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AND

GEOLOGICAL SURVEY

POTENTIAL GEOLOGIC HAZARDS AND CONSTRAINTS FOR BLOCKS IN PROPOSED NORTH ATLANTIC OCS OIL AND GAS LEASE SALE 52

BY

George B. Carpenter, Alex P. Cardinell, Darryl K. Francois, L. Keith Good
Robert L. Lewis, and Newell T. Stiles

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Metric equivalents

1 meter = 3.2808 feet

1 kilometer = 0.6214 statute miles

1 nautical mile = 1.1508 statute miles = 1,852 meters

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ABSTRACT

Analysis of high-resolution geophysical data collected over 540 blocks tentatively selected for leasing in proposed OCS Oil and Gas Lease Sale 52 (Georges Bank) revealed a number of potential geologic hazards to oil and gas exploration and development activities: evidence of mass movements and shallow gas deposits on the continental slope. No potential hazards were observed on the continental shelf or rise. Other geology-related problems, termed constraints because they pose a relatively low degree of risk and can be routinely dealt with by the use of existing technology have been observed on the continental shelf. Constraints identified in the proposed sale area are erosion, sand waves, filled channels and deep faults.

Piston cores were collected for geotechnical analysis at selected locations on the continental slope in the proposed lease sale area. The core locations were selected to provide information on slope stability and to establish the general geotechnical properties of the sediments. Preliminary results of a testing program suggest that the surficial sediment cover is stable with respect to mass movement.

INTRODUCTION

This report presents the results of the Minerals Management Service's (formerly the Conservation Division of the U.S. Geological Survey) high-resolution geophysical (HRG) study conducted for the prelease assessment of potential geologic hazards for the 540 blocks in proposed North Atlantic OCS Lease Sale 52 on Georges Bank. The location and geographic setting of proposed Lease Sale 52 is shown in Figure 1. Also included in the report are significant amounts of data from other sources, most notable being the results of the HRG survey conducted in 1976 as part of the geohazards analysis for OCS Lease Sale 42 and a suite of 17 piston cores collected by the USGS, Office of Marine Geology (Woods Hole, MA). The report dealing with Sale 42 (Hall, 1979) showed the Georges Bank area in general and acreage offered for Lease in Sale 42 in particular to be nearly free of serious geology related problems to oil and gas exploratory activities.

Geologic features and conditions having a potential for risk to oil and gas exploration and development can be categorized as either hazards or constraints, depending on their inherent risk (Carpenter and McCarthy, 1980). Obviously, nearly any geologic feature or condition could present some minimal risk to some phase of drilling or production operations, but in the majority of cases the risk is insignificant, requiring no control measures beyond simple awareness of its presence. The geologic hazards and constraints discussed in this report will, in most operational situations, require at least some degree of physical control.

Geologic hazards are judged to have the greatest potential risk because present-day drilling technology cannot routinely eliminate their potential for damage to drilling structures. Slumps, slides, and shallow high-pressure gas deposits (the latter inferred from bright spots on seismic profiles) are examples of geohazards known to occur in the Georges Bank area.

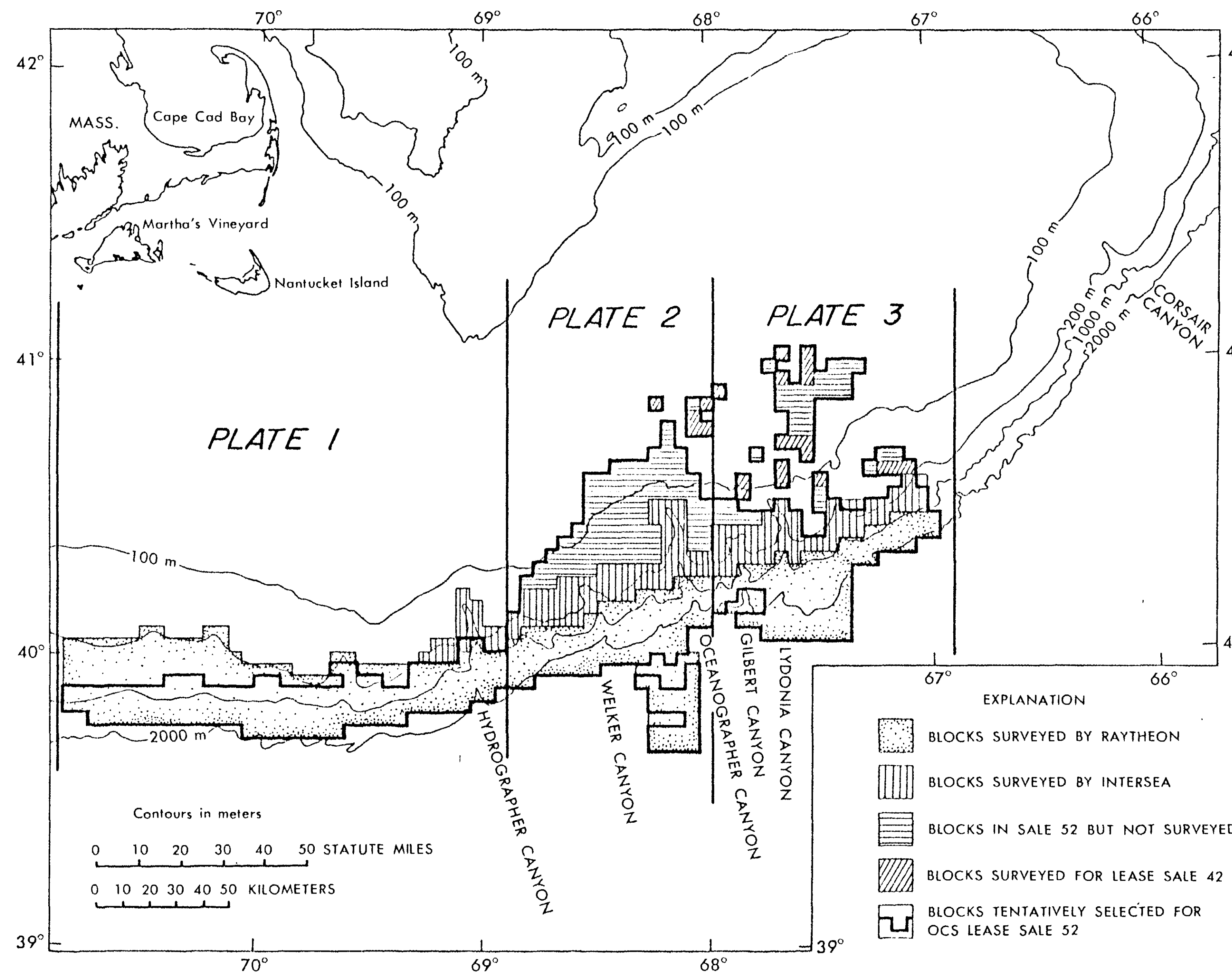


Figure 1.--Map showing the blocks tentatively selected for leasing in proposed OCS Oil and Gas Lease Sale 52. Various factors involved in the survey strategy are indicated on the map.

Geologic constraints have a lower risk potential than geologic hazards because their adverse effects can be routinely reduced or eliminated through conventional oil drilling technology (Carpenter and McCarthy, 1980). Constraints found in the proposed sale area are erosion, sand waves, filled channels, and deep faults. It should be noted that while erosion and sand waves have only been identified as constraints, their level of activity is extremely high on many areas of Georges Bank and may warrant special precautions.

The rationale for the assignment of risk to any given geologic feature or condition is discussed under the individual subject headings. In addition to the previously mentioned exclusive data collected for Sale 42 and proposed Lease Sale 52, data from other sources, a literature search, and contacts with other authorities in the field have been used in this discussion of geologic hazards and constraints.

Natural hazards resulting from weather and ocean dynamics are likely to present a special set of problems to oil and gas development but are beyond the scope of this report. Other hazards, such as those related to seismicity and soil stability, are not directly definable with our HRG data base, but their existence and level of activity can often be inferred by presence of reflector displacement or slump/slide structures which are recorded on HRG data. These results can then be used as the basis for later, problem specific studies.

DATA COLLECTION AND INSTRUMENTATION

The majority of the data involved in this report were acquired by private sector geophysical service companies under exclusive contract to the Minerals Management Service. Data collection during three separate surveys by Offshore Navigation Inc., Intersea Research Corporation, and Raytheon Ocean Systems Co. was monitored by MMS observers throughout the course of the fieldwork. Blocks involved in each phase of the survey have been separately identified and plotted on figure 1.

Twenty-three blocks originally offered for lease in Sale 42 have been renominated for proposed Lease Sale 52. These blocks were surveyed in the summer of 1976 by Offshore Navigation Inc. under contract 14-08-0001-15919. Side-scan sonar, single channel sparker, echo sounder, and 3.5 kHz subbottom profiler data were collected over an 800 x 3200-m grid.

One hundred and twenty-one blocks near the edge of the continental shelf which were tentatively selected for proposed Lease Sale 52 were surveyed by Intersea Research Corporation under contract 14-08-0001-18984. Echo sounder, high frequency analog seismic profiler, and 12 channel, 1/2-ms digital data were collected over a 1600 x 1600-m grid.

The remaining blocks in the proposed sale are largely on the continental slope and rise and were surveyed by the Raytheon Ocean Systems Co. in the summer of 1981 under contract 14-08-0001-19027. Narrow beam echo sounder, and high- and low-frequency analog seismic reflection data were collected over a 1600 x 1600-m grid. Navigation systems for all surveys were grossly similar in that radio-positioning units with satellite navigation backups were used throughout.

A number of additional blocks on the slope, aside from those tentatively selected for the proposed sale, also were surveyed because they are located upslope of sale blocks. These blocks have been included in the survey because a slump or slide occurring upslope of a leased block could presumably sweep large volumes of translated sediments and debris through that block. It is thus prudent to assess the potential for mass movement in all blocks on the slope rather than only those tentatively selected for the proposed lease sale.

Proposed Lease Sale 52 also includes blocks on the continental shelf (exclusive of the 23 blocks renominated from Sale 42) which were not included in the HRG survey. Existing published, unpublished, and in-house data provided a strong indication that the Georges Bank Shelf is relatively free of serious geohazards. Since adequate data exists to characterize the shelf in this area, if not to map it in detail, the acquisition of additional data was judged unnecessary.

Copies of all contracted deliverables have been archived with the National Oceanic and Atmospheric Administration, EDIS/NGSDC, Code D-621, 325 Broadway, Boulder, Colorado, 80303 and are available to interested parties. This data bank includes microfilm copies of geophysical profiles and the complete series of navigation maps submitted by the contractor at a scale of 1:48,000. As previously mentioned, the data set involved in prelease hazards determinations for proposed Lease Sale 52 is divided into three unequal parts. To obtain the data collected for Sale 42 (largely on the continental shelf) refer to data set AT-15919 in correspondence to EDIS/NGSDC. The data set number for data collected near the shelf/slope break is AT-18984 and that for data on the slope and upper rise is AT-19027.

BACKGROUND INFORMATION

Proposed lease Sale 52 includes over three million acres of land on the North Atlantic Outer Continental Shelf off the southern New England Coast. The sale area extends approximately 350 km east-southeast from just south of Cape Cod, Massachusetts and is bounded by latitudes 40°N and 42°N and longitudes 67°W and 72°W. Geological and geophysical information that is most pertinent to proposed Lease Sale 52 is summarized here.

The major physiographic feature in the sale area is Georges Bank, a broad, shallow topographic high that is 150 km wide and 280 km long. It is the most southwesterly of several similar features that exist on the continental shelf south of Nova Scotia and is marked by widespread areas of sand shoals, channels and a flat featureless shelf (Schlee and others, 1979; Wade, 1977). Water depths over Georges Bank range from approximately 5 m near its northern edge to 400 m near the shelf edge. The northern half of Georges Bank is beneath water of approximately 60 m depth (Schlee and others, 1979). In water depths of 60 to 80 m over the northern and eastern sections of the bank, a large group of broad northwest-southeast trending sand ridges exists. The ridges are spaced 2 km to 15 km apart and they are 5 km to 30 km long and 10 m to 35 m high. Superimposed on these ridges are second order sand waves that are 10 m to 20 m high, 100 to 700 m apart, and as much as 10 km long (Twichell, 1981). The second order sand waves can be perpendicular to the shoal axis or parallel the general trend of the large features.

Georges Bank is bounded on the north by the Franklin and Georges Basins and on the northeast by the Northeast Channel, an ocean trough 40 km wide and 230 m deep that extends from the Gulf of Maine across the continental shelf. To the southwest, Georges Bank is bounded by Great South Channel, a deep water passage 35 km wide and 80 m deep (Schlee and others, 1979). The continental slope on the south side of Georges Bank is cut by six major submarine canyons (from east to west: Corsair, Lydonia, Gilbert, Oceanographer, Welker, and Hydrographer) and several unnamed canyons. The slope angle ranges from 5° to 8° (Schlee and others, 1979; Austin and others, 1980).

Seismic profiles across Georges Bank reveal a "mid-bank divide" that separates the eastern and western wedges of Pleistocene sediments. Seismic reflectors within the western wedge appear to represent three sets of truncated foreset beds whose total thickness increases westward to 175 m. The eastern wedge appears to be a massive deltaic sequence that progrades eastward and thickens to 200 m (Poag, 1978). To the south, 102 m of shelly, glauconitic olive gray, silty sand and clay, were cored, and in the north 60 m of gray sand and gravel have been recovered. In the Franklin Basin just north of Georges Bank, 90 m of soft, dark olive-gray, sandy and silty clay with scattered large pebbles compose the Pleistocene section. In this area, Miocene and particularly Eocene lithoclasts and microfossils are abundantly reworked into the inner and middle shelf Pleistocene sediments. South of the Bank on the continental slope, the Pleistocene section is at least 305 m thick and contains dark or olive gray glauconitic, silty sand and silty clay with diatom rich intervals. Most of these sediments originated on the inner and middle shelf (Poag, 1978). The surface of Georges Bank is covered by a thin layer of recent sediment, derived from glacial till, consisting of quartzose sand (medium to coarse grained) with small amounts of gravel. The coarsest sediment is associated with areas between shoals.

Seismic profiles have identified at least five erosional surfaces within the top 100 m of sediment. These well developed unconformities separate discrete depositional sequences that appear to be related to the periodic availability of larger supplies of sediment and to the regressions and transgression of the sea during the Pleistocene. Other profiles indicate that glaciers extended over the northern margin of Georges Bank (Knott and Hoskins, 1968). The Gulf of Maine adjacent to the bank also has been deeply eroded by glacial ice. In addition, disturbed sediments are observed in the northern section of Georges Bank to a depth of 80 m below sea level. Altogether, the evidence indicates that there were four or five periods during Pleistocene time in which glacial material was deposited down-slope and dissected by rain and melt waters during regressions of the sea. These were followed by transgressions in which the sedimentary deposits were smoothed and channels filled by reworking of surficial sediments (Lewis and others, 1980).

Surficial sediments are reworked by storm waves and strong tidal currents. These hydrodynamic processes have produced four types of surface bedforms in the Georges Bank area: large sand waves, small sand waves, megaripples, and featureless sea floor. The sand waves are divided into two groups based on their size and location. Large sand waves have crest heights greater than 4 m and are located near the crest of the Bank in an area covered by northwest trending ridges. Small sand waves have crest heights less than 4 m and are located in patches in the troughs between the ridges and in a discontinuous band seaward of the large sand wave area. Megaripples occur by themselves, but most often are superimposed on the large sand waves. Outside the megarippled area, the sea floor is featureless. These bedforms are distributed according to surface tidal current strength. Large sand waves are found where surface tidal current strength is greater than 70 to 80 cm/s. Small sand waves occur where tidal current strength is 60 to 80 cm/s. The megaripple areas are defined by tidal current strengths of 40 to 70 cm/s and featureless sea floor is present where tidal current strengths do not exceed 40 to 50 cm/s, (Twichell, 1981). At the present time, tidal currents augmented by storm surge are the most active process operating in the Georges Bank area that modify surface sediment deposits (Twichell, 1981).

HAZARDS

Slumps or Slides

As with previous Atlantic OCS sales offering acreage on the continental slope, mass movement of surface sediments is likely to be the single most important geohazard impacting exploration and development activities in proposed Lease Sale 52. A total of eight blocks are directly affected by slumps/slides with a larger number of blocks located downslope of the failures (pl. 1).

Figure 2 is typical of the geophysical evidence for mass movement in the proposed sale area. Approximately 30 m of sediment (as indicated by the height of the escarpment in the center of figure 2) has been detached and moved downslope. Roughly one square mile of surface area has been affected by this particular slump which appears to be typical of others in the proposed sale area. The 1600 x 1600 m data collection grid has, however, undoubtedly missed smaller mass movement features.

The interpretation of mass movements from seismic reflection data on the Georges Bank Continental Slope is complicated by rough, erosional topography related to the many canyon systems in this area. Out-of-plane reflections (side echoes) can be superimposed on the normal incidence data and may give the appearance of being structures, when in fact they are merely the partial record of adjacent topography. This effect is absent in topographically smooth areas, but intercanyon areas unaffected by erosional processes (i.e., original morphology and gradient of the ancestral slope) are probably not present on the Georges Bank continental slope. The transitions between adjacent canyon systems appear abrupt; one system immediately grading into the next with no intervening uneroded topography. (Peter Popenoe, USGS, oral communication, 1981).

Most of the larger mass movements are probably Pleistocene in age (Embley and Jacobi, 1977) although some activity has no doubt persisted into the present at a reduced rate and scale. One of us (G. C.) participated in a joint NOAA/USGS submersible experiment in Baltimore and Norfolk

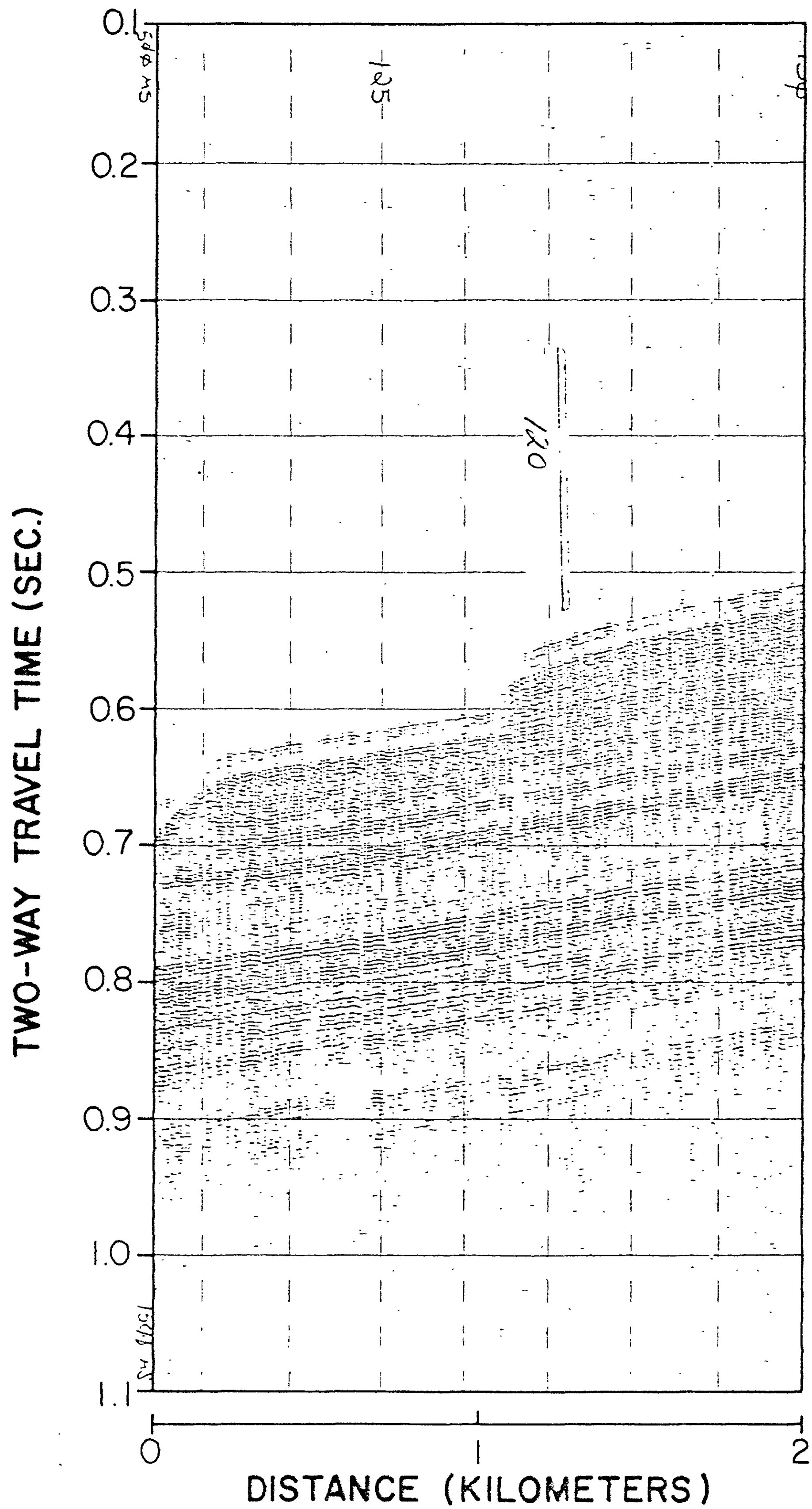


Figure 2.--Analog seismic reflection profile showing a possible slide/slump scar on the Continental Slope in block NJ 19-1-120. Vertical exaggeration x 15.

Canyons and observed many instances of recent small scale slope failure on the heads and walls of submarine canyons. There is no reason to expect that mass movement processes would be any less active in the Georges Bank Canyons. Since the degree of risk posed by mass movement is loosely related to the area and amount of failed material, it may be that contemporary small scale slumps/slides present relatively little risk to exploration and development. However, until some of these features are dated and the time frame of the most significant events is firmly established, a conservative approach must be taken with regard to near surface sediment failures and their effect on hydrocarbon exploration and development.

We have shown areas with slopes steeper than 15° as a supplement to the geohazards mapping exercise (pls. 1-3) since it is one of the few parameters involved in slope failure that can be directly measured with geophysical data. Readers are cautioned against attaching any particular significance to the choice of 15° as it is merely our subjective division between "steep" and "not steep" with reference to an average continental slope inclination of about 7°. Geotechnical factors of equal or greater importance in soil strength analysis are given in the section entitled "Slope Stability Analysis".

High angle slopes themselves, while not a hazard or constraint if they are stable, present problems to any drilling operation. Slope angles higher than about 2° to 3° can require extensive preparation (even in floating drilling operations) of the sea floor to reduce the angle so that a temporary guide base can be installed (Edward Wall, MMS, Oral Communication, 1982). In some local areas, slopes approach vertical (fig. 3).

Shallow Gas

Two small possible accumulations of shallow gas (as defined by bright spots on seismic reflection profiles) have been found in the proposed sale area. The sequence of high amplitude reflectors which appear to terminate against a structure in the center of figure 4 is interpreted as being the result of shallow gas.

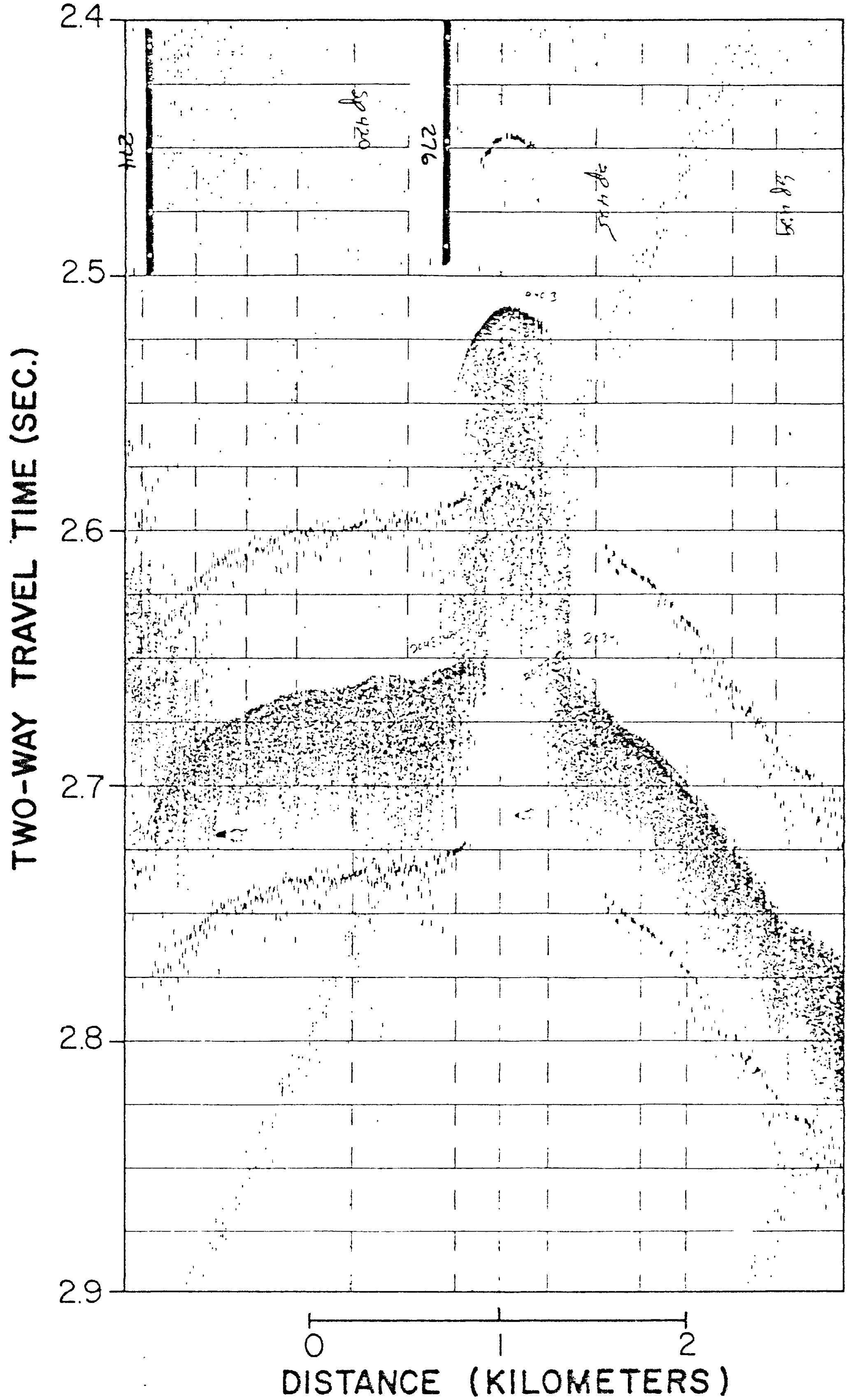


Figure 3.--Echogram across a pinnacle. Note the extreme local slope which approaches 90°. Block NK 19-11-962. Vertical exaggeration x 20.

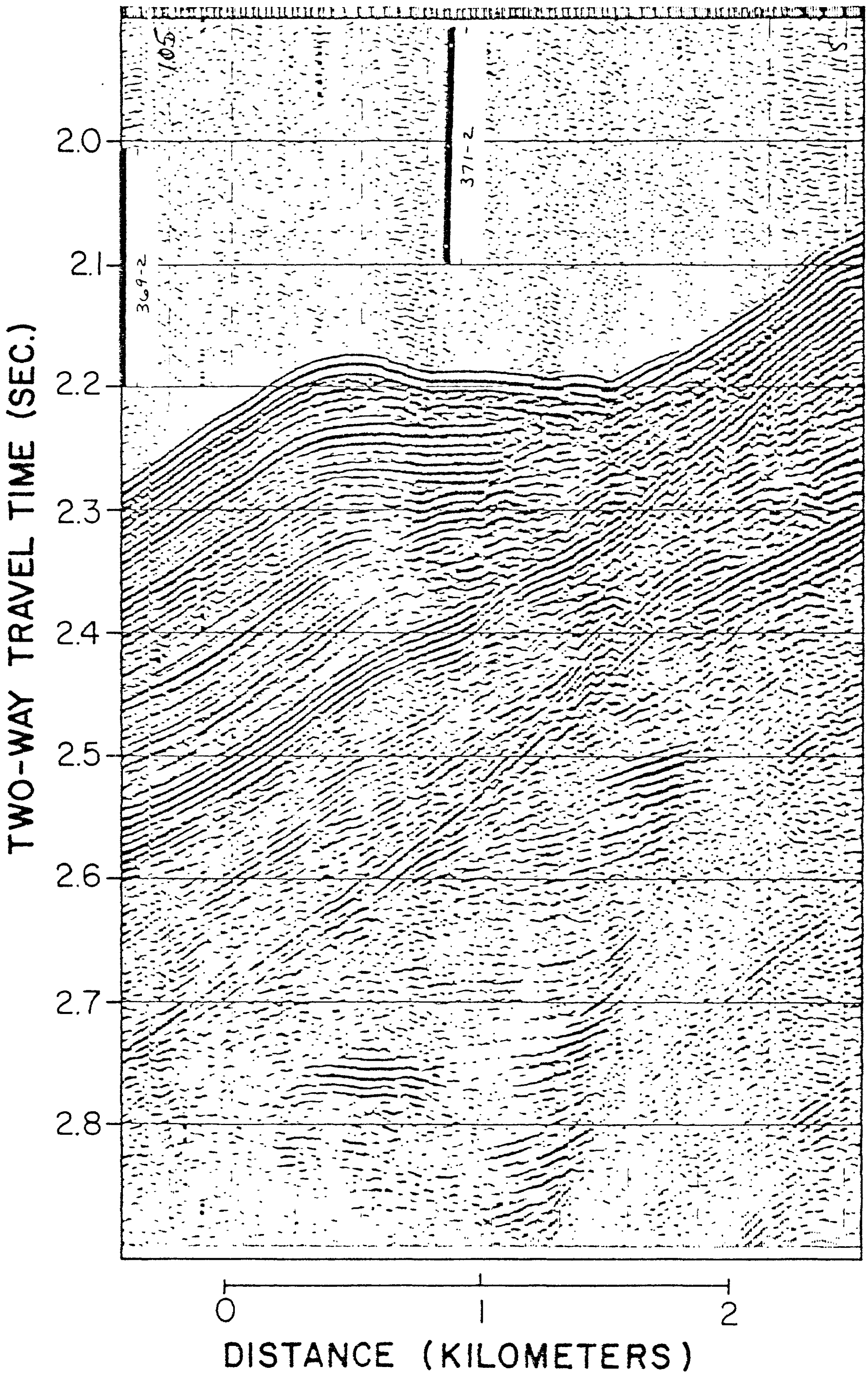


Figure 4.--Seismic reflection profile of a shallow gas deposit. The sequence of high amplitude reflectors in the center of the profile which terminate against a structure are believed to be the result of trapped gas. Block NK 19-12-587. Vertical exaggeration x 15.

Such shallow gas deposits can be significantly overpressured and, if penetrated before casing is set, can result in a blowout. A sudden influx of gas into unconsolidated sediments can also weaken them to the point of failure (Carpenter, 1981) and may result in damage to platforms or well head structures.

Other geologic problems related to gas appear to be absent or only rarely present in the proposed sale area. No evidence for the occurrence of clathrates (hydrated gas) has been found on any of the geophysical data. Gassy sediment containing diffuse interstitial gas (usually seen on HRG profiles as "acoustically turbid zones") are not nearly as common in the Georges Bank area as in other major basins to the south. Since sediment strength is related to gas content (Whelan and others, 1975), it may be that surface sediments in the proposed sale area are somewhat more resistant to failure than similar sediments in other areas which do contain gas.

CONSTRAINTS

Erosion/Sand Waves

Erosion and sand waves have been grouped as a single constraint because they are the result of bottom water circulation and tend to cluster together. Their occurrence in the Georges Bank sale area is limited to parts of the continental shelf (Twichell, 1981). They are absent or only weakly developed on the lower slope and upper rise. The degree to which they are a problem to bottom founded structures is a direct function of the intensity of the bottom current activity which produces them. Surface and subsurface currents on Georges Bank are vigorous, resulting in a high order of active erosion, scour, and sand wave construction (Lewis and others, 1980).

The morphologic result of the circulation pattern is seen on HRG data (especially side-scan sonar) in the form of large and small sand waves and megaripples. Flat, featureless but highly reflective (on echo sounders) areas, which we interpret as zones of erosion and/or scour, are common on the parts of the shelf most affected by the bottom current regime. The high reflectivity of these areas is believed to result from extensive reworking (no layering) and winnowing of surface sediments or from lag deposits between sand waves.

Bottom-current activity and bed-load transport are at a maximum near the crest of the Bank and taper off regularly away from it (Twichell, 1981). The proposed lease sale area is to the southeast of the zone of most intense sediment transport, but the height of the resulting sand waves (20 m) and the observation that they may migrate as much as 150 m/y (Twichell, 1981) presents difficulties to activities near the sale area such as pipe laying or even navigation.

Operational problems resulting from erosion, scour, and sand waves can be routinely dealt with unless the level of their activity is unusually high. The most serious of these problems is the removal of foundation materials from under and around bottom-fixed structures either by erosion or by sand wave migration away from the structure. Minor problems, such as abrasion by entrained sand, might occur, particularly in winter when current velocities tend to be high.

Filled Channels

Filled channels are common in the proposed sale area but are generally restricted to the continental shelf and upper slope. They are a result of the complex pattern of subareal Pleistocene drainage on the Bank and appear on HRG data as local erosional unconformities (fig. 5). Most of the channels are incised into a regional unconformity (fig. 6) which is mantled by about 20 to 100 m of late Pleistocene till and outwash throughout much of the shelf (Lewis and others, 1980). The general grain of the channeling is north-south.

Filled channels present a number of minor difficulties to oil and gas operations, most of which are related to the non-uniformity of fill deposits with respect to the surrounding sediments (Carpenter and McCarthy, 1980). Drilling platforms which straddle the boundary between a filled channel and adjacent sediment could conceivably tilt because of differences in load bearing ability. This problem is unfortunately not detectable with HRG data because there is only a very restricted correlation between acoustic character and shear strength of sediments.

Fill deposits are normally unsorted with highly variable grain size. This type of deposition can result in loss of drilling fluids because layers with high porosity can function as "thief zones". If the grain size of fill sediments is particularly large (cobble to boulder range), the setting of casing is likely to be difficult. There is also a remote possibility that the mode of deposition of channel fill could result in a distribution of small scale source/reservoir beds that might produce pockets of shallow gas. However, no bright spots were observed on any of the shallow reflection data on the continental shelf in the proposed sale area.

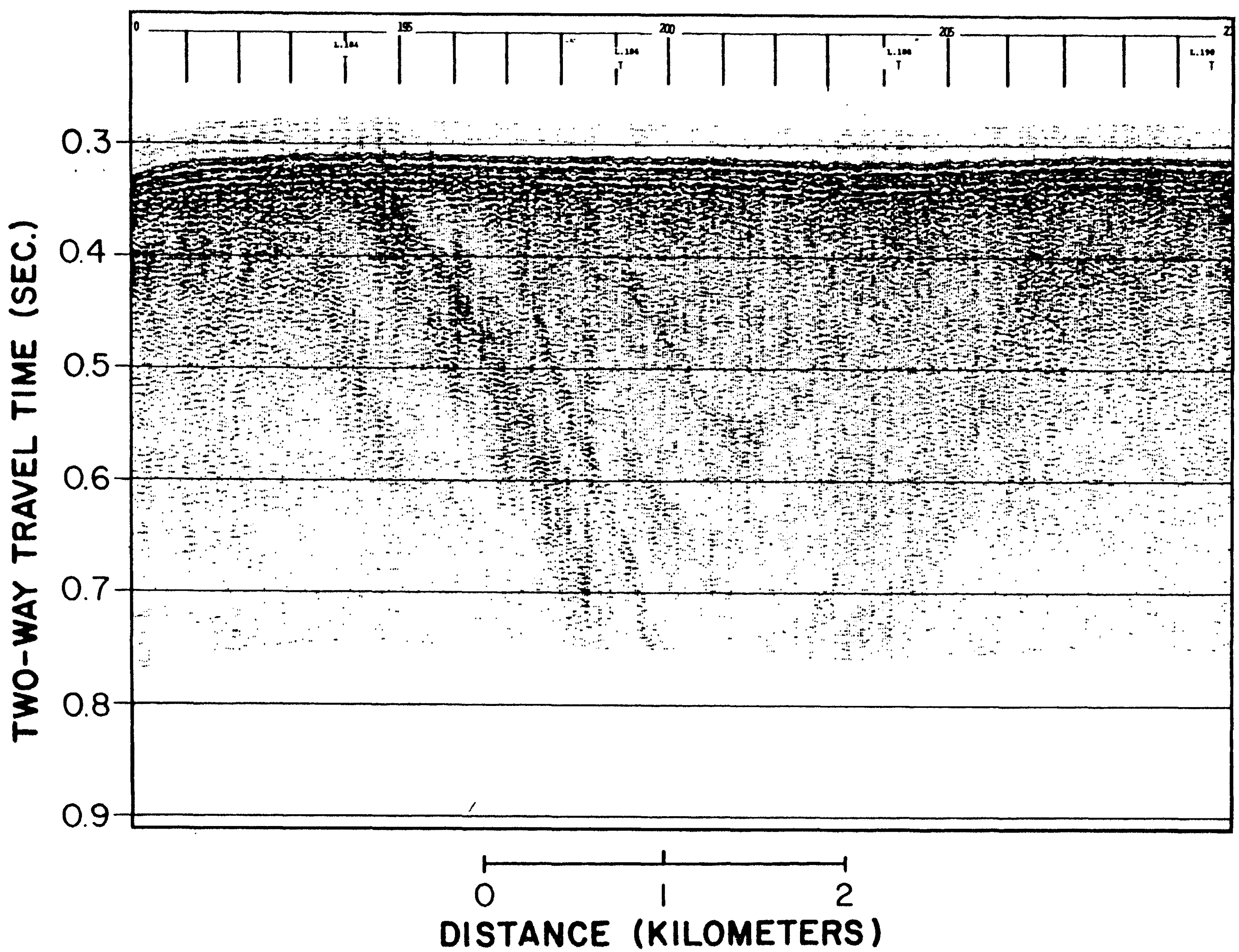


Figure 5. Seismic reflection profile across a large buried channel on the Continental Shelf in block NK 19-11-780. Vertical exaggeration x 8.

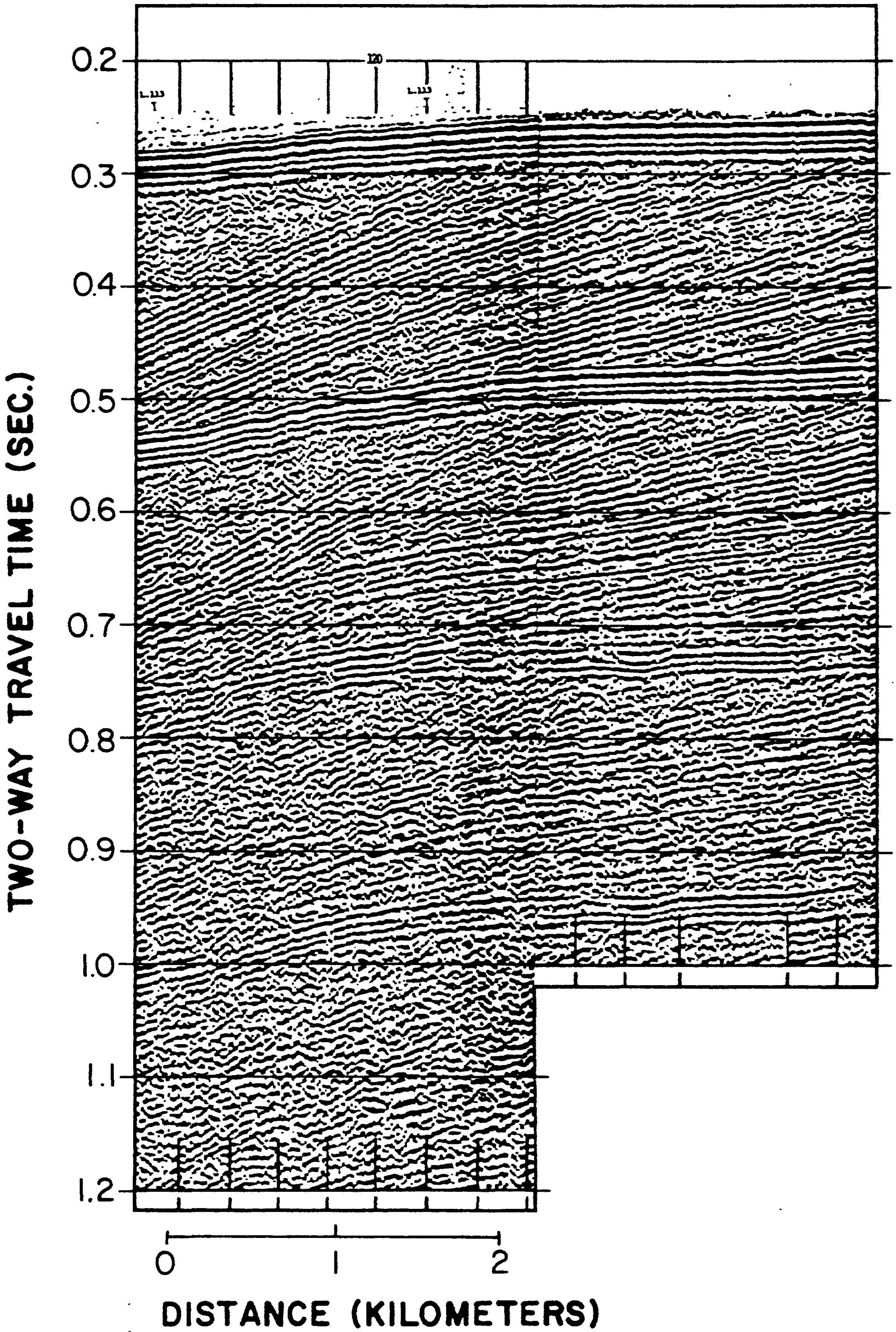


Figure 6. Seismic reflection profile showing the near surface erosional unconformity found over much of the Georges Bank Shelf. Block NK 19-11-904. Vertical exaggeration x 8.

Deep Faulting

Our data show two short, en-echelon deep faults in block NK 19-12-494. These faults do not cut the surface and are restricted to deeper sediments. These sediments are believed to be Tertiary to pre-Tertiary in age, (Hall, 1979) and the faulting is assumed to be presently inactive.

Deep, old faulting below foundation zone sediments is considered to be a constraint rather than a hazard because it is assumed to be dormant or nearly so. Despite long quiescence, however, these faults are planes of weakness and should be considered to have a limited potential for failure. Fault planes are also potential conduits for gas from depth, a factor implicated in a number of platform losses due to blowouts or cratering of foundation sediments (Danenberger, 1980).

SLOPE STABILITY ANALYSIS

Seventeen piston cores were collected from a variety of locations on the Georges Bank Continental Slope by the U.S. Geological Survey aboard the RV Endeavor in August 1979 (cruise EN-042) and October 1980 (cruise EN-056) (fig. 7). The core sites were selected on the basis of high resolution geophysical data. The cores from cruise EN-042 were collected at sites in the western half of the proposed lease sale area at water depths of 800-1593 m on apparent mass-movement scarps and deposits. The piston cores from cruise EN-056 were collected from scattered sites in the eastern half of the study area at water depths of 800-2420 m. Objectives of the geotechnical study were to verify the occurrence of past mass movement, provide more quantitive information on slope stability, and establish the general geotechnical properties of the sediments.

The geotechnical test program included (1) consolidation tests to determine the consolidation and compressibility characteristics of the sediments, (2) consolidated-undrained triaxial tests with pore pressure measurements to determine both drained and undrained strength parameters, (3) index property measurements on the consolidation and triaxial test specimens and at 0.5 m intervals where possible in the several cores (these measurements included Atterberg limits, particle size distribution, specific gravity, and moisture content), and (4) vane shear measurements at 0.5 m intervals in the cores. Results of the geotechnical testing program are found in table 1 (pages 32-33) and table 2 (pages 35-47).

Geotechnical data were correlated with geophysical data to evaluate the stability of the bottom sediments at each coring site. The first step in the evaluation involved comparison of the shear strength of the material (determined from laboratory measurements) with gravity-induced shear stresses on the failure plane which were calculated from the infinite-slope model of stability analysis (fig. 8). The available shear strength on a failure plane may be considered in terms of its drained or undrained

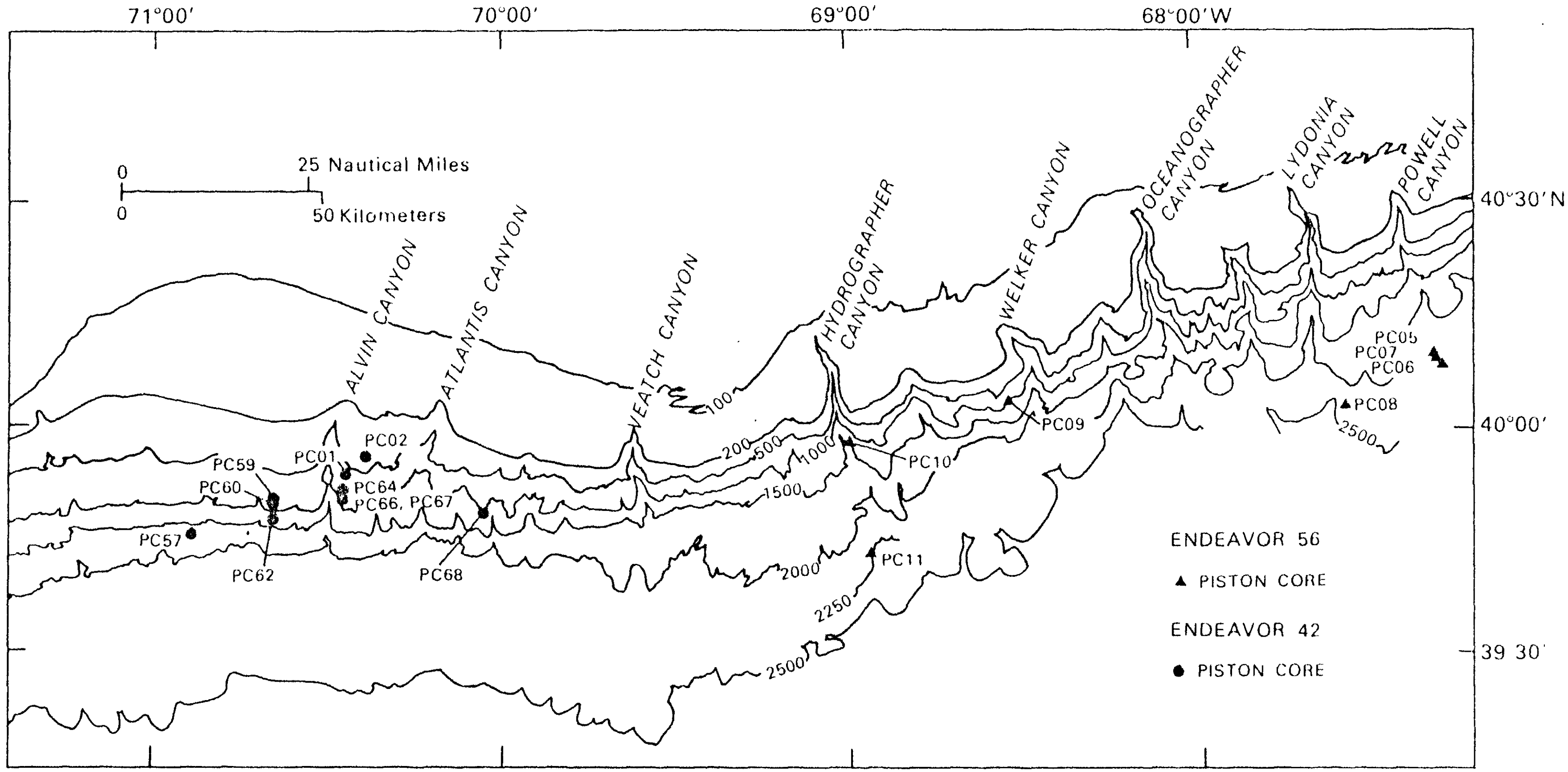
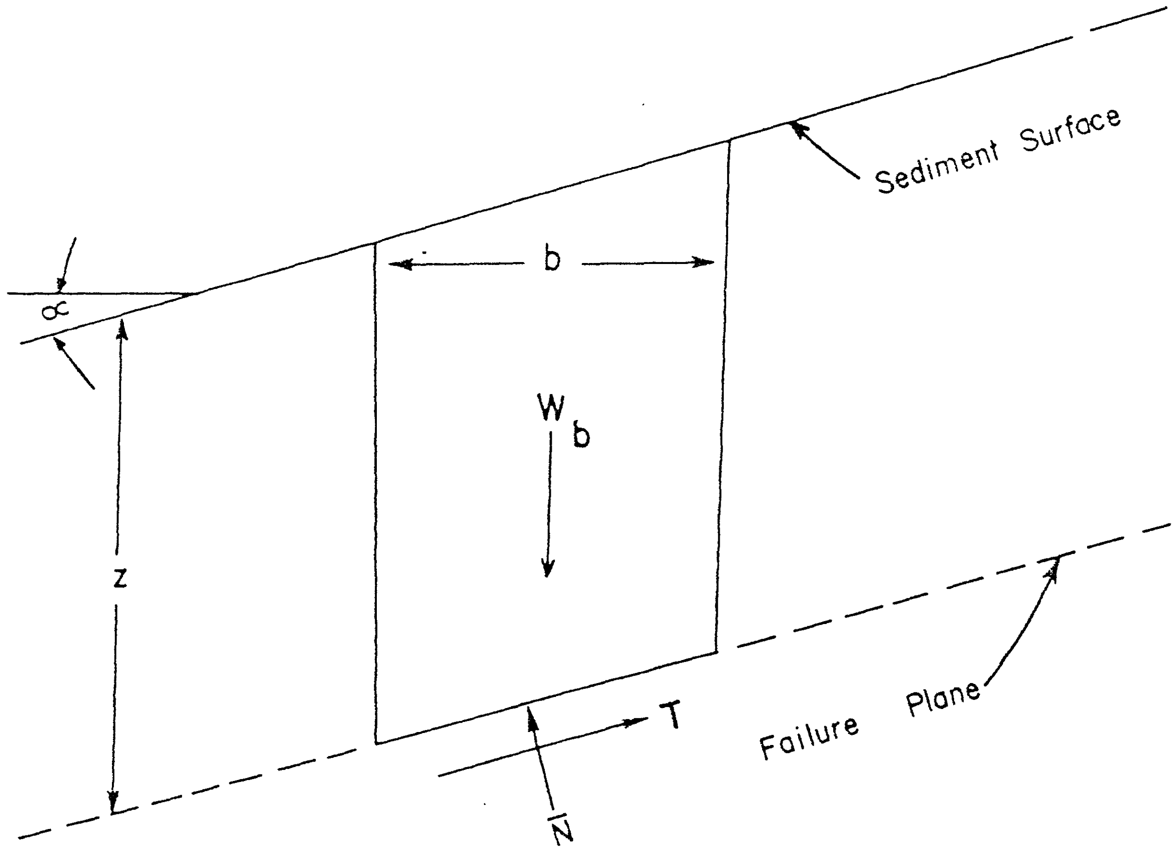


Figure 7. Map showing the locations of all piston core sites from cruises EN-042 and EN-056 used in this study. From James Booth (Unpublished data).



Where:

$W_b = (\gamma_b z)\ b = \bar{\sigma}_v b$

$T = W_b \sin \alpha = (\gamma_b z)\ b \sin \alpha$

$\bar{N} = W_b \cos \alpha = (\gamma_b z)\ b \cos \alpha$

$\tau = (\gamma_b z) \cos \alpha \ \sin \alpha$

$\bar{\sigma}_n = (\gamma_b z) \cos^2 \alpha$

$\bar{\sigma}_v = \gamma_b z$

$s_d = c + \bar{\sigma}_n \tan \bar{\phi}$

Figure 8--Infinite-slope stability analysis diagram with formulas for calculation of bouyant weight of soil (w_b), shear force on failure plane (T), shearing stress on failure plane (τ), and effective stress normal to failure plane (N).

behavior (see pages 29 and 30), depending on sediment characteristics and loading. The result of this comparison is expressed in terms of the factor of safety (FS) which is the ratio of the available shear strength of the sediment to the applied shear stress. The results include FS values for both drained and undrained conditions at 12 of the 17 coring sites, and are based on the minimum strength parameters measured on sediment samples from that site (table 2). These FS values may be used to identify those areas in which slope failure is most likely to occur. However, FS values of either FS $\leq$ 1 or FS >1 alone do not represent absolute conditions of slope stability but must be considered with additional factors such as in situ gas, the presence of cements and assumptions attendant to the infinite slope model.

Calculations of infinite slope failure analysis were made for both drained and undrained conditions (fig. 8). Definitions of symbols and units used in figure 8 and derivations of the FS formula listed follow on pages 29 and 30. For each core sample, minimum strengths were used for FS calculations so as to provide a conservative estimate of soil strength.

The factor of safety values were calculated in all cases for the maximum slopes in the region where each core was taken. No values less than 1.0 were recorded from any of the sites where values have been calculated. Moreover, in all cases where safety factors were derived, these values were associated with overconsolidation ratio (OCR) values of 1.0 or more. An OCR value determined from a consolidation test, is defined as a ratio of maximum previous effective overburden stress ($\bar{\sigma}_m$) to the calculated effective overburden stress ($\bar{\sigma}_v$). If $_m$ equal $\bar{\sigma}_v$ (OCR = 1), the sediment is considered to be normally consolidated. Materials with an OCR greater than 1.0 are overconsolidated.

Several of the core sites (PC-57, PC-05, PC-06, PC-07, PC-11) are located outside the proposed Lease Sale 52 area. The test results are included because they aid in the general understanding of the slope stability of Georges Bank Continental Slope sediments. At several sites, it was difficult to collect enough samples to perform all the required tests because of the problems involved in collecting good samples at certain site locations (for example, very hard sediment or steep valley walls). Consequently, not all piston core sites have had the same number and types of tests performed on them.

There are several points to consider when evaluating the strength parameters and FS values recorded in tables 1 and 2:

1. All cores have been disturbed to some unknown degree and, therefore, the FS values presented here are only approximations.
2. The OCR values reflect the apparent overconsolidation state; that is, the presence of cements, gas, or other in situ factors may alter the OCR value.
3. The FS values are for static slope conditions. They do not take into account any possible influence of dynamic processes such as cyclic loading induced by earthquakes or internal waves.

The average shear strength values in the study area range from 0.75 to 50.2 kPa (table 1). The highest shear stengths were found in core PC-57 while the lowest shear strengths were found in core PC-09. Sediments sampled in the western half of the study area (Alvin Canyon and Atlantis Canyon area) have higher strengths (range of 3.1 to 50.2 kPa; average of 9.5 kPa) than those cores in the eastern half of the study area (range of 0.75 to 21.8 kPa, average of 4.73 kPa). This difference in shear strength ranges is not surprising because the piston core sites in the western half of the study area were specifically selected to sample small scale mass-movement features, while those sites in the eastern half represent a more random sample selection. The average shear strength values from the sites on the western half of the study area are almost twice the strength that is expected for normally consolidated fine-grain sediments. The average shear strength values from the eastern half tend to fit the range of values reported by Keller and others (1979).

Sensitivity is defined as the ratio of undisturbed to remolded shear strength, and the values in the study area range from 2 to 15 (PC-67, low value; PC-57, high value) (table 1). The average sensitivity values of the core samples in the western half of the study area are higher (5, range of 2 to 15) than those from the eastern half (4, range of 2 to 11). Fine-grained marine sediments typically have sensitivities of 2 to 4. These values indicate that these sediments on the average, are considered sensitive and range from slightly sensitive to slightly quick.

Maximum moisture content (w) values of the piston core samples ranged from 48 to 113 % (average, 69.4 %) in the study area. The highest moisture content value was at core PC-06 and the lowest moisture content was at core PC-66. Moisture contents are higher for sediments collected on the mid-to-lower slope. Within most of the cores, moisture content is at or above the liquid limits through its length.

As previously mentioned, the majority of piston cores from the eastern half of the study area were taken farther downslope (800-2420 m water depths) and reflect higher moisture content and liquid limit values and lower average undrained shear strengths than those from the western half. The average wet bulk densities (recorded in table 1) are lower for the eastern cores (1.69 g/cc) than those from the west (1.75 g/cc). The lowest average γ_t for a core (1.59 g/cc) was in PC-11 which is one of the deepest piston core locations on the slope. The highest average γ_t (1.85 g/cc) is in PC-59 located on the upper slope.

The index properties in table 1 support the engineering properties of the core samples derived from the geotechnical testing program. The combination of low moisture contents (w), low porosites (n), and high bulk densities (γ_t) are consistent with the higher shear strengths (tables 1 and 2). High shear strengths occur both as discrete layers within cores (PC-05, PC-06) (cores PC 57, PC 66) and are associated with low moisture content, low porosity, and high wet bulk density values.

There is little evidence that in situ gas is present in significant enough levels to influence the slope stability of sediments within the proposed OCS Lease Sale 52 area. The core samples were tested for gas content aboard the RV Endeavor by the U.S. Geological Survey (Marine Organic Geochemistry laboratory) of Reston, Virginia. The measured gas levels in all cores were near background levels (1 to 25 ppm by volume). Furthermore, as noted earlier, there is little evidence of gas pockets (bright spots) in the HRG data within the proposed lease sale area.

Two cores showed much higher shear strengths in the upper 0.5 m than would be expected at that level. Booth and others (1981) believe that the most likely explanation for these anomalous strengths is that the core sites (PC-57, PC-59) may have been once buried under sediment which has since been removed by mass movement.

Alternative explanations for these high shear strengths include the presence of cements or the removal of overburden by scour. Booth and others (1981) showed that the criteria for recognizing cements in marine sediments (for example, peak loading resistence developing early in strains less than 2% versus the 8-10% found in the samples) are not completely met in either case. Although the possibility that cements exist in these sediments cannot be completely ruled out, their presence is unlikely because other evidence, such as the presence of calcareous materials, is lacking. Similarly, evidence for scour at the two sites is lacking. These fine-grained sediments would require a current of several tens of cm/sec for erosion to occur (Keller and Shepard, 1978). Keller and others (1979) indicate that currents capable of eroding these fine-grained sediments do not appear to exist below 800 m water depth (upper slope). Evidence of mass-movement has been found with HRG data near two sites (PC-57, PC-59). Thus, the combination of high shear strengths, index property measurements, and the HRG data support the interpretation that these features may represent slump or slide scars, and that these sediments were once buried under a considerable thickness of overburden.

The results of the slope stability analyses are summarized below:

1. The surficial sediments on the Georges Bank Continental Slope are inorganic clayey silts and silty clays of medium to high plasticity.
2. In all cases where the factor of safety has been determined, they are greater than 1.0, and are associated with sediments with overconsolidation ratios or 1.0 or more.
3. Two core sites (PC-57, PC-59) are associated with mass-movement scars, identified by Booth and others (1981). The shear strengths, index property measurements, and HRG data at these sites support that interpretation.
4. The high shear strengths measured are associated with normally consolidated to overconsolidated sediments.
5. The surfical sediments sampled are stable with respect to mass movement.

Factor of Safety (FS) Derivation for
Infinite Slope Stability Model

ϕ = friction angle with respect to effective stress in degrees

α = slope angle in degrees

c = cohesion intercept in terms of effective stress in kN/m^2

z = depth to failure plane from sediment surface in meters

b = width of soil element in meters

W_b = bouyant weight of soil element in kN

γ_b = bouyant unit weight of soil element in kN

$\bar{\sigma}_v$ = effective vertical stress in kN/m^2

T = shearing resistance on failure plan in kN

τ = effective stress normal to failure plane in kN/m^2

S = available shear strength in kN/m^2

S_u = available undrained shear strength in kN/m^2

S_d = available drained shear strength in kN/m^2

A. Undrained Analysis:

$$FS = \frac{\text{available undrained shear strength}}{\text{shear stress required for equilibrium}}$$

$$FS = (s_u/\tau)$$

$$FS = \frac{s_u/\bar{\sigma}_v}{\cos\alpha \sin\alpha}$$

Where $\bar{\sigma}_v = \gamma_b z$

$$= (\gamma_b z) \cos\alpha \sin\alpha$$

Undrained analysis is appropriate in examining sediment under short term failure conditions. In this case, the sediment is sheared to failure before any excess pore pressure generated during shearing has time to dissipate.

B. Drained Analysis:

$$FS = \frac{\text{available drained strength}}{\text{shear stress required for equilibrium}}$$

$$FS = \frac{(\gamma_b z \ \cos^2\alpha)\tan\bar{\phi}}{\gamma_b z \cos\alpha \sin\alpha}$$

$$FS = \frac{\tan\bar{\phi}}{\tan\alpha}$$

Drained analysis is appropriate for use with long term stability analysis. Drained analysis will typically yield higher FS values than undrained analysis for normally consolidated and underconsolidated clays.

Symbols, Definitions and Units of Tables

w = moisture content, in % of dry-soil weight

w_L = liquid limit, in % of dry-soil weight

w_p = plastic limit, in % of dry-soil weight

I_p = plasticity index = $w_L - w_p$

I_L = liquidity index = $\frac{w - w_p}{I_p}$

n = porosity = $\frac{V_v}{V}$ with V_v = volume at voids and V = total volume

γ_t = bulk density, in g/cc

S_u = undrained shear strength in kPa

S_u = remolded, undrained shear strength in kPa

S_t = sensitivity = $\frac{\text{Undisturbed } S_u}{\text{Remolded } S_u}$

$\bar{\sigma}_m$ = maximum previous overburden stress in kPa

$\bar{\sigma}_v$ = vertical effect stress in kPa

OCR = $\frac{\bar{\sigma}_m}{\bar{\sigma}_v}$ = overconsolidation ratio

Note: Consult a soil mechanics text book such as Lambe and Whitman (1969) for more detailed explanation of symbols.

Table 1

Index Property Measurements for Georges Bank Piston Core Sites*
(---, limited data; ND, no data)

Site No	Core No	Location	Block No.	Water Depth (m)	Core Recovery (m)		w	w_L	w_p	I_p	I_L	n	t	Undisturbed Vane s_u kPa	Remolded Vane s_u-r kPa	s_t
GD-01	PC-01	39°54.12'	NJ 19-1-82	697	5.20	Max:	63	69	26	44	1.10	63	1.77	10.4	1.8	7.3
		70°27.52'				Min:	50	50	19	27	0.80	57	1.66	7.8	1.0	5.5
						Avg:	56.8	58.8	23.5	35.1	0.96	48	1.72	8.57	1.35	6.43
GD-03	PC-02	39°56.47'	NJ 19-1-39	534	3.13	Max:	59	61	25	39	0.96	62	1.82	9.3	1.8	8.2
		70°23.55'				Min:	46	47	20	27	0.79	55	1.71	5.4	0.9	3.1
						Avg:	51.1	55	22.3	32.3	0.88	58	1.77	6.89	1.2	6.1
GB-02	PC-57	39°46.24'	NJ 19-1-206	1,593	0.53	Max:	79	84	33	64	0.84	68	1.76	50.2	4.4	15
		70°53.71'				Min:	49	54	28	21	0.41	57	1.58	4.4	0.6	11
						Avg:	63.3	69.3	30.3	42	0.67	62.3	1.67	21.3	2.6	13
GB-03	PC-59	39°50.49'	NJ 19-1-122	851	1.71	Max:	40	58	28	27	0.76	52	1.91	15.6	2.8	8.6
		70°39.64'				Min:	36	40	21	19	0.50	49	1.86	13.4	1.8	5.0
						Avg:	38.7	49	24.5	23.3	0.65	51.0	1.88	14.6	2.2	6.8
GB-04	PC-60	39°50.21'	NJ-19-1-122	856	1.91	Max:	59	64	30	34	1.03	62	---	8.3	2.4	3.5
		70°39.65'				Min:	57	58	28	30	0.79	---	1.70	---		---
						Avg:	58	61	29	32	0.91	62	1.70	8.3	2.4	3.5
GB-05	PC-62	39°49.35'	NJ 19-1-166	937	0.96	Max:	52	54	25	31	0.93	53	1.84	12.3	2.8	4.5
		70°39.70'				Min:	42	43	23	15	----	---	1.76	9.2	3.3	2.8
						Avg:	47	48.5	24	24.5	0.93	53	1.80	10.8	3.05	3.65
GB-06	PC-64	39°51.89'	NJ 19-1-125	813	3.84	Max:	65	61	29	34	1.14	64	1.74	7.1	3.6	4.2
		70°27.85'				Min:	54	52	26	28	0.81	59	1.66	4.4	1.1	1.9
						Avg:	58.4	57	26.9	30.1	1.02	61	1.71	5.8	1.94	3.2
GB-07	PC-66	39°51.35'	NJ 19-1-125	835	0.32	Max:	48	56	27	29	0.72	57	1.78	ND	ND	ND
		70°27.88'				Min:	---	----	---	---	----	---	----			
						Avg:	48	56	27	29	0.72	57	1.78			

Table 1 (continued)

Index Property Measurements for Georges Bank Piston Core Sites

Site No	Core No	Location	Block No.	Water Depth (m)	Core Recovery (m)		w	w_L	w_p	I_p	I_L	n	t	Undisturbed Vane s_u kPa	Remolded Vane s_{u-r} kPa	s_t
GB-07	PC-67	39°51.37'	NJ 19-1-125	837	2.16	Max:	59	65	29	35	1.02	61	1.70	5.1	2.7	1.9
		70°27.90'				Min:	56	58	28	30	0.85	60	1.70	3.1	3.1	1.5
						Avg:	57.7	60.3	27.3	33	0.94	60.7	1.70	4.1	2.9	1.7
GB-07	PC-68	39°51.38'	NJ 19-1-125	834	2.45	Max:	58	57	27	34	1.13	61	1.77	12.8	5.2	3.0
		70°28.87'				Min:	50	53	24	26	0.83	57	1.71	8.1	3.5	1.8
						Avg:	52.4	55.2	25.8	29.4	0.92	58.8	1.75	10.4	4.38	2.38
05	PC-05	40°10.47'	NK 19-12-804	2,190	7.92	Max:	76	59	28	37	2.33	67	1.79	9.28	3.28	12.2
		67°19.34				Min:	48	39	17	18	0.89	56	1.60	2.01	0.25	2.2
						Avg:	57	49.1	22.2	26.9	1.32	60.3	1.72	4.12	0.95	5.67
06	PC-06	40°08.52'	NK 19-12-849	2,375	4.71	Max:	113	108	40	88	1.61	72	1.89	21.82	9.91	7.4
		67°17.37'				Min:	38	53	18	33	0.46	51	1.47	1.69	0.38	1.6
						Avg:	97.2	80.1	28.4	54.3	1.01	60	1.59	7.58	4.26	4.1
07	PC-07	40°10.08'	NK 19-12-805	2,235	3.90	Max:	69	55	27	31	2.25	65	1.79	10.66	5.25	5.02
		67°18.57'				Min:	48	39	12	19	0.90	56	1.64	1.25	0.50	2.0
						Avg:	55.7	46.8	24.8	22	1.27	59.6	1.73	4.96	1.65	3.96
08	PC-08	40°03.26'	NK 19-12-888	2,420	4.29	Max:	80	54	25	37	1.89	68	1.74	3.14	0.88	6.3
		67°34.95'				Min:	54	38	16	18	1.33	59	1.58	1.38	0.38	2.4
						Avg:	63.7	47.9	20.1	27.7	1.61	62.8	1.67	2.46	0.61	4.04
09	PC-09	40°04.39'	NK 19-11-911	800	4.29	Max:	59	56	25	31	1.75	61	1.99	3.14	2.76	11.0
		68°32.50'				Min:	30.1	33	19	12	1.10	45	1.70	0.75	0.25	2.1
						Avg:	43.8	43.8	21.3	22.5	1.38	53	1.85	2.71	1.25	5.05
10	PC-10	39°59.05'	NK 19-11-990	1,200	3.32	Max:	83	67	26	43	1.6	69	1.96	5.23	2.75	2.9
		69°01.39'				Min:	45	36	17	16	0.75	46	1.57	1.44	0.50	1.4
						Avg:	69	52.4	22.6	29.8	1.25	60.8	1.71	3.5	1.66	2.35
11	PC-11	39°44.35'	NK 19-11-210	2,225	7.55	Max:	106	103	39	64	1.78	73	1.81	5.56	1.0	8.2
		68°56.26'				Min:	46	39	16	23	0.38	57	1.49	1.97	0.5	2.8
						Avg:	82	73.1	29.7	43.8	1.20	65.7	1.59	3.56	0.72	5.06

*See section on symbols and units to explain symbols used in table

Slope Stability Analysis Table

The partial results of the consolidation and triaxial tests have been compiled and are listed in Table 2 with data furnished by James S. Booth of the U.S. Geological Survey in Woods Hole, Massachusetts (published data, 1981; unpublished data, and written comm., 1982). The factor of safety values were computed for the maximum slope angles near core-site locations. Only surface and near surface faults located near core site locations are mentioned under Geologic Factors. Evidence of gas within each piston core is mentioned under Geologic Factors. Refer to table 1 and figure 7 for a summary of core site locations.

Table 2

Georges Bank Sample Sites: Slope Stability Analysis

Core No: PC-01 Block No: NJ 19-1-82

Latitude: 39°54.12' Longitude: 70°27.52'

Water Depth (m): 697 Core Recovery (m): 5.20

Slope angle, α: 2.4°

Geotechnical Data:

Texture: Silty Clay

Angle of Shearing Resistance with Respect to Effective Stress, Ø:	22.6°
Undrained Shear Strength, Effective Vertical Stress Ratio Su/ov	No Data Available
Overconsolidation Ratio, OCR:	No Data Available
Cohesion Intercept in Terms of Effective Stress, c:	9.9

Stability Analysis (Infinite Slope Model):

Factor of Safety (undrained):	18.4
Factor of Safety (drained)	17.7

Geologic Factors:

Feature Sampled: Intervalley Ridge - Upper Slope

Faults: None

Gas: No appreciable amounts of gas above background levels detected in core

Additional Comments:

None

Table 2 (continued)

Georges Bank Sample Sites: Slope Stability Analysis

Site Data:

Core No: PC-02 Block No: NJ 19-1-39

Latitude: 39°56.47' Longitude: 70°23.55'

Water Depth (m): 534 Core Recovery (m): 3.13

Slope Angle, α : 1.2°

Geotechnical Data:

Texture: Silty Clay

Angle of Shearing Resistance with Respect to Effective Stress, ϕ:	27.2°
Undrained Shear Strength, Effective Vertical Stress Ratio, S_u/σ_v:	1.13
Overconsolidation Ratio, OCR:	9.0
Cohesion Intercept in Terms of Effective Stress, c:	7.4

Stability Analysis (Infinite Slope Model):

Factor of Safety (undrained):	54.0
Factor of Safety (drained):	22.6

Geologic Factors:

Feature Sampled: Intervalley Ridge - Upper Slope

Faults: None

Gas: No appreciable amounts of gas above background levels detected in core

Additional Comments:

Moderate disturbance in core.

Table 2 (continued)

Georges Bank Sample Sites: Slope Stability Analysis

Site Data:

Core No: PC-59 Block No: NJ 19-1-386

Latitude: 39°50.49' Longitude: 70°39.64'

Water Depth (m) : 851 Core Recovery (m): 1.71

Slope Angle, α : 3.8°

Geotechnical Data:

Texture: Silty Clay

Angle of Shearing Resistance with Respect to Effective Stress, Ø:	27.9°
Undrained Shear Strength, Effective Vertical Stress Ratio, S_u/σ_v:	1.0
Overconsolidation Ratio, OCR:	No Data Available
Cohesion Intercept in Terms of Effective Stress, c:	1.8

Stability Analysis (Infinite Slope Model):

Factor of Safety (undrained):	16.6
Factor of Safety (drained):	8.0

Geologic Factors:

Feature Sampled: Intervalley Ridge - Midslope

Faults: None

Gas: No appreciable amounts of gas above background levels detected in core

Additional Comments:

None

Table 2 (continued)

Georges Bank Sample Sites: Slope Stability Analysis

Site Data:

Core No: PC-64 Block No: NJ 19-1-125

Latitude: 39°51.89' Longitude: 70°27.85'

Water Depth (m): 813 Core Recovery (m): 3.84

Slope Angle, α : 3.07°

Geotechnical Data:

Texture: Silty Clay

Angle of Shearing Resistance with Respect to Effective Stress, $\emptyset$:	No Data Available
Undrained Shear Strength, Effective Vertical Stress Ratio, S_u/σ_v:	0.60
Overconsolidation Ratio, OCR:	3.8
Cohesion Intercept in Terms of Effective Stress, c:	No Data Available

Stability Analysis (Infinite Slope Model):

Factor of Safety (undrained):	No Data Available
Factor of Safety (drained):	No Data Available

Geologic Factors:

Feature Sampled: Canyon Wall - Midslope

Faults: None

Gas: No appreciable amounts of gas above background levels detected in core

Additional Comments:

Moderate disturbance in core sample.

Table 2 (continued)

Georges Bank Sample Sites: Slope Stability Analysis

Site Data:

Core No: PC-66 Block No: NJ 19-1-125

Latitude: 39°51.35' Longitude: 70°27.88'

Water Depth (m): 835 Core Recovery (m): 0.32

Slope Angle, α : 6.2°

Geotechnical Data:

Texture: Silty Clay

Angle of Shearing Resistance with Respect to Effective Stress, ϕ:	18.7°
Undrained Shear Strength, Effective Vertical Stress Ratio, S_u/σ_v:	1.6
Overconsolidation Ratio, OCR:	No Data Available
Cohesion Intercept in Terms of Effective Stress, c:	7.9

Stability Analysis (Infinite Slope Model):

Factor of Safety (undrained):	14.9
Factor of Safety (drained):	3.1

Geologic Factors:

Feature Sampled: Canyon Wall - Midslope

Faults: None

Gas: No appreciable amounts of gas above background levels detected in core

Additional Comments:

None

Table 2 (continued)

Georges Bank Sample Sites: Slope Stability Analysis

Site Data:

Core No: PC-67 Block No: NJ 19-1-125

Latitude: 39°51.37' Longitude: 70°27.90'

Water Depth (m): 837 Core Recovery (m): 2.16

Slope Angle, α : 4.76°

Geotechnical Data:

Texture: Silty clay

Angle of Shearing Resistance with Respect to Effective Stress, Ø:	No data available
Undrained Shear Strength, Effective Vertical Stress Ratio, S_u/o_v:	No data available
Overconsolidation Ratio, OCR:	38
Cohesion Intercept in Terms of Effective Stress, c:	No data available

Stability Analysis (Infinite Slope Model):

Factor of Safety (undrained):	No data available
Factor of Safety (drained):	No data available

Geologic Factors:

Feature Sampled: Canyon Wall - Midslope

Faults: None

Gas: No appreciable amounts of gas above background levels detected in core.

Additional Comments:

Considerable disturbance in core sample.

Table 2 (continued)

Georges Bank Sample Sites: Slope Stability Analysis

Site Data:

Core No: PC-05 Block No: NK 19-12-804

Latitude: 40°10.47' Longitude: 67°19.34'

Water Depth (m): 2,190 Core Recovery (m): 7.92

Slope Angle, α : 3.7°

Geotechnical Data:

Texture: Silty Clay

Angle of Shearing Resistance with Respect to Effective Stress, Ø:	17.5°
Undrained Shear Strength, Effective Vertical Stress Ratio, S_u/σ_v:	0.18
Overconsolidation Ratio, OCR:	2.2
Cohesion Intercept in Terms of Effective Stress, c:	2.5

Stability Analysis (Infinite Slope Model):

Factor of Safety (undrained):	2.8
Factor of Safety (drained):	4.9

Geologic Factors:

Feature Sampled: Possible Canyon Wall - Midslope[1]

Faults: None

Gas: No appreciable amounts of gas above background levels detected in core

Additional Comments:

[1]Piston core site is outside proposed OCS Lease Sale 52 area. We presently have no HRG data coverage at this site. Small amount of disturbance of core sample.

Table 2 (continued)

Georges Bank Sample Sites: Slope Stability Analysis

Site Data:

Core No: PC-06 Block No: NK 19-12-849

Latitude: 40°08.52' Longitude: 67°.17.37'

Water Depth (m): 2,375 Core Recovery (m): 4.71

Slope Angle, α : 2.3°

Geotechnical Data:

Texture: Silty Clay

Angle of Shearing Resistance with Respect to Effective Stress, ϕ:	27.4°
Undrained Shear Strength, Effective Vertical Stress Ratio, S_u/σ_v:	0.43
Overconsolidation Ratio, OCR:	1.5
Cohesion Intercept in Terms of Effective Stress, c:	3.2

Stability Analysis (Infinite Slope Model):

Factor of Safety (undrained):	10.7
Factor of Safety (drained):	12.9

Geologic Factors:

Feature Sampled: Possible Canyon Wall, Lower Slope[1]

Faults: None

Gas: No appreciable amounts of gas above background levels detected in core

Additional Comments:

[1]Piston core sites is outside proposed OCS Lease Sale 52 area. We presently have no HRG data coverage at this site. Moderate amount of disturbance of core sample.

Table 2 (continued)

Georges Bank Sample Sites: Slope Stability Analysis

Site Data:

Core No: PC-07 Block No: NK 19-12-805

Latitude: 40°10.08' Longitude: 67°18.57'

Water Depth (m): 2,235 Core Recovery (m): 3.90

Slope Angle, α : 2.7°

Geotechnical Data:

Texture: Silty Clay

Angle of Shearing Resistance with Respect to Effective Stress, Ø:	31.4°
Undrained Shear Strength, Effective Vertical Stress Ratio, S_u/o_v:	0.44
Overconsolidation Ratio, OCR:	2.0
Cohesion Intercept in Terms of Effective Stress, c:	1.1

Stability Analysis (Infinite Slope Model):

Factor of Safety (undrained):	9.4
Factor of Safety (drained):	12.9

Geologic Factors:

Feature Sampled: Possible Canyon Wall - Lower Slope[1]

Faults: None

Gas: No appreciable amounts of gas above background levels detected in core

Additional Comments:

[1]Piston core site is outside proposed Lease Sale 52 area. We presently have no HRG data coverage at this site. Small amount of disturbance of core sample.

Table 2 (continued)

Georges Bank Sample Sites: Slope Stability Analysis

Site Data:

Core No: PC-08 Block No: NK 19-12-888

Latitude: 40°03.26' Longitude: 67°34.95'

Water Depth (m): 2,420 Core Recovery (m): 4.29

Slope Angle, α : 2.3°

Geotechnical Data:

Texture: Silty Clay

Angle of Shearing Resistance with Respect to Effective Stress, $\emptyset$:	23.4°
Undrained Shear Strength, Effective Vertical Stress Ratio, S_u/σ_v:	0.30
Overconsolidation Ratio, OCR:	1.5
Cohesion Intercept in Terms of Effective Stress, c:	2.9

Stability Analysis (Infinite Slope Model):

Factor of Safety (undrained):	7.5
Factor of Safety (drained):	9.2

Geologic Factors:

Feature Sampled: Intervalley Ridge - Lower Slope

Faults: None

Gas: No appreciable amounts of gas above background levels detected in core

Additional Comments:

Small amount of disturbance of core sample.

Table 2 (continued)

Georges Bank Sample Sites: Slope Stability Analysis

Site Data:

Core No: PC-09 Block No: NK 19-11-911

Latitude: 40°04.39' Longitude: 68°32.52'

Water Depth (m): 800 Core Recovery (m): 4.29

Slope Angle, α : 11.3°

Geotechnical Data:

Texture: Silty Clay

Angle of Shearing Resistance with Respect to Effective Stress, ϕ:	21.7°
Undrained Shear Strength, Effective Vertical Stress Ratio, S_u/σ_v:	0.26
Overconsolidation Ratio, OCR:	3.1
Cohesion Intercept in Terms of Effective Stress, c:	4.1

Stability Analysis (Infinite Slope Model):

Factor of Safety (undrained):	1.4
Factor of Safety (drained):	2.0

Geologic Factors:

Feature Sampled: Valley Wall - Midslope

Faults: None

Gas: No appreciable amounts of gas above background levels detected in core

Additional Comments:

Small amount of disturbance of core sample.

Table 2 (continued)

Georges Bank Sample Sites: Slope Stability Analysis

Site Data:

Core No: PC-10 Block No: NK 19-11-990

Latitude: 39°59.05' Longitude: 69°01.39'

Water Depth (m): 1,200 Core Recovery (m): 3.32

Slope Angle, α: 11.3°

Geotechnical Data:

Texture: Silty Clay

Angle of Shearing Resistance with Respect to Effective Stress, ϕ:	24.2°
Undrained Shear Strength, Effective Vertical Stress Ratio, S_u/σ_v:	1.0
Overconsolidation Ratio, OCR:	3.0
Cohesion Intercept in Terms of Effective Stress, c:	3.2

Stability Analysis (Infinite Slope Model):

Factor of Safety (undrained):	5.2
Factor of Safety (drained):	2.2

Geologic Factors:

Feature Sampled: Canyon Wall - Lower Slope

Faults: None

Gas: No appreciable amounts of gas above background levels detected in core

Additional Comments:

Small amount of disturbance of core.

Table 2 (continued)

Georges Bank Sample Sites: Slope Stability Analysis

Site Data:

Core No: PC-11 Block No: NK 19-11-240

Latitude: 39°44.35' Longitude: 68°56.26'

Water Depth (m): 2,225 Core Recovery (m): 7.57

Slope Angle, α: 0.8°

Geotechnical Data:

Texture: Silty Clay

Angle of Shearing Resistance with Respect to Effective Stress, Ø:	32.6°
Undrained Shear Strength, Effective Vertical Stress Ratio, S_u/o_v:	0.18
Overconsolidation Ratio, OCR:	No Data Available
Cohesion Intercept in Terms of Effective Stress, c:	0.7

Stability Analysis (Infinite Slope Model):

Factor of Safety (undrained):	57.3
Factor of Safety (drained):	45.8

Geologic Factors:

Feature Sampled: Intercanyon Ridge - Lower Slope

Faults: None

Gas: No appreciable amounts of gas above background levels detected in core

Additional Comments:

Moderate amount of disturbance of core sample. Piston core site is outside of proposed OCS North Atlantic Lease Sale 52 area. We presently have no HRG data coverage at this site.

CONCLUSIONS

Blocks on the continental shelf and rise which were tentatively selected for proposed OCS Oil and Gas Lease Sale 52 were found to be free of potential geologic hazards to exploratory oil and gas operations. However, geology related near-surface hazards were observed on a number of blocks on the continental slope. These potential hazards consisted of two occurrences of shallow gas and evidence of mass movement in eight tentatively selected blocks. Mass movements are believed to be the most serious and widespread potential hazard affecting hydrocarbon exploration and development in the proposed Lease Sale 52 area. The potential hazards and the blocks in which they occur are listed below. The listing is based on a literature search, a small number of sediment samples, and HRG data collected for Lease Sale 42 and proposed Lease Sale 52.

The geotechnical test results and analysis suggest that the surficial sediment cover within the proposed OCS Lease Sale 52 area is stable with respect to mass movement. Analysis of the plasticity characteristics of these sediments indicate that they reflect values characteristic of silty clays/clayey silts of medium to high plasticity. Evaluation of shear strengths, index properties, and consolidation states imply that the surficial sediments are normally consolidated to overconsolidated. All drained factor of safety values are greater than 1 for static slope condition.

Shallow Gas

NK 19-12-587, -708

Slumps or Slides

NJ 19-1-119, -120, -163, -164, -172, -173, -210, and -211

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