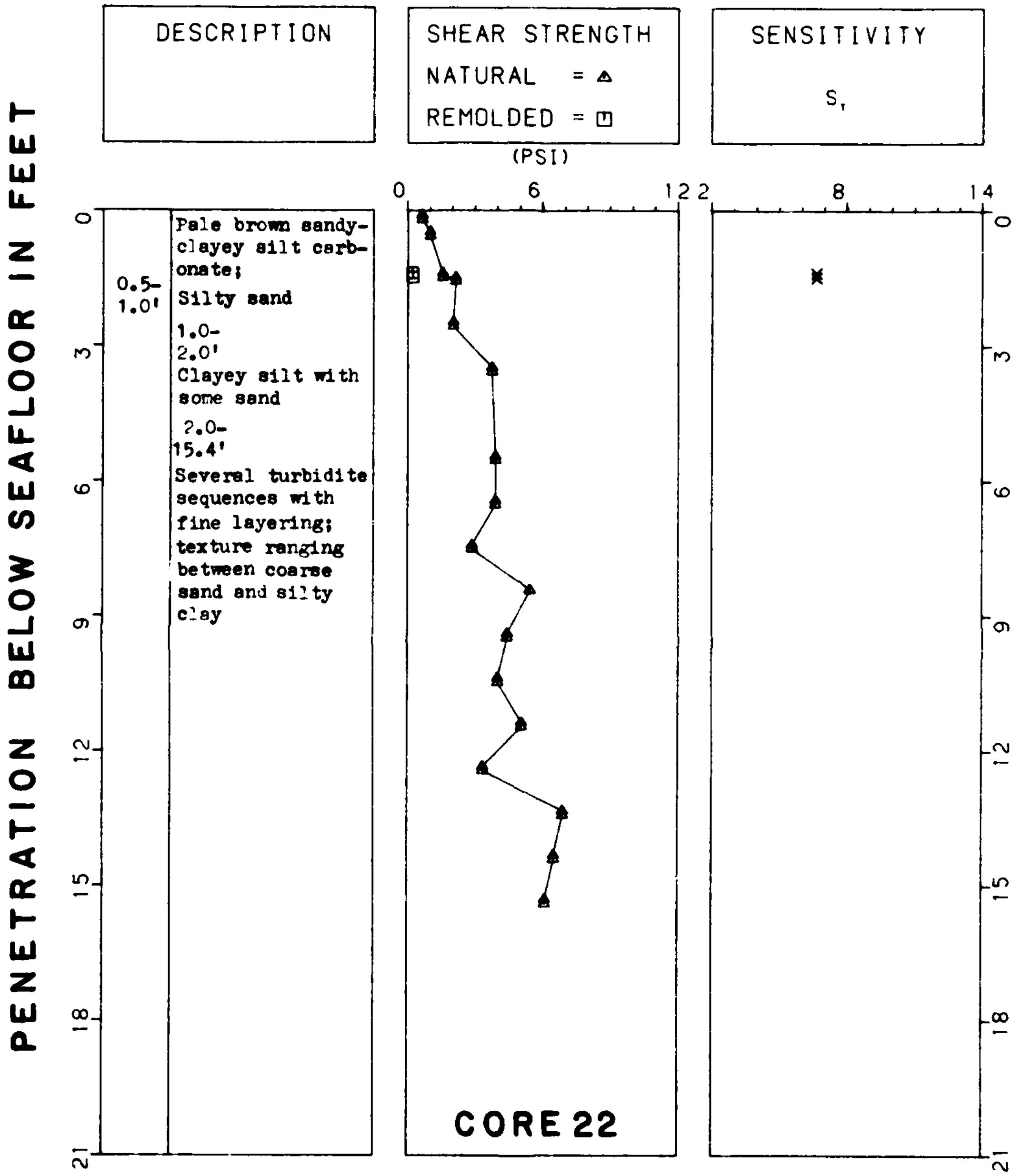
Plot A-6.8.1, continued. Soil properties



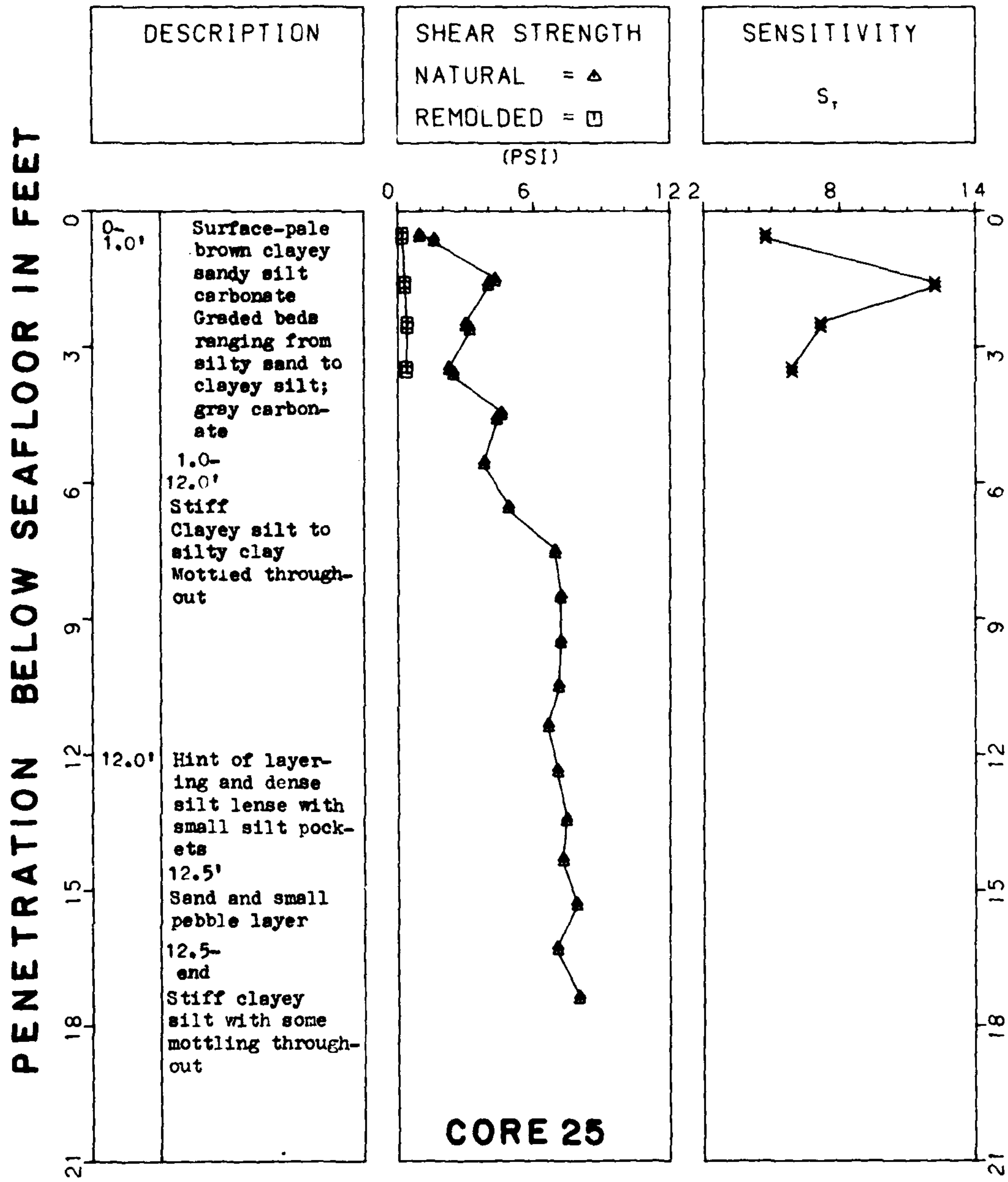
Plot A-6.8.2. Strength measurements.



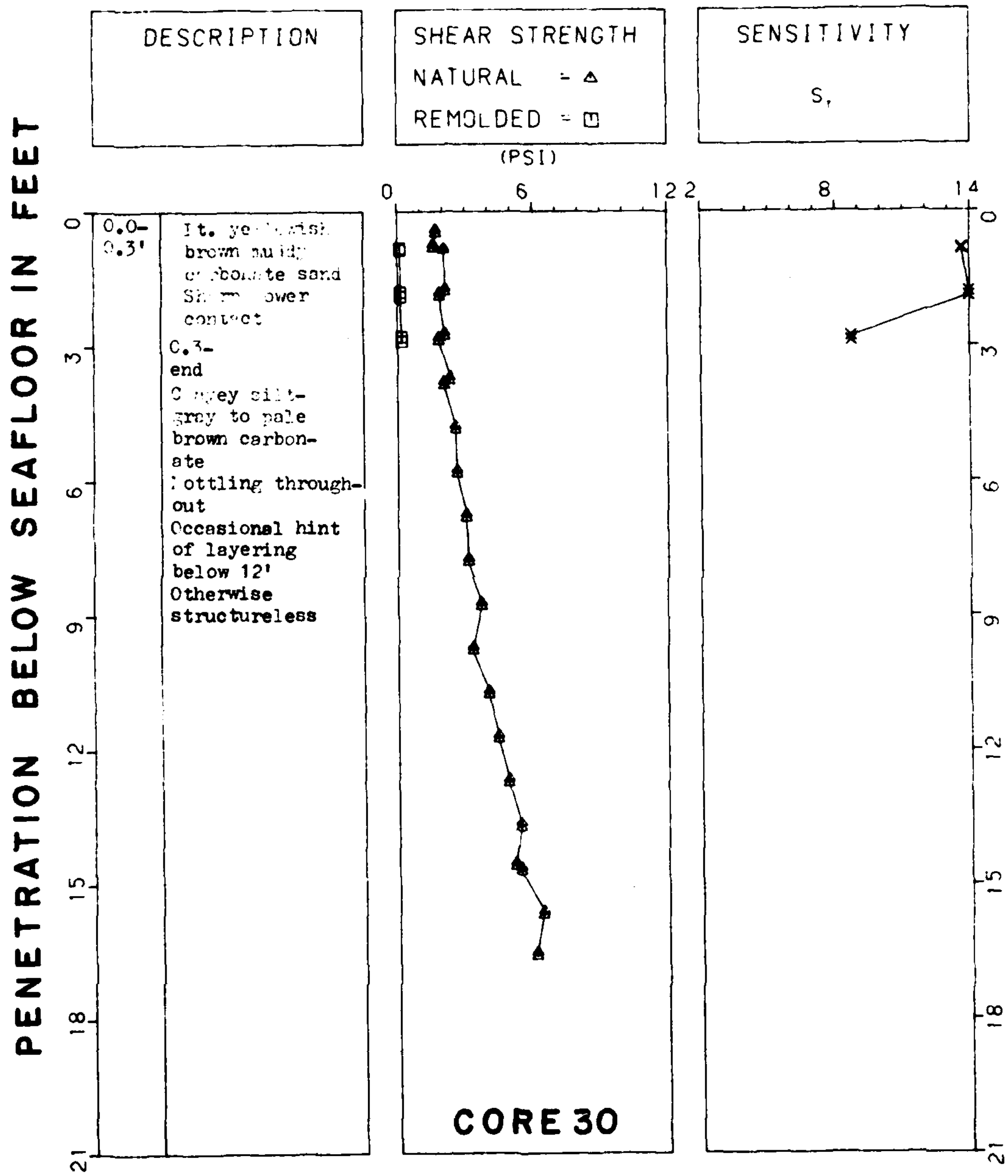
Plot A-6.8.2, continued. Strength measurements.



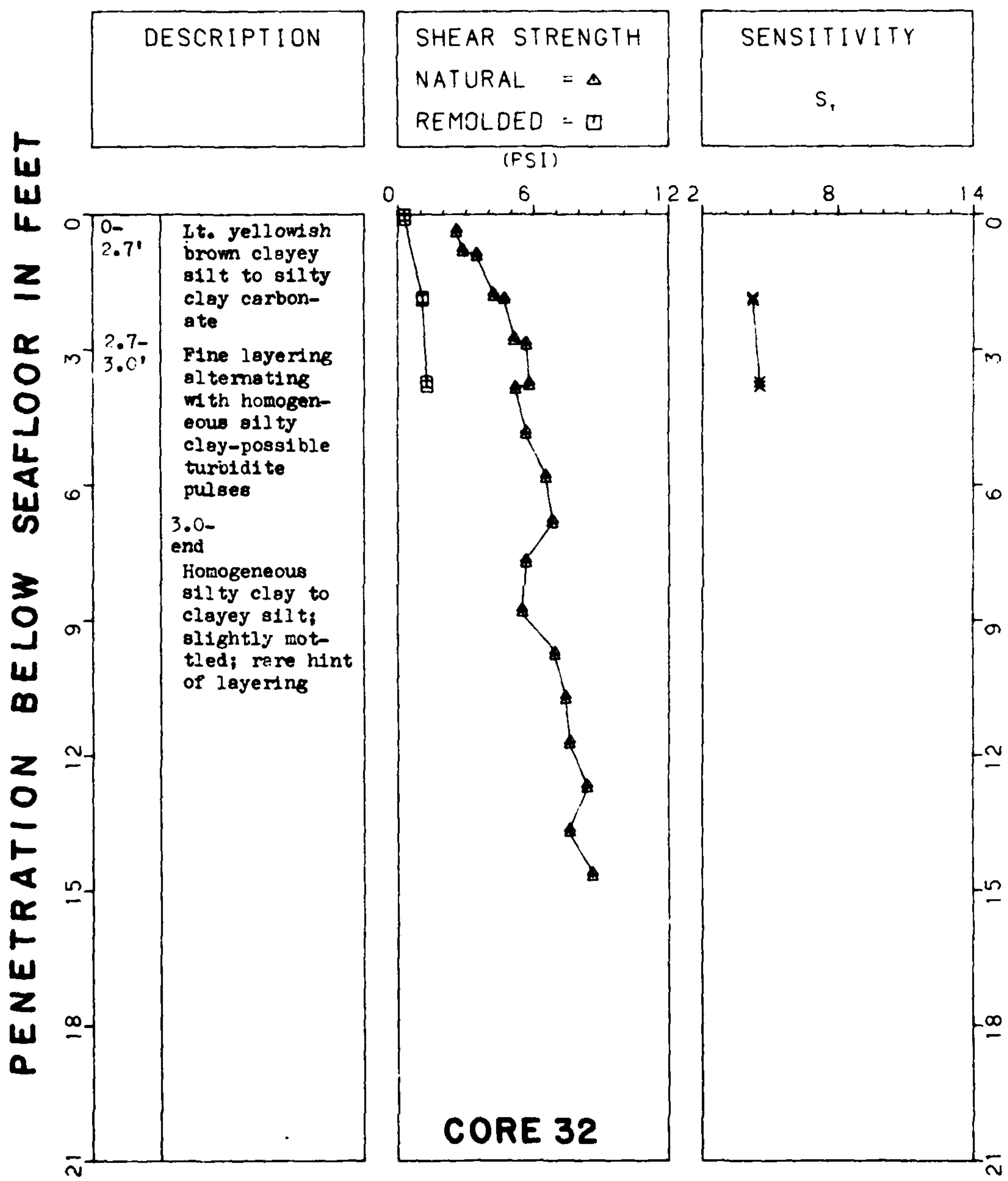
Plot A-6.8.2, continued. Strength measurements.



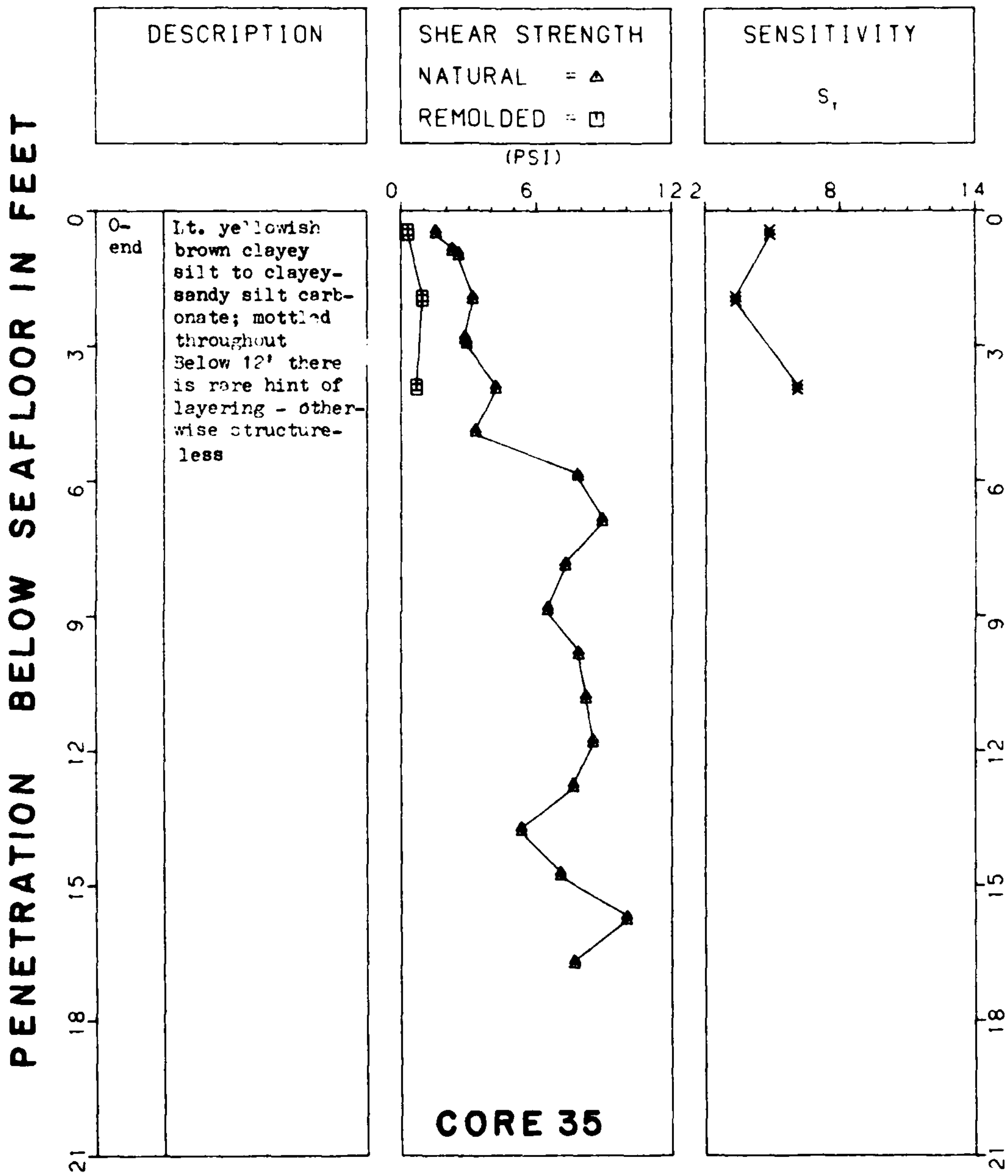
Plot A-6.8.2, continued. Strength measurements.



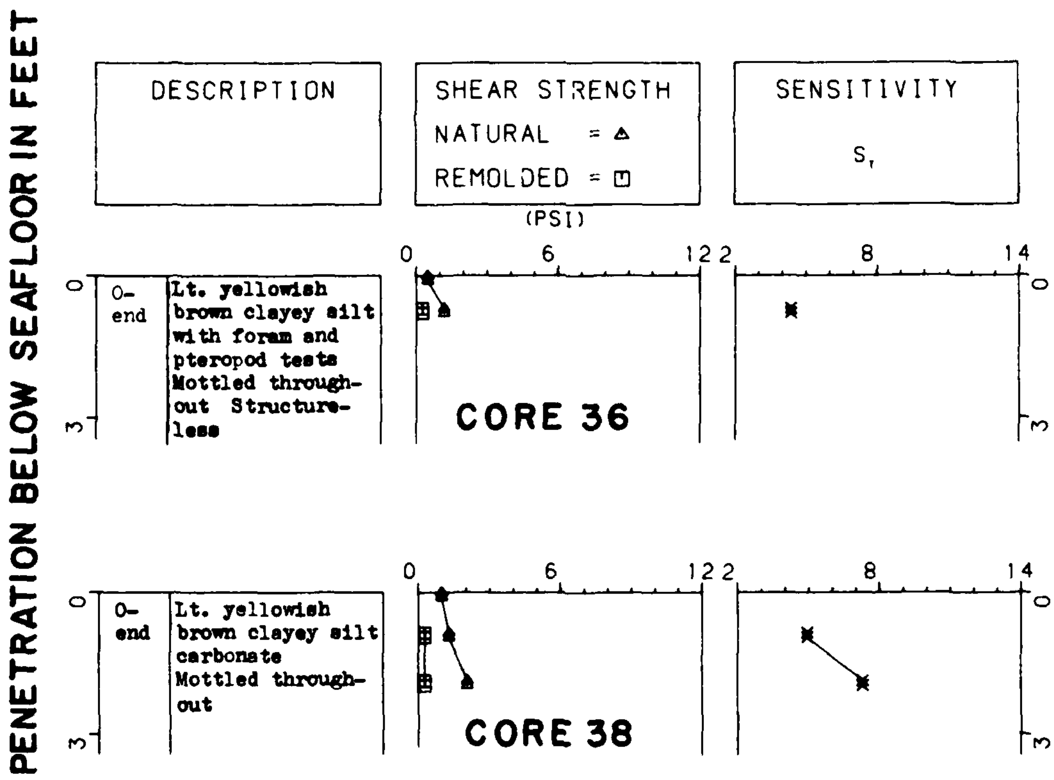
Plot A-6.8.2, continued. Strength measurements.



Plot A-6.8.2, continued. Strength measurements.



Plot A-6.8.2, continued. Strength measurements.



PART 4

ENGINEERING SIGNIFICANCE

W.J. Burton

PART 4.

ENGINEERING SIGNIFICANCE

The purpose of this part of the report is to place in perspective the data gathered from the north margin of St. Croix and the VIT, particularly with respect to the installation of underwater structures and equipment in the area investigated. As previously indicated Parts 2 and 3) the area has wide variations in seafloor topography and sediment geotechnical properties. Accordingly, situations requiring the installation of structures and equipment whose placement, orientation and settlements are to fall within narrow limits, will necessitate further examination of the sea floor and sediment properties at the specific locales of interest.

This part of the report relates the current findings to the siting and placement of hardware on or beneath the sea floor. Some typical applications are:

- Installing of structures to support hydrophones for an underwater tracking range;
- Anchoring mooring lines from floating platforms or submerged bodies;
- Siting and constructing off-shore towers;
- Selecting routes for underwater cables and determining the best methods for their burial/protection anchoring;
- Placing and securing pipelines on or beneath the sea floor; etc.

For purposes of presentation, the geological and geophysical characteristics and the geotechnical properties of the bottom will be discussed separately, although their effects are interrelated as far as foundation engineering for the sea floor is concerned.

4.1 Geological and Geophysical Considerations

The major geological and geophysical aspects of interest center around the slopes, sediment thicknesses, bottom terrain, and the ongoing seafloor processes.

4.1.1 Slopes, Sediment, Terrain

As indicated (Part 2), the overall island slope is steep and local gradients vary considerably. Moreover, the slope is covered with a veneer of unconsolidated sediments, appreciable amounts of coarse debris, and (less frequently) large massive blocks of material. Beneath the layer of unconsolidated sediment, a hard, calcareous material, occurs in some places. Occasionally sediment-barren outcrops of rock or clay form cliff-like escarpments. This combination of circumstances creates potentially unstable situations, heightened by the fact that the area undergoes some level of frequent seismic activity, which could trigger mud slides or shifting of boulders.

Chern and Tudor [4.1] have defined a slope as potentially unsafe if it exceeds 4° in an area that is not in a delta or seismic zone (where even gentler slopes are unstable). Herrmann [4.2], in specifying guidelines for design of small (maximum dimension less than 15 feet), non-strategic structures, restricted the applications of the procedures to sea floors with slopes of less than 10°. Based on these considerations, it is readily apparent that hardware placed on the north slope of St. Croix will require that special attention be given to its location and to the design of its foundation and anchoring system. Otherwise, there is potential risk of the item sliding downslope. A similar risk is not expected for hardware placed on the basin floor where gradients are only a few degrees.

Sediments in the basin, like those on the slope, exhibit high variability in texture and are also characterized as calcareous oozes. Lee and Clausner [4.3] state that calcareous oozes are very susceptible to failure when subjected to repeated loading. The mass physical and mechanical properties (Part 3) reveal that the sediments in the Virgin Island Trough and on the north slope of St. Croix exist in a metastable state and thus are subject to becoming a viscous fluid when disturbed. Such disturbance could result from installation of a structure, seismic activity, or wave-induced bottom instability during storms. As shown in Figure 3.26, the tendency for the material to liquify is most pronounced in the upper meter of the sea floor; however, the data also indicate that the sediments are highly susceptible to being quick throughout the upper 18 ft, (5 1/2 m).

The dynamic behavior of calcareous oozes is not well-understood. Furthermore, there is little practical experience in assessing the performance of structure-sediment interaction involving such oozes [4.4]. The placement of numerous low-capacity anchors or foundations to hold a structure would probably be preferred to relying on a few large-capacity supports, especially since the region is subject to disturbance by seismic activity [4.4, 5].

Texturally, the slope and basin sediments are classified overall as sandy-clay silts. Thus, they are predominantly cohesive, fine-gained carbonate sediments. Because of this, the liquid limits and plasticity indices (Figs. 3.26, 27) can be considered representative of the materials. Accordingly, one would not expect radical changes in the properties of the sediment as might occur if large amounts of intravoid water were introduced into sediment interstices by grains (carbonate shells) crushing because of applied load. (From a practical standpoint, these considerations are probably only of academic interest in view of the high liquidity indices of the material [Fig. 3.26].)

4.1.2 Processes

The investigation of the north St. Croix Margin revealed evidence of material being transported downslope to the basin by a variety of processes. Moreover, there are indications that the downslope movement of materials may have created gullies that scar the face of the slope and thus contribute to the local morphology. The presence of cracks in the surficial slope sediments reveal failure and incipient slumping. There is also evidence of active bioturbation that results in the reworking of the surficial sediments, keeping them in an unconsolidated state with high liquidity indices. All of these factors must be considered in designing and installing underwater structures and equipment for use in the area. In addition, the steepness of the slopes will contribute to the generation of stresses in the sediment as it is loaded by the structure. This can only aggravate the potential for failure of the sediment around foundations and anchors.

With respect to the so-called Salt River, it is important to point out that this is really an embayment and not a river in the true sense. There is no source for the "river" and, therefore, it is at best an intermittent stream. During periods of high rainfall, significant drainage does occur at the Salt River embayment and this flow transports debris down the slope.

Measurements of currents were not conducted during the investigations covered in this report. The presence of currents will induce hydrodynamic drag forces on underwater structures and also give rise to scouring action of the sea floor around the base of the structure. Some data from the literature are available that may be germane to specific areas of the region investigated. Shepard and Dill [4.6] report measurements of currents 10 ft (3 m) above the bottom at three locations along each of the axes of the Christiansted and Salt River Canyons in water less than 650 ft (200 m) deep. The measurements were made over a five-day period in June 1976. Maximum current velocities were downcanyon and amounted to approximately 0.95 and 0.6 fps for the Salt River and the Christiansted Canyons, respectively.

Another investigation reported by Underwood [4.7] which involved a limited series of current measurements off the eastern end of Vieques, showed current velocities to be approximately 2.2 fps near the bottom. This site is well outside the geographic area of this report, but may be relevant from the standpoint of a comprehensive investigation involving the region encompassing and including the VIT. From this latter point of view, some other sources of information that may be of interest are found elsewhere [4.6, 9].

In cases where an engineer must work without the benefit of data on currents, Herrmann and Valent [4.9] give some general guidelines for estimating the magnitude of the currents. They recommend that at water depths between 30 and 400 feet and at deeper locations near bay entrances, narrow passages, etc., a maximum water current velocity of 5.1 fps may be assumed. In deep water locations, other than the above, a velocity of 2.3 fps may be assumed. They also show a plot of threshold water velocity versus grain diameter for general use in predicting incipient scouring of sediments in deep water.

To minimize the effects of scour, the footings for structures should have as low a profile as possible. Because there is evidence of bioturbation, the undermining of a structure by benthic fauna can be minimized by using a mechanical barrier on the bottom edge of the footing [4.9]. This barrier takes the form of a skirt or key that penetrates the sediment to a depth of 6 inches. The key will also restrict lateral movement of the structure. The extremely low level of organic carbon (0.5%) indicates that the bottom materials are inorganic and therefore are not subject to weakening by the presence and action of organic components.

4.2 Geotechnical

The gathering and analyses of the sediment samples (Fig. 3.1) were limited by time and funding considerations. In view of this, the decision was made to concentrate on portions of the slope and basin that lie generally north from the Salt River area. Geographically, this region is the most attractive setting for placement of structures and underwater equipment that require interconnection of activities in the deepest part of the basin with, say, monitoring and support equipment situated on the St. Croix Island.

The selection of parameters and the approach taken to analyzing and presenting the geotechnical data have been guided by the recommendations of the Naval Civil Engineering Laboratory [4-3].

4.2.1 Mass Physical and Mechanical Properties

The mass physical and mechanical properties (wet unit weight, undrained shearing strength, void ratio, etc.) have been used to establish the variability of the bottom sediments, their loading characteristics, and other engineering properties. The geotechnical properties of the sediments consistently show wide variations in magnitude with depth as demonstrated by the values of wet unit weight and undrained shear strength (Figs. 3.19, 20), In presenting the data, envelopes have been constructed on the plots of the parameters to indicate conservative values when applying the parameters to design engineering. For example, in using the wet unit weight to calculate the effective overburden pressure on an anchor embedded in the sea floor, one would use the values from the left envelope in Figure 3.19 to estimate a conservative value of the holding strength of the anchor.

The measurements of geotechnical parameters in the cores extend to a depth of about 18 ft in the sediment and may not be adequate for some applications. Lee and Clausner [4.3] state that for embedment anchors, the strength of the sediment should be known to a subbottom depth of approximately 30 to 50 ft. In situations pertaining to surface-bearing foundations, they also state that the strength of the soil should be known to a depth of 1.5-2 times the width of the footing. On the island slope these guidelines are probably not applicable because of the thin sediment cover. With respect to the basin floor, the application of these guidelines for strength-depth determination will have to be applied with caution. Because the sediments have sensitivity values in the "sensitive" and "extra-sensitive" range (Fig. 3.22), the sea floor is weak especially after undergoing disturbance. Thus, from the standpoint of load bearing capability of the sediment, the design of foundation and mooring-and-anchoring systems will require special considerations.

Lee and Clausner [4.3] note that disturbance of cohesive sediments almost always lowers their in situ strengths by about a factor of three or more. The high sediment sensitivities obtained in this investigation support their observation. As a result, large factors of safety must be used in selecting sediment bearing capacities on which to base designs of footings for structures.

In applications requiring deflection sensitive, downward-bearing foundations for which settlements must be predicted, the data are inadequate. Such predictions require knowledge of certain consolidation parameters, namely: C_c; the compression index; C_v, the coefficient of consolidation; and C_s, the recompression swell index. These parameters were not determined because of funding and time constraints. As previously noted, the behavior of calcareous oozes is not well understood, and because of the paucity of the experience involving the interaction of structures and calcareous oozes, the prediction of such settlements may not be possible at present.

4.2.2 Index Properties

The determinations of the Atterberg Limits (Liquid Limit, Plastic Limit, and Plasticity Index) reveal the bottom sediments to be of low plasticity and to behave as inorganic silts of medium compressibility (Fig. 3.27). This finding supports the evidence of very low organic carbon (0.5%) in the bottom materials. In addition, since the calcium carbonate is already broken down into very fine particles and thus free of intraparticle water, the porosities and void ratios as measured are considered reliable. Likewise, the liquid limits for the materials are not subject to being increased because of water being released from internal voids in fossil components of the sediments when such components are crushed under loading.

The susceptibility to strength loss is also reflected in the plot of liquidity index versus depth (Fig. 3.26). As mentioned earlier, the values of liquidity index are greater than unity for most measurements indicating that any disturbance of the sediment results in a significant loss of strength. Therefore, the bottom might be unsuitable for the placement of structures. Details of soil plasticity and other Atterberg limits are found in Appendix A-6.7.4.

4.3 Obstructions

A comprehensive determination of potential obstructions to future engineering activities in the St. Croix area was not part of this investigation. During the data collecting period, however, no stationary floating objects existed in the surface waters of the survey area except for an acoustic instrument buoy that is maintained by Tracor Marine. Some effort was made during a previous study [4.10] to estimate ship traffic in the area.

Because the data collection involved dredging the bottom, contact was made with the Long Lines Division of the American Telephone and Telegraph Company (AT&T). It was confirmed that no working communication cables existed on the north slope of St. Croix and, therefore, imposed no restrictions on the dredging operations. A furnished map shows that the nearest cables (emanating from St. Thomas) pass St. Croix about 7-9 miles east of the island and 11-13 miles west of the island. It is not known, however, whether or not old, out-of-use cables (or pipelines) exist on the north slope or in the trough. In discussions with AT&T, Tracor Marine, and tracking range personnel, there was no knowledge of any obsolete cables leading to the island.

The presence of plant and animal life, particularly near shore, that might influence biological fouling and attack of structures and underwater equipments and, in turn, induce corrosion, were also not assessed other than in a cursory manner. The shallow water areas have some grass growing in them, but it did not appear to be in great abundance. Neither was there evidence of large amounts of grass having settled out down the island slope [4.11]. The potential for large amounts of plant growth or coral becoming attached to a cable and, in turn, cause damage to the cable because of hydrodynamic forces interacting with the cable/plant-growth system, is not believed to be of major significance. However, such possibilities need to be more thoroughly evaluated before a definitive position can be taken.

References for Part 4

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PART 5

CONCLUSIONS AND RECOMMENDATIONS

PART 5. CONCLUSIONS AND RECOMMENDATIONS

The following paragraphs summarize the conclusions reached in the course of this investigation and list recommendations arising therein.

5.1 Conclusions

The significant findings resulting from this investigation are listed below.

a) The submarine slope off the north side of St. Croix is comparable in steepness with most of the steepest fault scarps of the sea floor. Its overall average gradient ranges between 18-23°, but local slopes vary between 5-43°. In general, the steeper gradients occur on the upper slope area off Salt River.

b) Submarine canyons cut the slope off Christiansted Harbor and Salt River, respectively, and are the principal topographic features of the slope. Both canyons terminate at midslope and only the larger canyon (Christiansted) is a major conduit for transporting erosional debris.

c) The lower slope off Christiansted Canyon is dissected by a system of gullies which transport erosional debris from the canyon mouth to the basin floor. Major gullying is not associated with Salt River Canyon.

d) The floor of the VIT is relatively a smooth, gently sloping (1-2°) turbidite plain with a sediment thickness of at least 1.5 sec (1500 m) and a regional gradient to the west and south. Most of the sediment filling the VIT is probably derived from the Virgin Islands Shelf to the north.

e) The basin floor is interrupted at 17°54'N, 64°48'W by a prominent topographic "high," which acts as a barrier to the westward transport of sediment. As a result, the sea floor is 300 m higher on the east side of the "high" than on the west.

f) A major slump and or tectonic uplift has altered the configuration of the VIT such that the floor of the trough is markedly narrower at its eastern end (east of the topographic "high").

g) Sediment thickness on the north slope of St. Croix is not seismically resolvable. Coring attempts indicate that the sediments may, in fact, only measure a meter, or so, in thickness. In some areas, a thin, hard crust exists a few centimeters beneath the sediment surface.

h) Visual observations show that the north slope of St. Croix is sediment covered and that rock outcrops are generally infrequent (at least in the areas of observations). This conclusion is also supported by dredging attempts.

i) Pelagic deposition, downslope creep, slumping, and turbidity currents are all active mechanisms that transport sediment to the basin floor. Despite the steepness of the slope, slumping does not appear to be a major mechanism on the north slope of St. Croix perhaps because of the thin sediment cover.

j) Sediments within the study area can be classified as calcareous oozes composed primarily of biogenic debris. The texture of the sediments is highly variable but generally falls within the sandy-clay silt range. In general, sand and gravel form a significant portion of the slope sediments except off Christiansted Canyon. Large, massive blocks of coral and rock debris are widely dispersed on the slope.

k) With few exceptions, average water contents range between 55-65%. Some of the highest values and greatest ranges were associated with sediments taken from the topographic "high" in the VIT.

l) Wet unit weight displayed significant variability due to localized differences in grain size and degree of consolidation.

m) Shear strength measurements varied widely, with strength and variability increasing significantly with depth below the sea floor. The presence of sensitive and extrasensitive sediments and the high liquidity indices (>1.0) indicate potentially unstable seafloor deposits. This instability was also supported by the visual observation of cracks in the slope sediments.

n) The high carbonate content of the sediments, differing depositional environments (shelf, slope, trough), and bioturbation contribute to the observed high variability in the geotechnical properties, sediment types, and textures.

o) Steep gradient, sediment instability, and seismic risk combine to make the north slope of St. Croix a potentially hazardous environment for engineering applications. In contrast, the floor of the VIT is a more stable environment because of much lower gradients.

p) Given the calcareous nature of the sediments and considerable variability of the geotechnical parameters, large factors of safety are advisable when choosing bearing capacities for the design of structural footings.

q) Atterberg Limits reveal that the sediments are inorganic silts of low plasticity and medium compressibility. As such, it is not anticipated that they will undergo radical changes in their properties because of applied load.

r) Evidence of significant bottom current action was not observed on the north slope of St. Croix or in the basin.

s) Obstructions (ships, buoys, cables, etc.) are not expected to be a major consideration to future engineering activities.

5.2 Recommendations

It is felt that the information and interpretations presented in this report add significantly to existing knowledge of the VIT and, particularly, of the north slope of St. Croix. Nevertheless, the environmental scenerio remains incomplete. The following recommendations address this deficiency.

a) Further resolution of fine-scale morphologic features (gullies, terraces, etc.) cannot be accomplished by conventional bathymetric surveys. To significantly improve resolution, it will be necessary to employ side-scan sonar imagery.

b) Current measurements (at any level in the water column) are nonexistent for the most of the VIT. Such measurements will be necessary to assess current/sediment dynamics in the trough axis and on the escarpments.

c) The demonstrated variability of the sediment geotechnical parameters points to the need for further investigation of these parameters to develop a definitive understanding of the sediments.

d) Additional bottom photographic information should be collected. Underwater photography provides the only means of obtaining direct information concerning the seafloor. Ideally, the photographic coverage should be coordinated with a side-scan survey to provide "ground truth" verification of features resolved by the survey.

e) This investigation did not attempt an exhaustive assessment of engineering obstacles (ships, buoys, cables, etc.). It is suggested that such an assessment be performed prior to any engineering activities.

f) Site specific surveys should be conducted at identified areas of engineering importance. These surveys should incorporate all investigative elements (bathymetry, seismic reflection, side-scan, sediment cores and analyses, photographs, dredges, current meters, etc.) necessary to completely determine the bottom morphology, sediment character, and sediment dynamics at the site.

g) As in the case of the side-scan sonar imagery, the use of a submersible is highly recommended for future study of the slope off St. Croix. This is especially true for site specific survey areas where "ground truth" verification is especially critical. The submersible should be instrumented for in situ measurement of geotechnical parameters.

PART 6.
GLOSSARY

AOML - Atlantic Oceanographic and Meteorological Laboratories

ASTM - American Society for Testing Materials

CHESNAVFACENGCOM - Chesapeake Division, Naval Facilities Engineering Command

DSRV - Deep Sea Resarch Vessel

NOAA - National Oceanic and Atmospheric Administration

NORDA - Naval Ocean Research and Development Activity

NSTL - National Space Technology Laboratories

OTEC - Ocean Thermal Energy Conversion

VIT - Virgin Islands Trough

Abyssal Plain - see Turbidite Plain

Acoustic basement - the deepest, continuous observable reflecting horizon in a seismic reflection profile. It may or may not be "true" basement (see basement).

Acoustically laminated - layering observed in seismic reflection profiles and produced by acoustic impedance differences in the sediment column.

Basement - the primary crustal material of the earth between the sedimentary deposits.

Bight - prominent bend or curve.

Escarpment - a long, more or less continuous cliff or relatively steep slope facing in one general direction.

Fan - a gently sloping, fan-shaped body of detritus normally forming at the termination of a canyon (or similar feature) or at a place where there is a notable decrease in gradient, i.e. base of a steep slope.

Graben - an elongate crustal unit or block that has been lowered by faulting relative to the blocks on either side.

Hummocky - uneven, irregular.

Hyperbolae (hyperbolated) - downward arching echo trace produced by a depth recorder and usually caused by some type of "sharp" projection on the sea floor (e.g. outcropping rock ledge on a slope).

Outcrop - exposure of rock.

Pelagic deposition - slow, continuous deposition of fine-grained terrigenous minerals and skeletal remains of organisms that live in the surface waters of the ocean.

Slumping - the sliding downslope of a mass of unconsolidated sediment.

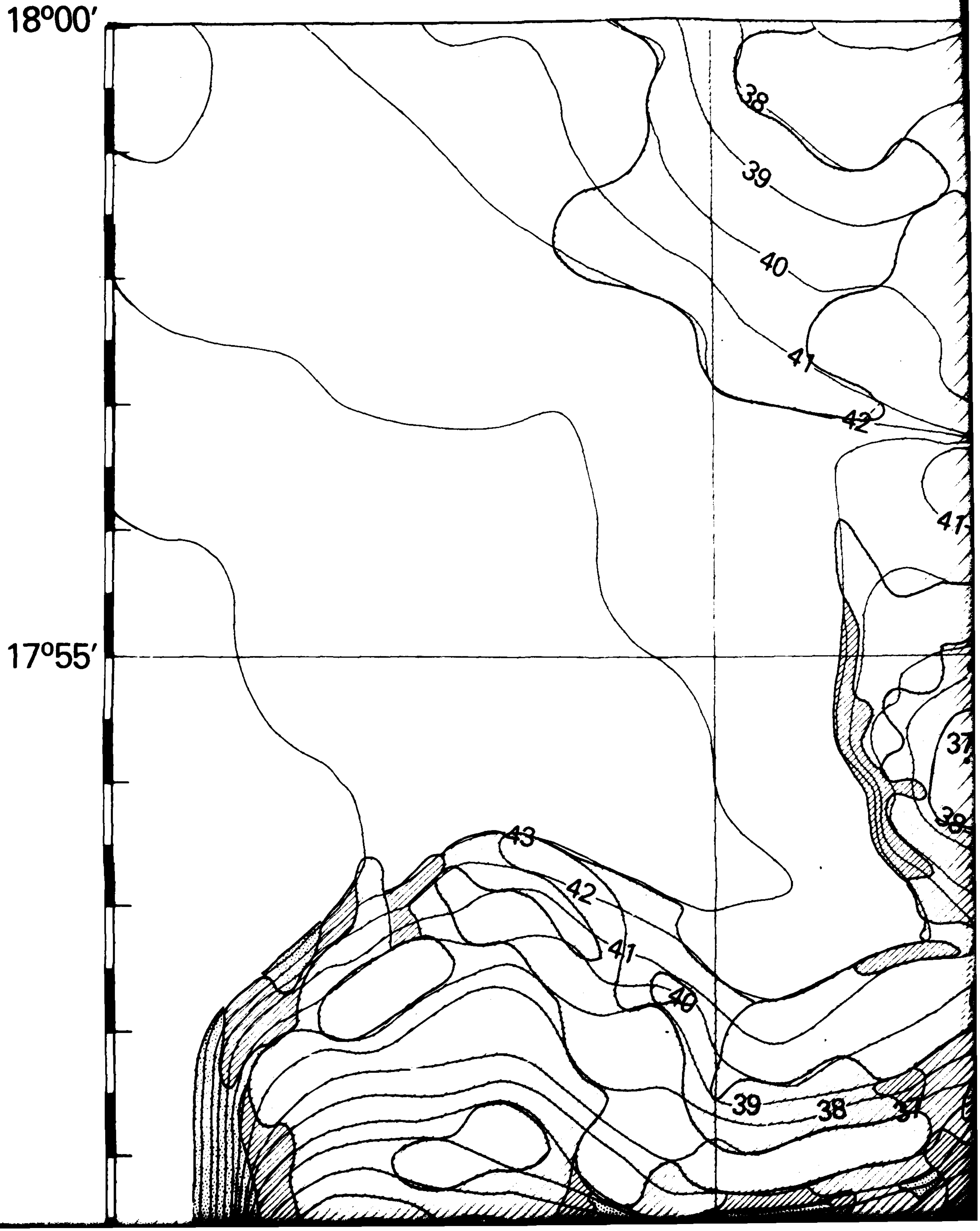
Swale - low relief ridge/valley topography; undulating.

Turbidity current - Bottom-flowing, short-lived, powerful, gravity-driven current laden with suspended sediment which moves swiftly down a submarine slope and spreads horizontally across the basin floor.

Turbidite - The sediment layer, usually consisting of sand and silt, which is deposited by a turbidity current.

Turbidite plain - A flat, very gently sloping region of the sea floor, usually at the base of a slope, that has derived most of its sediment from turbidity currents. Abyssal plains, which are formed in this way have slopes less than 1:1000 and occur at the base of continental rises.

Slope Map of Por



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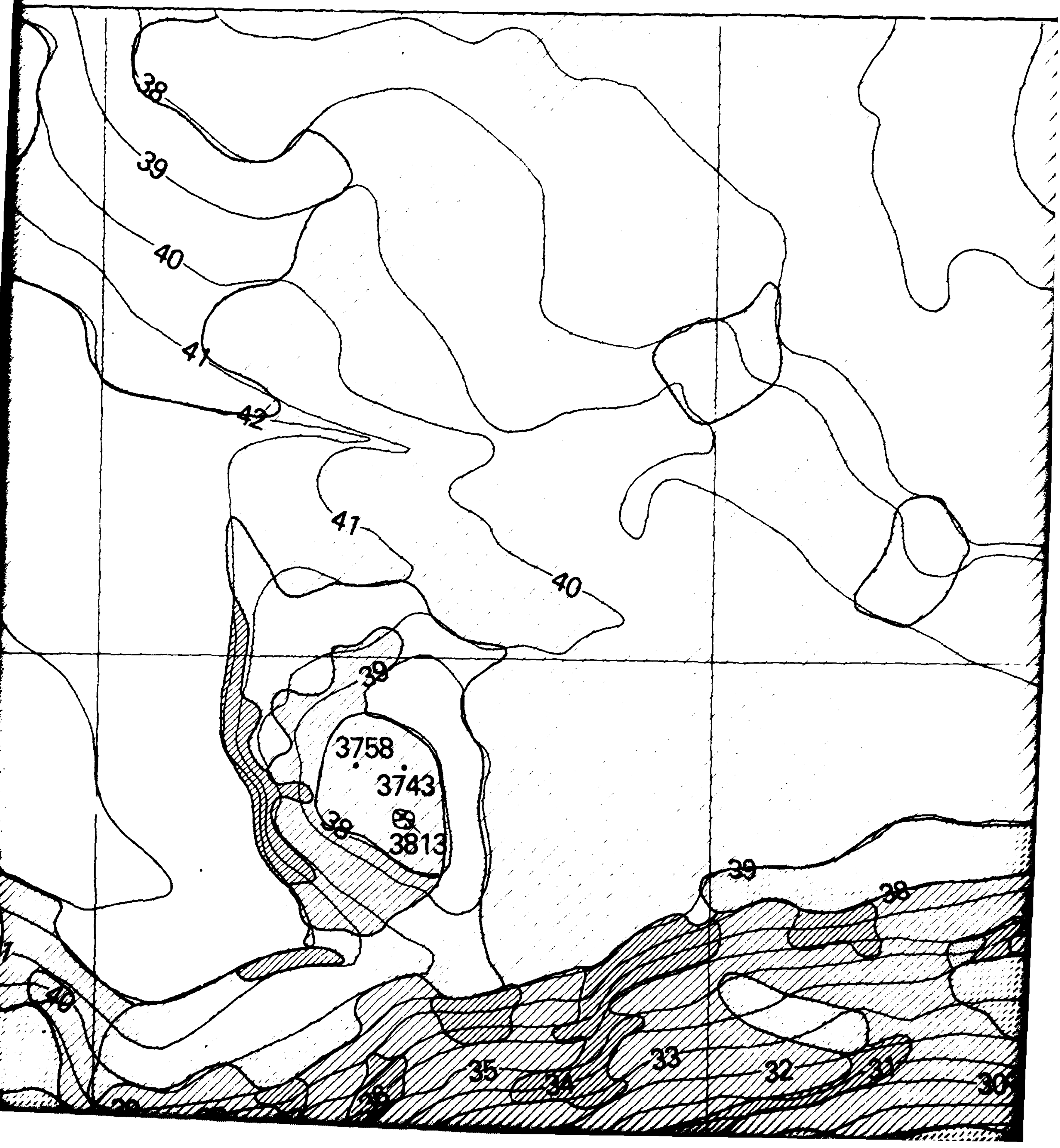
Slope Map of Portion of St. Croix Margin



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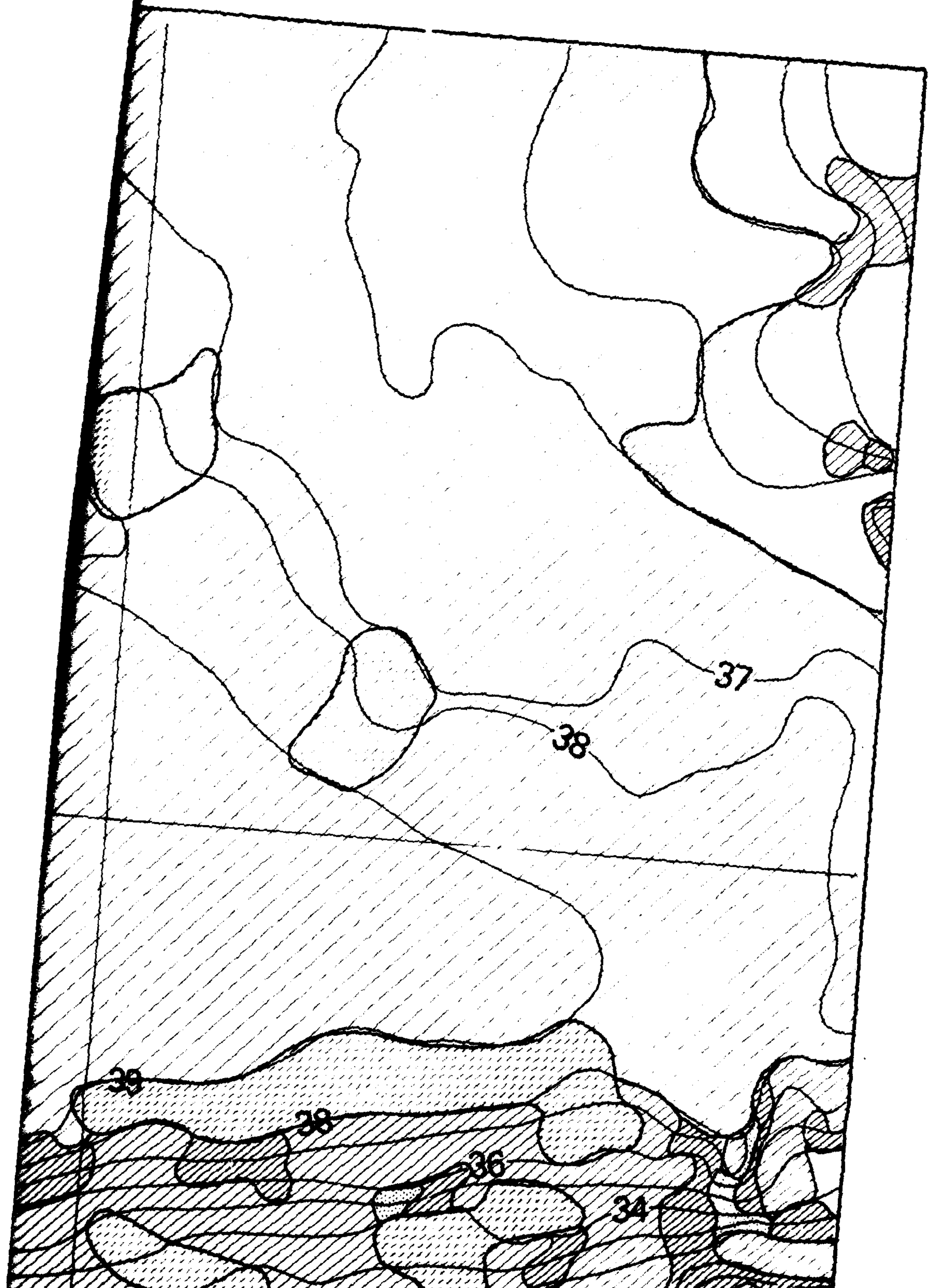

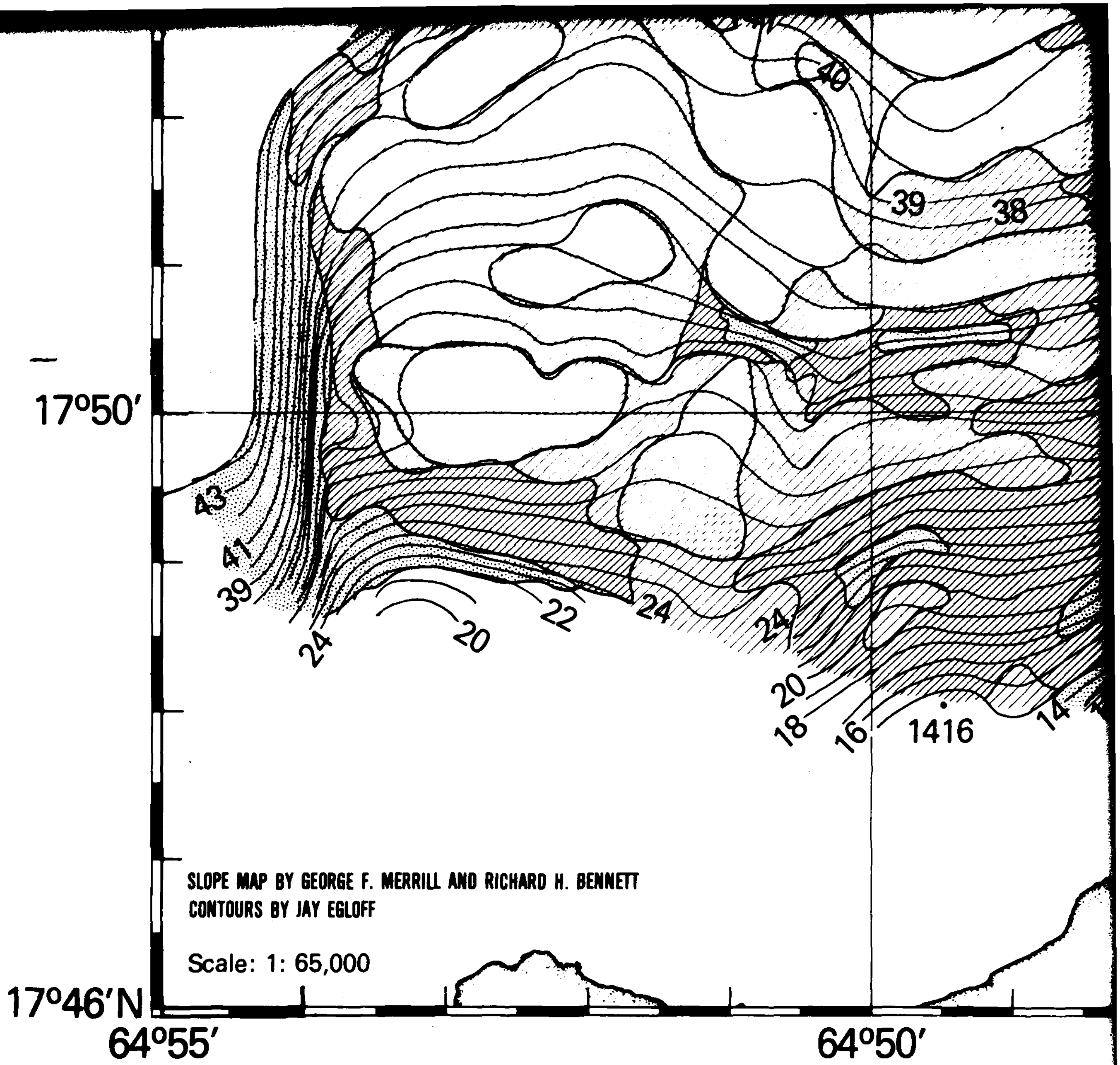

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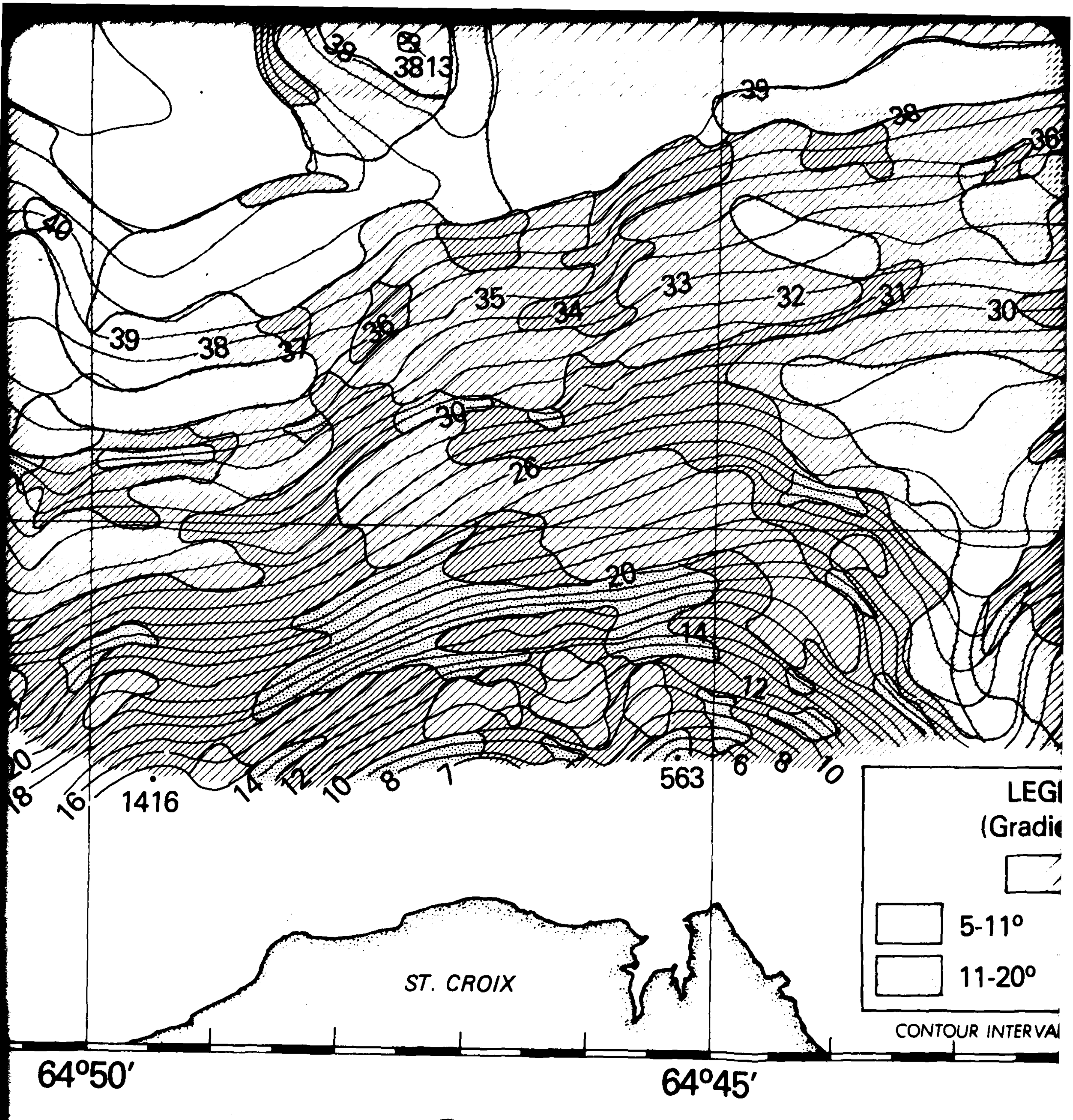
SLOPE MAP BY GEORGE F. MERRILL AND RICHARD H. BENNETT
CONTOURS BY JAY EGLOFF
Scale: 1: 65,000
17°50′
17°46′N
64°55′
64°50′

(4)



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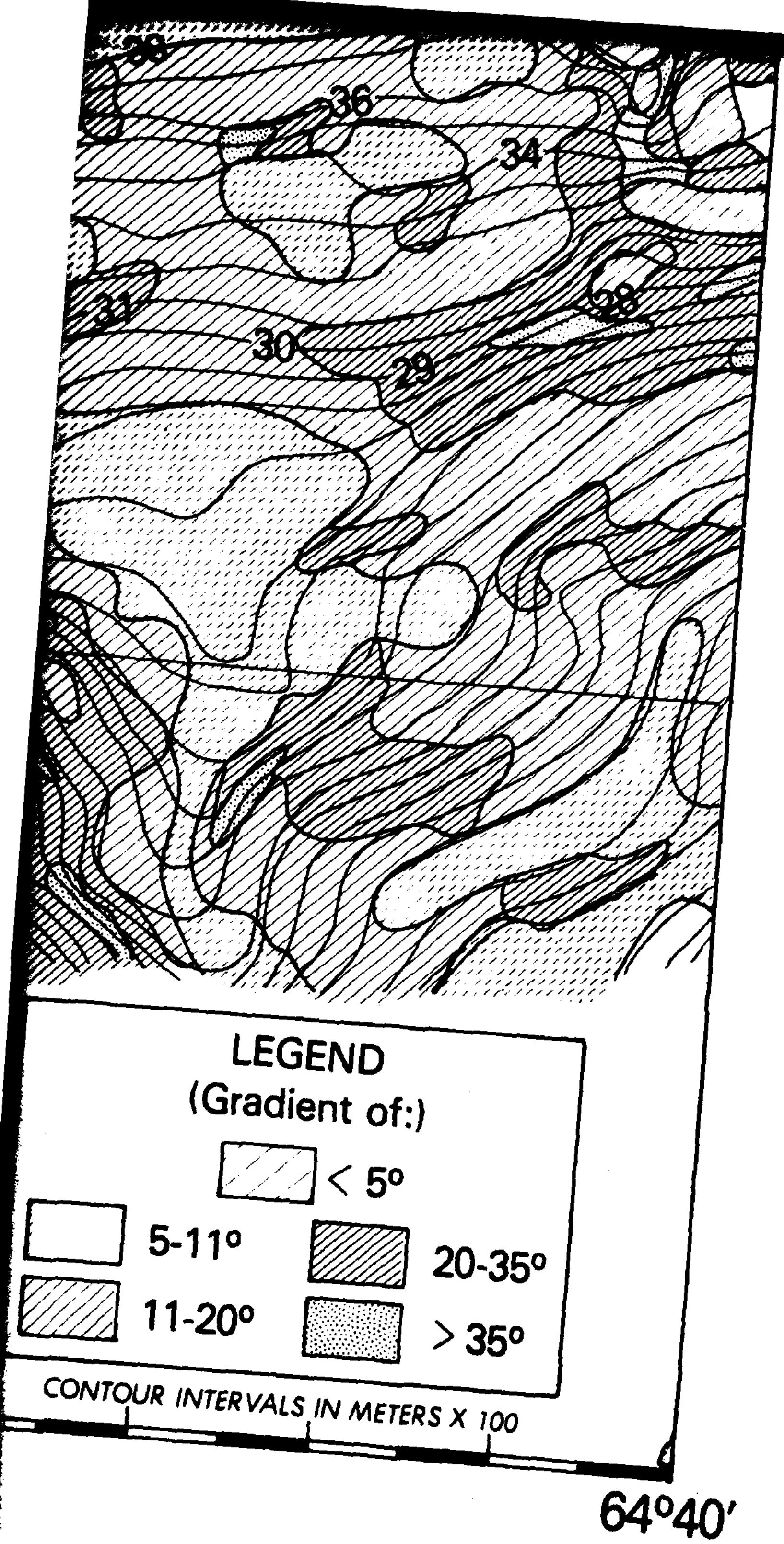
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(Gradient of:)
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5-11°
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11-20°
> 35°
CONTOUR INTERVALS IN METERS X 100
64°40′

DATE

ILME