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Proceedings of the North Atlantic Submarine Canyons Workshop

February 7-9, 1989

Volume I
Synthesis Summary

U. S. Department of the Interior
Minerals Management Service
Atlantic OCS Region

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Proceedings of the North Atlantic Submarine Canyons Workshop

February 7-9, 1989

Robert E. Miller
Contracting Officer's Technical Representative

U.S. Department of the Interior
Minerals Management Service
Atlantic OCS Region

Vienna, Virginia

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16. Abstract (Limit: 200 words)

A three-day workshop on North Atlantic submarine canyons was held in February 1989. About 20 participants reviewed available information and made recommendations.

There are nine major submarine canyons along the southern flank of Georges Bank and several smaller ones. The canyons are unique habitats. Physical and biological features are complex and heterogeneous--within canyons and between canyons. Of the total, two canyons--Lydonia and Oceanographer--have been studied in detail. Lydonia is smaller, primarily low-energy, with deposition of fine-grained sediments. Oceanographer is larger, relatively high-energy, with erosional scouring and little deposition.

The canyon heads, particularly those with boulder fields and "pueblo villages," are habitats and nursery grounds for commercial species that include tilefish and lobsters. Attached filter-feeding faunas are common in some areas.

Metals and other contaminants from exploratory drilling are unlikely to cause environmental impacts beyond the vicinity of the wellsite. Many contaminants are in forms biologically unavailable to marine organisms.

An oil spill would primarily cause surface-layer impacts--affecting fish eggs and larvae. Water-column impacts are unlikely. Transport of oil to the bottom may occur, primarily in shallow water. Mechanisms are unknown, but may include adsorption onto sinking fine sediments and particles ("scavenging"), including krill fecal pellets. Chemical effects on settling larvae may be more important than physical effects on the benthos.

Recommendations and findings include: 1) no rigs within 500 m of canyon boundary; 2) worst-case calculations indicate contaminants from drill site unlikely to cause impacts; 3) produced water must meet discharge standards, with monitoring; and 4) there is insufficient information on possible impacts from gas blowouts.

Research needs included studies on sedimentary processes, canyon fisheries, additional canyon types, and studies linked to future drilling.

Revewers' comments, abstracts, an agenda, and an attendee list are appended.

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PREFACE

The purpose of this workshop was to provide a forum for the presentation and discussion of the available environmental information on the geological, biological, chemical, and physical characteristics of the North Atlantic Submarine Canyons which incise the continental shelf of the Minerals Management Service's North Atlantic planning area. This environmental information was presented by scientific experts from their respective fields.

The format of the workshop was designed to foster an open and free scientific exchange of ideas, and opinions, with the primary focus placed on reaching consensus with respect to the environmental effects of offshore petroleum exploration and development activities on these submarine canyon environments.

This report is organized into three major sections. The first section contains the formal papers that were presented during the first day of the workshop and the follow up questions and answers. The second section consists of the roundtable discussions held on the second day focusing on the geology and geochemistry, and biological communities of the North Atlantic submarine canyons. The third section is the Final Summary Synthesis and Conclusions reached by the workshop panel members.

This workshop was sponsored by the Atlantic OCS Regional Office of the Minerals Management Service.

ACKNOWLEDGEMENTS

The Minerals Management Service wishes to express its sincere appreciation to each of the workshop participants without whose diligence and cooperation, this workshop effort would not have been possible. Further expressions of gratitude are due to the Walcoff and Associates project staff for their support in the coordination and logistics of the workshop, and especially to the senior rapporteur, his staff, and the court reporter for their preparation of the workshop summary synthesis and conclusion volume, and the transcript.

Grateful appreciation is also extended to the members of the Minerals Management Service's Branch of Environmental Studies and the Atlantic Region OCS Environmental Studies Unit. Their cooperation and assistance prior to and during the workshop aided significantly in the successful completion of this deliberative approach to the resolution of complex and controversial environmental issues.

Robert E. Miller, Ph.D.
Atlantic Region OCS
Minerals Management Service

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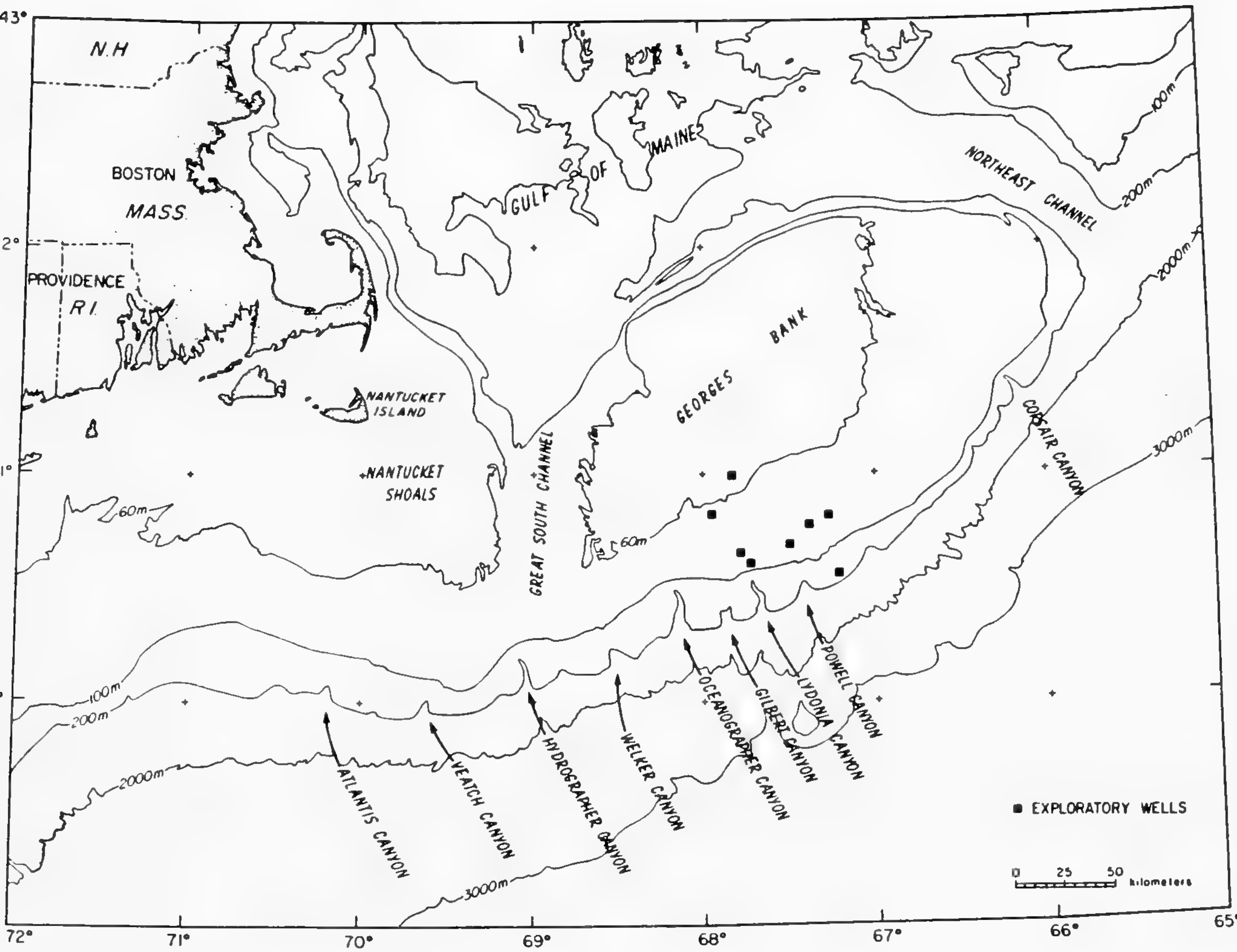

Figure 1. The nine major submarine canyons along the southern flank of Georges Bank--the subject of the North Atlantic Submarine Canyons Workshop. Not shown are several smaller canyons, such as Heeltapper and Dogbody. The eight squares on Georges Bank are the locations of the eight exploratory wells drilled in 1980 and 1981.

INTRODUCTORY REMARKS:
THE VIEW OF THE MINERALS MANAGEMENT SERVICE
ENVIRONMENTAL STUDIES PROGRAM

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and
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The goal of this workshop on North Atlantic submarine canyons is to provide a forum for the synthesis and dissemination of available information on submarine canyons of the North Atlantic and for discussion by scientific experts and concerned parties. This presentation and discussion will lead, it is hoped, to identifying the points of agreement, points of disagreement, and recommendations. The foregoing will focus largely on technical material, but will not exclude policy aspects.

A NEW APPROACH

This workshop represents a new approach for the Environmental Studies Program. About 2 years ago, during a studies planning session, it was recognized that additional field studies in canyon head areas would not necessarily provide new data or resolve outstanding questions. What was more important was to disseminate existing information and foster discussion. This was consistent with a recent audit of the Minerals Management Service (MMS) Environmental Studies Program by the General Accounting Office--which was generally favorable to the program, but which suggested the need for improved information transfer and dissemination.

Studies on North Atlantic submarine canyons had been underway for some time, data were available, and a number of publications on the topic had recently been completed. For this reason, submarine canyons were identified as an appropriate topic for a new studies program approach--that of focusing a workshop on a given topic.

THE ENVIRONMENTAL STUDIES PROGRAM

Historically, the role of the Environmental Studies Program has been contracting for studies aimed at acquiring field and laboratory data and for literature summaries or bibliographies. The scientific studies and literature summaries are designed to:

- enhance the leasing process by providing information for prediction of impacts,
- provide information on ways impacts to human, marine, biological, and coastal environments can occur,
- ensure that available information is in a form useful to decision makers, and
- provide a basis for future monitoring of Outer Continental Shelf (OCS) activities.

We no longer need to focus entirely on these traditional types of studies, but need to do more with risk perception and communication. At present, there is a growing trend toward synthesis reports and open-forum discussions.

WORKSHOP HYPOTHESES

To provide a basis for the workshop and to stimulate discussion, two hypotheses were proposed:

1. In submarine canyons of the North Atlantic margin where erosional environments exist, the probability of serious environmental impact to faunal assemblages from oil and gas activities in the vicinity of canyon heads is low, and

2. In submarine canyons of the North Atlantic margin where depositional environments may exist, the rate of accumulation of drilling-related contaminants from oil and gas activities is slow enough not to present serious environmental risks to faunal assemblages in the canyon heads.

To enhance exchange, the number of participants was limited, although a number of observers have been accommodated.

NEW STUDIES?

Although much information is in hand, new studies are not ruled out. While the program is not necessarily soliciting recommendations for new studies, if there are technical issues that could be resolved through scientific studies, a recommendation would be appropriate. Any new study would need to be focused on an issue that can be resolved or narrowed, and objectives, timing, needs, and users of the information must be clearly identified.

FACTS AND VALUES

The focus of the workshop is on science, and the facts that support the conclusions. A purpose of the workshop is to separate out value judgments from the Environmental Studies Program. We can analyze elements of the risk involved, but cannot decide if such risk is acceptable. The studies program is not involved in making value judgments. This is a separate issue, and left to decision makers and managers.

RESOLVING ISSUES

The Congress has in place a moratorium on leasing in submarine canyons and in depths out to 400 m. This action was recognized at the outset as a stopgap measure, and with evaluation of facts and deliberation, at least some of the complex environmental issues may be resolved. The workshop organizers are hoping for some level of consensus. Where this is not possible, mechanisms such as minority reports are possible.

In closing, it is important to state that it is the aim of the workshop to provide a forum where members may draw conclusions without undue bias or pressure from MMS.

PRE- AND POST-DRILLING BENCHMARKS AND MONITORING DATA ON OCEAN FLOOR FAUNA, HABITATS, AND CONTAMINANT LOADS IN THE GEORGES BANK SUBMARINE CANYONS

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The biology and geology of 18 submarine canyons of the northwest Atlantic was investigated by diver scientists, using manned submersibles, from 1973 through 1984. This effort entailed in-situ studies in 18 canyons ranging from Corsair, Georges, Nygren, Powell, Lydonia, Gilbert, Oceanographer, Filebottom, Hydrographer, and Veatch off Georges Bank to Atlantis, Block, Hudson, Toms, Wilmington, Baltimore, Washington, and Norfolk off southern New England and the Mid-Atlantic Bight. We concentrated on the canyons of Georges Bank and those immediately to the southwest. The principal motivation was fisheries assessment and habitat definition, including associated megabenthos. We were concerned particularly with the canyon heads.

From 1980 through 1984 scientists from several New England research institutions--National Marine Fisheries, U.S. Geological Survey, and National Undersea Research Center--conducted a before-, during-, and post-drilling study of the species abundance, community structure, animal-substrate relationships, and body-substrate burdens of trace metals, polychlorinated biphenyls (PCBs), and hydrocarbons within and downstream of oil and gas exploration areas on the south central portion of Georges Bank including Lydonia, Oceanographer, and Veatch Canyons.

Ocean floor stations at specific sites (marked with a 37-kHz pinger) were established in Lydonia Canyon (head of canyon and west wall) in 1980 and in Oceanographer Canyon (head and west wall) and Veatch Canyon (west wall) in 1981 and 1982. Photo and video transects were made in July, along transects oriented north, south, east, and west of the station marker. Estimates of species abundance and community structure were made by habitat type. We also collected surficial sediment samples, and animal samples (tilefish, scallops, lobsters, and Jonah crabs) for tissue analysis.

We have classified the habitats of the canyon region as follows:

- Type 1: Flat, featureless, with less than 5 percent overlay of rock and gravel; accounts for approximately 60 percent of canyon heads.

- Type 2: Similar to Type 1, but with more than 5 percent overlay of gravel and rock; about 10 percent of canyon head area.

- Type 3: Boulder field, highly productive of fishery resources; occupies about 5 percent of canyon head area.

- Type 4: "Pueblo Village" environment; very important in fisheries; accounts for some 20 percent of canyon head area.

- Type 5: Sand dune and sand wave environment of the canyon axis; occupies less than 5 percent of the canyon head area.

Canyons function as important nursery grounds for a wide variety of megabenthic fauna such as shrimps, cancer crabs, lobsters, white hake, cusk, ocean pout, conger eel, tilefish, black-bellied rosefish, etc. They provide shelter that rarely occurs in noncanyon areas of the outer shelf and upper slope for the adults of some 20 species. Our combined canyon studies show that the surficial geologic features of the canyon heads support unique ecosystems, largely because of their highly varied character.

We conclude that submarine canyons are complex three-dimensional environments where there is little, if any, impact from active fishing gear; they serve as refugia for many bottom-oriented species. Species diversity and abundance are greater in canyons than in noncanyon areas at comparable depths.

Habitat diversity on a scale of a few meters to several kilometers leads to species diversity.

Surficial sediments at each benchmark station were analyzed for trace metals (barium, cadmium, copper, chromium, lead, mercury, and zinc), hydrocarbons (aromatic and aliphatic), and PCBs. Scallops (muscle and viscera), cancer crabs (hepatopancreas, claw/tail tissue, and eggs), and tilefish (dorsal musculature) were subjected to the same analyses. Sediment and animal-bound PCBs were below the levels of detection (0.005 ppm) prior to drilling; subsequent analyses were not made (PCBs are not a component of drilling muds and cuttings). Concentrations of petrogenic hydrocarbons (FI, FII) were all undetectable before and after drilling. Trace metal concentrations in the surficial sediments and in crabs and lobsters remained relatively constant over time.

We did not find any effects from exploratory drilling. Since no impacts were identified, this five-year data base is considered an appropriate benchmark for future drilling operations.

Routine monitoring across habitat types from surface vessels appears to be a waste of time. Examination of the benchmark data on annual variation in species abundance, specifically for 14 designated key "indicator species," suggests that no one species is likely to reflect anything but a major impact from production drilling. We suggest that community composition be examined in a "site-specific" manner, that is, by habitat type and specific location, in order to define faunal benchmarks for future oil and gas exploration.

THE LYDONIA CANYON EXPERIMENT: CIRCULATION, HYDROGRAPHY, AND SEDIMENT TRANSPORT

Dr. Bradford Butman
U.S. Geological Survey
Branch of Atlantic Marine Geology
Woods Hole, MA

A field program (Butman 1988) was conducted to study the circulation and sediment dynamics in Lydonia Canyon, located on the southern flank of Georges Bank, and on the adjacent continental shelf and slope (Figure 2).

Its objectives were:

- to describe currents in Lydonia Canyon and the adjacent shelf and slope, primarily in depths shallower than 1,500 m,
- to explore the role of canyons in transporting sediments onto or off the shelf,
- to see whether canyons are sinks for fine grain sediments, and
- to compare Lydonia Canyon and Oceanographer Canyon.

The program included (1) in-situ measurements by an array of moored current meters, bottom tripods, and sediment traps maintained between November 1980 and 1982; (2) synoptic observations of the hydrography and suspended sediments; (3) sidescan-sonar and high-resolution seismic reflection surveys; (4) samples of the surficial sediments; and (5) direct observations of the sea floor from the submersible *Alvin*.

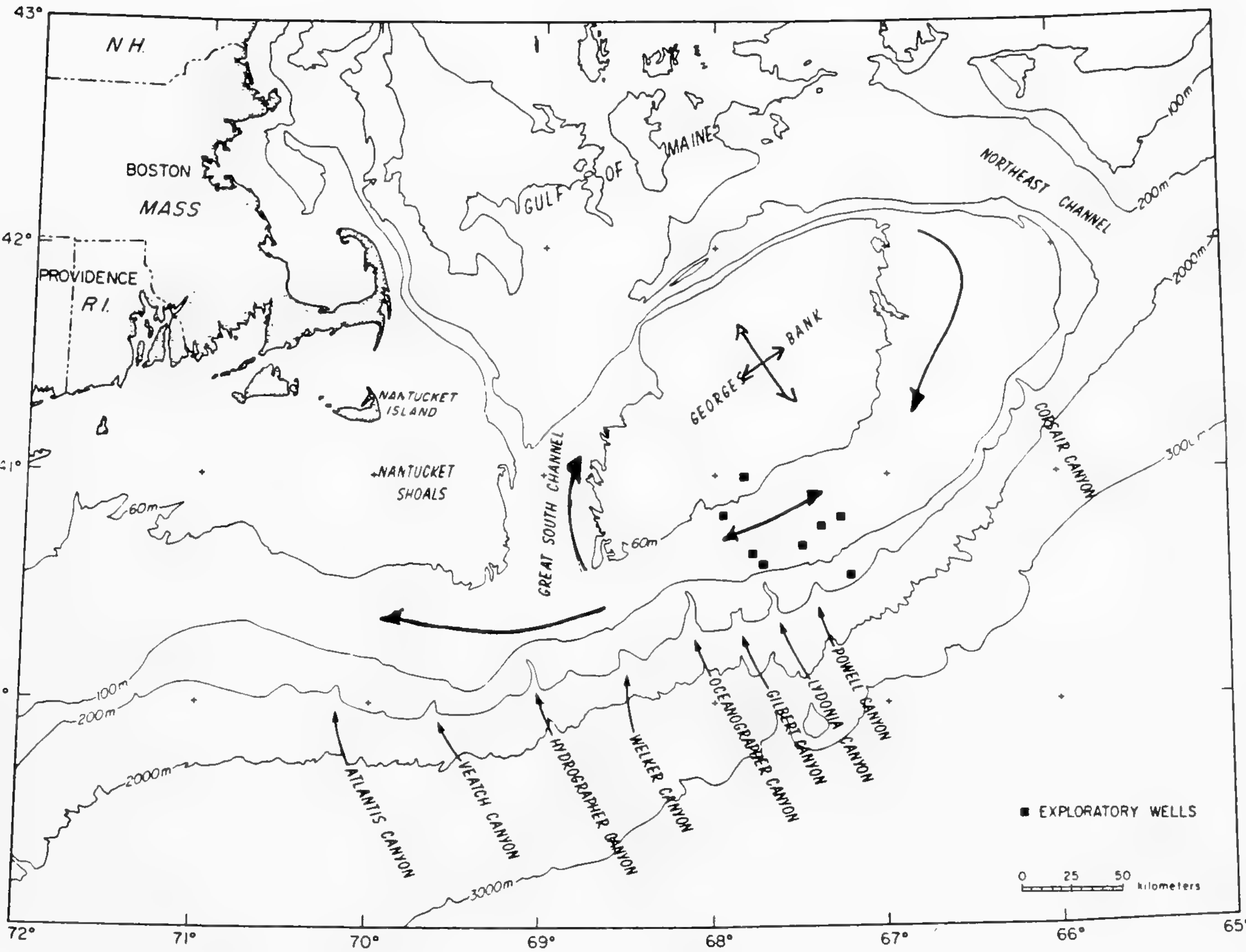

Figure 2. Georges Bank and currents. The principal canyons of Georges Bank and the southern New England shelf. Bold arrows indicate net nontidal circulation and the crossed two-headed arrows the major and minor axis of the tidal currents. Two-headed arrow on the southern flank indicates orientation of storm currents. Squares show locations of the eight exploratory wells drilled on Georges Bank.

WATER CIRCULATION

The mean Eulerian current (that is, current measured at a fixed point) was southwestward on the shelf adjacent to Lydonia Canyon and above the level of the canyon rim at speeds of 5 to 10 cm/s. This southwestward flow parallel to the isobaths is consistent with previous descriptions of the mean circulation on Georges Bank.

On the continental slope, mean flow was strongly influenced by Gulf Stream warm-core rings (Figure 3). Several rings passed to the south of Lydonia Canyon during the observation period; the strong clockwise flow around them caused eastward flow along the edge of the shelf as strong as 80 cm/s. There is some evidence that the warm-core rings affect flow in the canyon by generating packets of high frequency current fluctuations. On the slope, the influence of the rings in the water column extended to at least 250 m, but not to 500 m. The influence of the rings did not extend onto the continental shelf in water depths of 125 m.

Over the slope, there was a persistent off-shelf and down-slope component of flow near the bottom of a few centimeters per second. Within the canyon, the mean Eulerian flow near the bottom was complex (Figure 4). Near the head of the canyon, at 300 m, net Eulerian flow 5 meters above bottom (mab) was down-canyon at about 3 cm/s and was weak at 50 mab. At 550 m, the near-bottom flow was up-canyon. At 600 m, the near-bottom flow was weakly up-canyon; the flow at 100 mab was down-canyon. These observations suggest a convergence of the mean Eulerian flow between 300 and 600 m and possibly several cells of recirculation along the canyon axis. However, because of the energetic, nonlinear, high-frequency motion observed in the canyon and the small spatial scales, the mean Eulerian current may not indicate the actual Lagrangian water-particle motion. Further analysis is required to determine the Lagrangian circulation pattern.

Measurements made on the eastern rim of the canyon at about 200 m show westward flow directly across the canyon axis. Measurements on the eastern

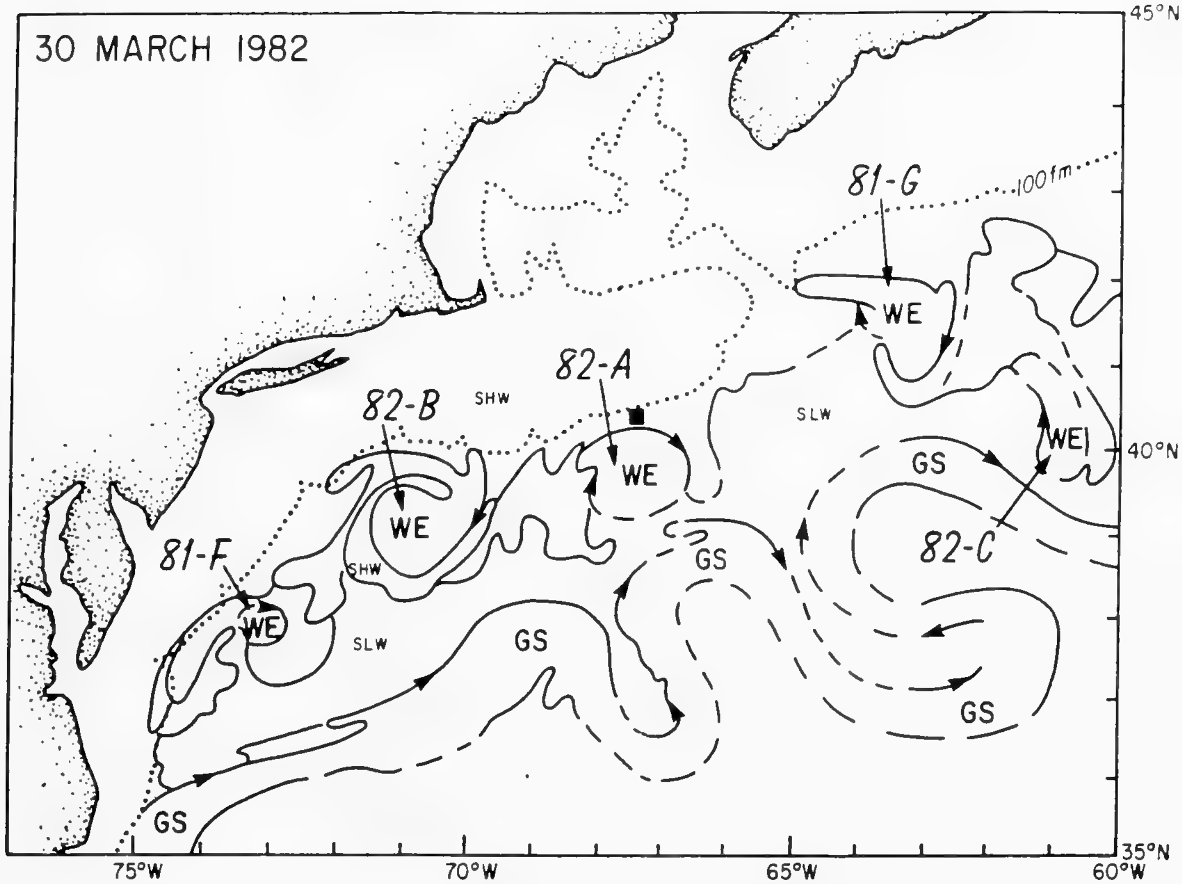

Figure 3. Gulf Stream rings. Position of the north wall of the Gulf Stream and five warm core rings in late March 1982 based on satellite imagery. Ring 82A lies just to the south of Lydonia Canyon. When these rings are close to the shelf break, the strong clockwise circulation around them causes eastward flow along the outer edge of the shelf. In the absence of rings, currents over the shelf and over the canyon are westward.

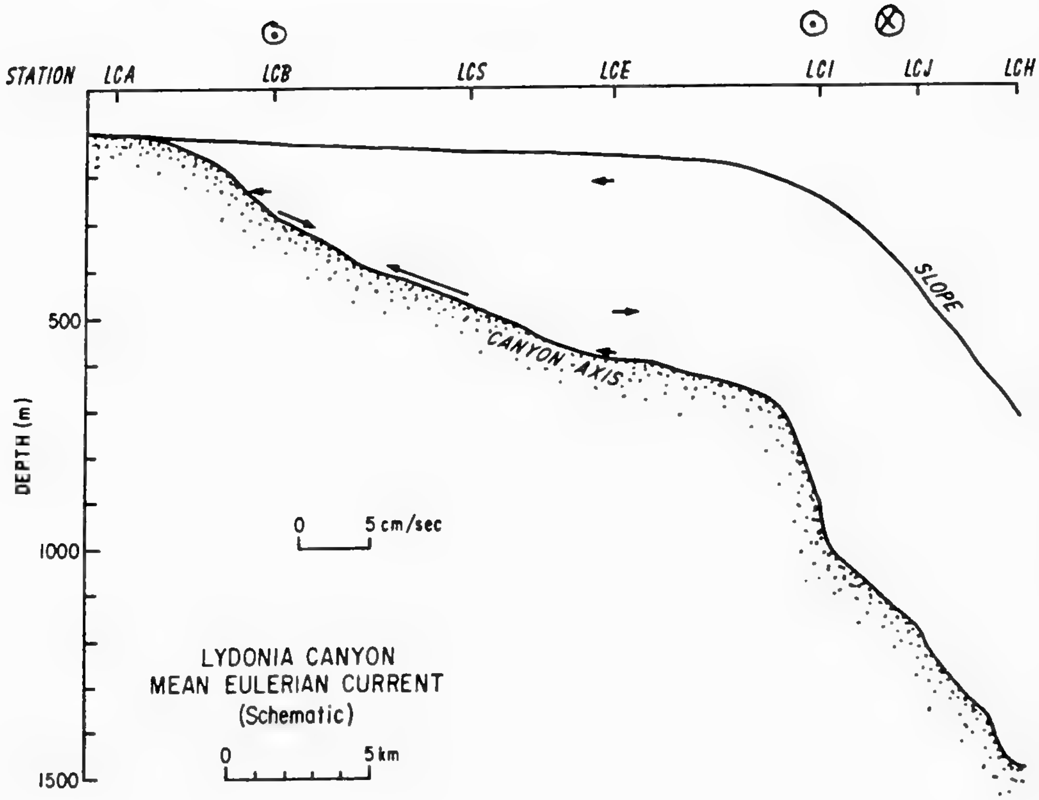

Figure 4. Mean Eulerian current. Schematic map showing the general direction of the mean Eulerian current near the bottom in the axis of Lydonia Canyon and over the adjacent shelf and slope. Note that the net is down-canyon near the head and up-canyon at about 450 m, suggesting a convergence toward the head. Over the shelf and slope, circled dots indicate westward flow (out of the page toward the reader) and circled x's eastward flow (into the page away from the reader). Over the outer edge of the shelf and slope, eastward flow is associated with the presence of warm-core rings (see Figure 3).

wall of the canyon, just a few kilometers away at comparable depths, show northward inflow along the eastern wall. On the western wall, flow was southward. The mean Eulerian currents in the canyon thus suggest a complex vertical Eulerian circulation along the axis and horizontal exchange along the canyon walls.

The current fluctuations with the canyon are aligned with the canyon axis. The strength of the high-frequency fluctuations (motions with periods shorter than about one day) increase toward the bottom and the head of the canyon. The low-frequency currents (motions which fluctuate at periods longer than about two days) were strongest over the slope and weakest in the canyon. Along-shelf current fluctuations over the shelf were correlated with cross-shelf flow over the canyon mouth (offshelf for southwestward flow), suggesting enhanced cross-shelf exchange in the region of the canyon. Fluctuations at semidiurnal periods dominate the current spectra. Near the canyon head, their strength changes substantially with time, indicating random generation of internal wave packets.

Similar studies in nearby Oceanographer Canyon show that currents there are dominated by tidal currents and are stronger than in Lydonia Canyon. Net Eulerian down-canyon flow was observed at both 200 and 600 m.

Kinetic energy spectra clearly show different current regimes on the shelf and slope and in the canyon (Figure 5). With these spectra, the current fluctuations can be conveniently separated using the periods at which they oscillate into low-frequency flows (periods of more than 30 hr), tidal currents (diurnal and semidiurnal), inertial fluctuations, and high-frequency motions (periods of 2 to 10 hr).

On the shelf and slope, there is a large energy component at lower frequencies (2 days or more) and the fluctuations are oriented along isobaths. Low-frequency currents within the canyons are oriented along the axis and are weak. At all stations, there was an energy peak correlated with semidiurnal tides. In the canyons, the amplitude of the tidal, inertial, and high-

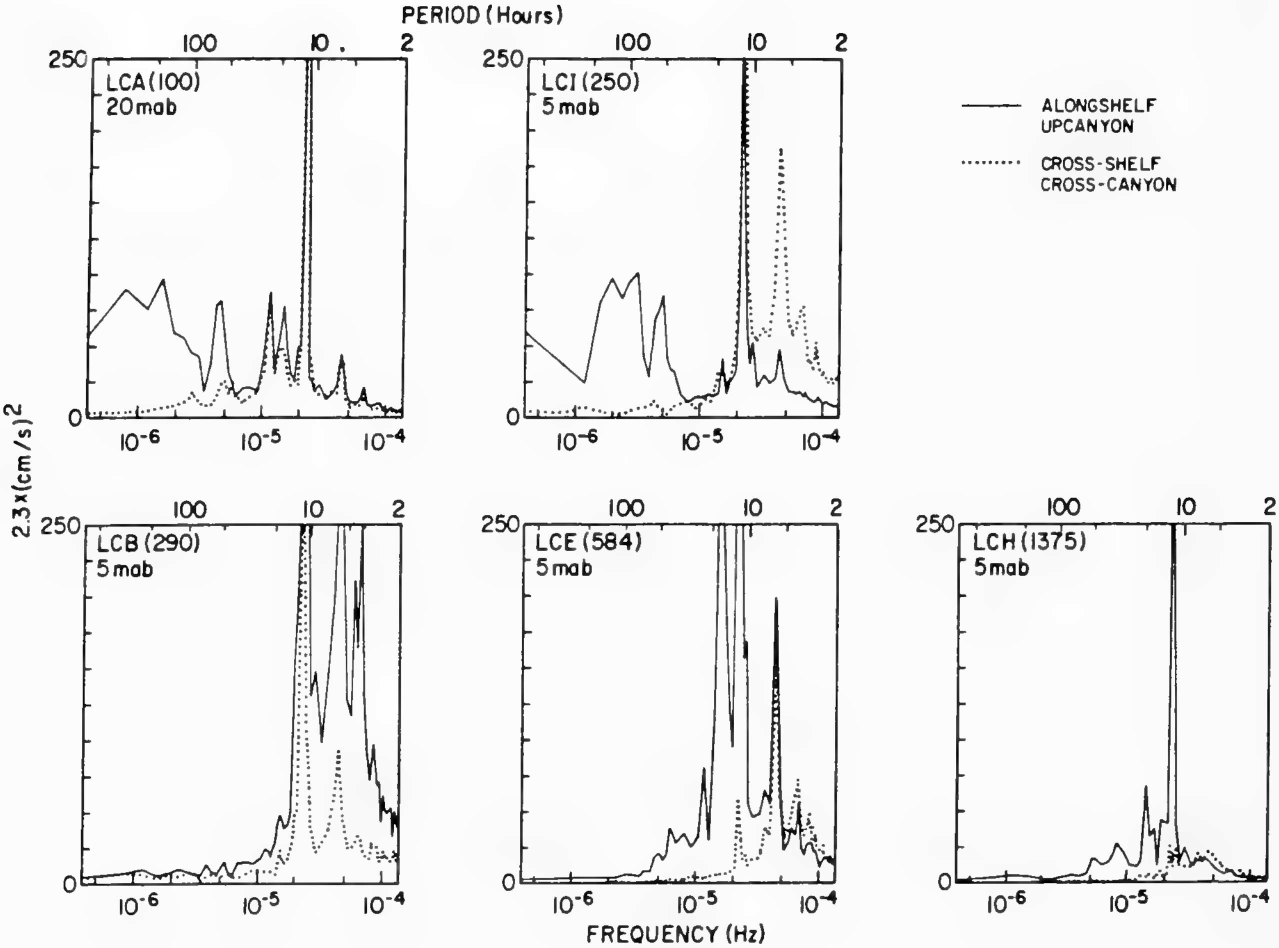

Figure 5. Kinetic energy spectra of near-bottom currents on the shelf (station LCA) and slope (station LCI) adjacent to Lydonia Canyon (resolved into alongshelf and cross-shelf) and along the canyon axis (stations LCB, LCE, and LCH, resolved into along-canyon and cross-canyon currents).

frequency motions varied along the canyon axis (Figure 6). There was a clear increase in high-frequency (2 to 10 hr) motions toward the canyon head. The Lydonia Canyon region is one of the few areas of the shelf where all frequencies are important in describing the system.

SEDIMENT TRANSPORT

Distribution of surficial sediments and high-resolution seismic reflection data suggests that very fine sand and silts and clays accumulate in the head of Lydonia Canyon and on areas of the adjacent shelf. There is little silt-plus-clay on the crest of the bank where currents are strong, but as much as 75 percent of the total sediment is located on the slope where currents are weaker (Figure 6). The data suggest a depositional environment surrounding the canyon head.

Silt-plus-clay content in the surficial sediments generally increased with depth along the canyon axis (Figure 6). This overall trend was interrupted at 300 to 400 m, where there is 30 to 40 percent silt-plus-clay. At 500 m, sediments get coarser. Finally, farther down the canyon, sediments get finer again. These distributions mirror current strengths: coarse sediments where currents are strong, fine sediments where they are weaker. However, current, sediment trap, and beam attenuation measurements show that surficial sediments are reworked and suspended along the canyon axis to a water depth of at least 600 m. Thus, although the texture suggests that fine sediments may be accumulating, the axis is not tranquil at depths less than 600 m.

The Georges Bank canyons are complex topographically, with steep walls that are vertical in places. One must consider not only sediment types on the canyon floor but also on the walls, which change in character from the deeper to the shallower parts.

Near-bottom current measurements on the slope from Baltimore Canyon to Georges Bank (Csanady et al. 1988) show that, below 500-m water depth

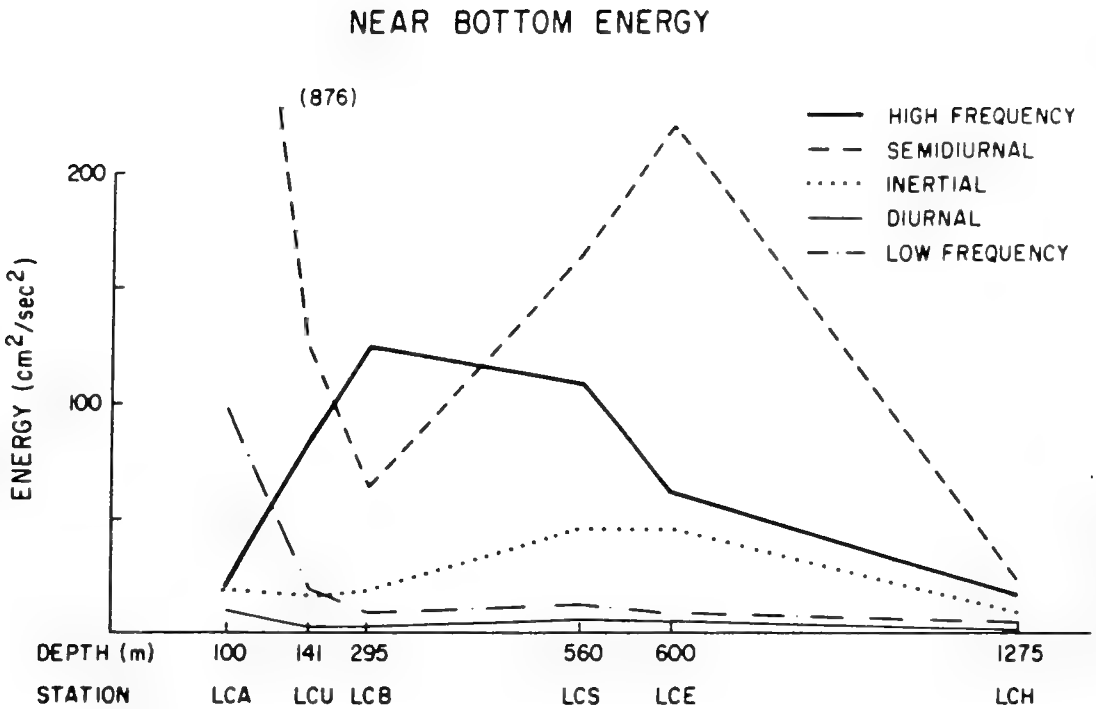

Figure 6. Spatial distribution of energy in the near-bottom currents along the axis of Lydonia Canyon. The amount of energy in five frequency bands (high frequency, semidiurnal, inertial, diurnal, and low frequency) changes along the canyon axis, presumably as a result of changes in the density field, bottom slope, and incident energy.

(depositional environment), currents exceed 20 cm/s only about 5 percent of the time, and are less than 5 cm/s 40 percent of the time (Figure 7). On the slope, the 300- to 500-m isobaths are an approximate transition zone between an erosional and a depositional environment. In Lydonia Canyon and Oceanographer Canyon, the currents at 300 and 500 m exceeded 20 cm/s at least 30 percent of the time. For these canyons, at the depths observed, currents are much stronger than on the adjacent slope. Profiles of beam attenuation compared sediment concentrations in the canyon and the adjacent shelf and slope. In the canyons, suspended sediments were always greater than on the slope at comparable depth. Suspended sediments increased near the bottom, especially near the canyon head, presumably due to bottom resuspension.

LYDONIA AND OCEANOGRAPHER CANYONS COMPARED

Both Lydonia Canyon and Oceanographer Canyon are complex environments where there are rapid changes (over a few hours) in suspended sediment concentration, temperature, current velocity, and direction. The two canyons differ in sediment texture, current strength, and direction of net flow. In Oceanographer Canyon a net down-canyon flow was observed at 300 and 600 m. Above about 500 m in Lydonia Canyon, currents exceed 20 cm/s 20 to 30 percent of the time; in Oceanographer Canyon, they exceed this rate 40 to 60 percent of the time (Figures 8 and 9). Based on the coarse-grained sediments and stronger currents, the head of Oceanographer Canyon is primarily erosional, whereas Lydonia Canyon has areas both of erosion and deposition. Both canyons are much more energetic than the adjacent slope. Though the erosional/ depositional classification of canyons is important in analyzing the hypotheses of this workshop, it is important to recognize that this classification is an extreme simplification.

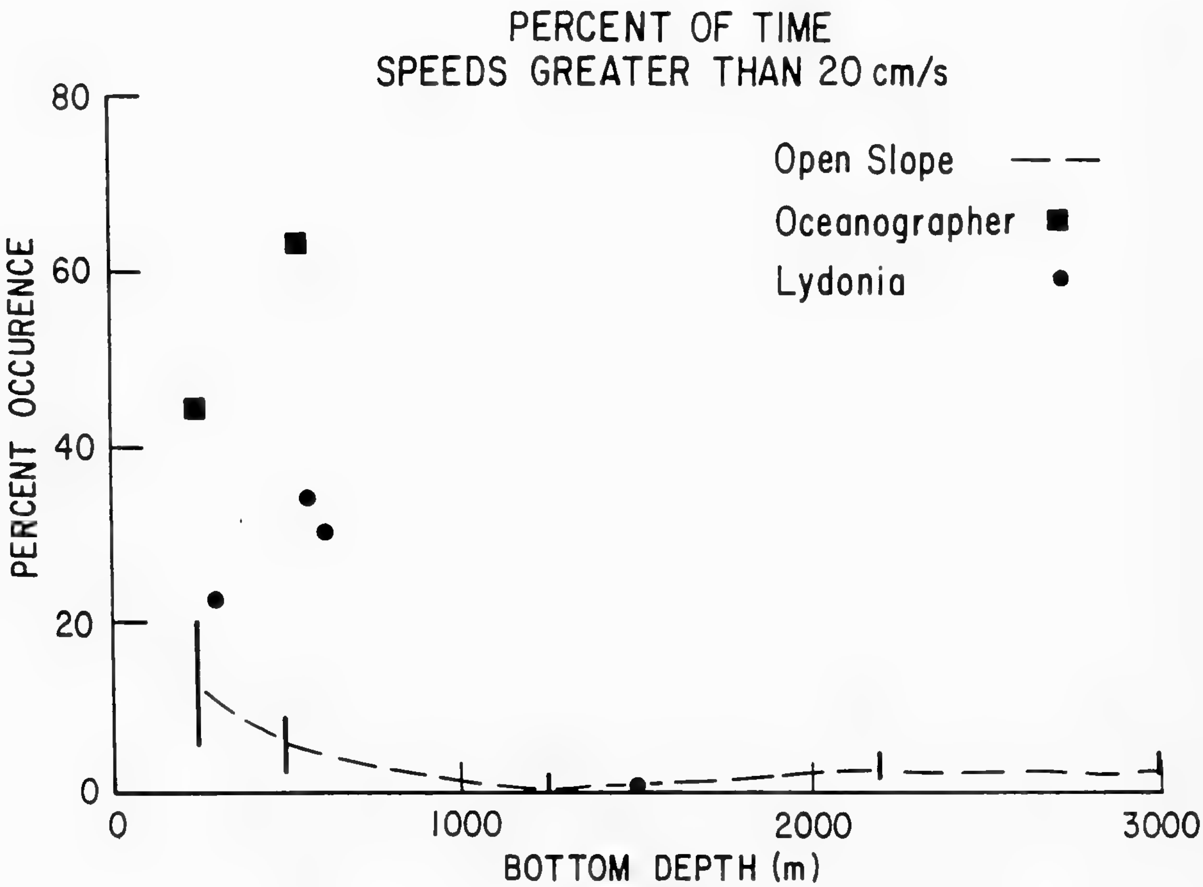

Figure 7. Percent current exceeds 20 cm/s. The percentage of time during which the near-bottom currents exceed 20 cm/sec in Lydonia and Oceanographer Canyon and over the adjacent slope. The currents are much stronger in these two major canyons at water depths less than 500 m than at comparable depths on the slope, suggesting a more erosional environment (adapted from Csanady et al. 1988).

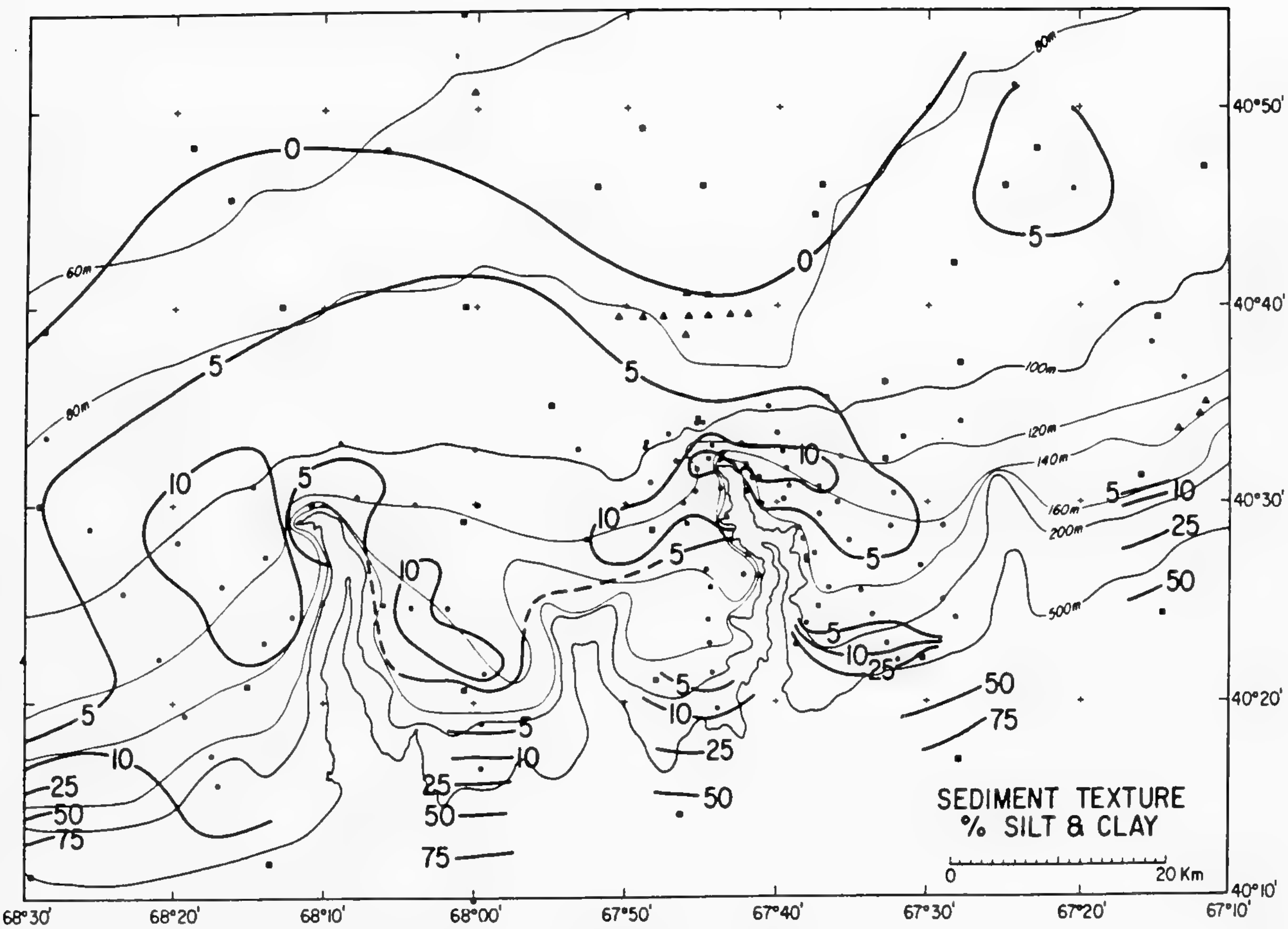

Figure 8. Percent fine sediments (silt-plus-clay) in the surficial sediments on the shelf and slope adjacent to Lydonia and Oceanographer Canyons. Symbols indicate location of samples from various field experiments. Texture within the canyons not contoured. Note the increase in fine-grained sediments in lobes to the east and west of Lydonia.

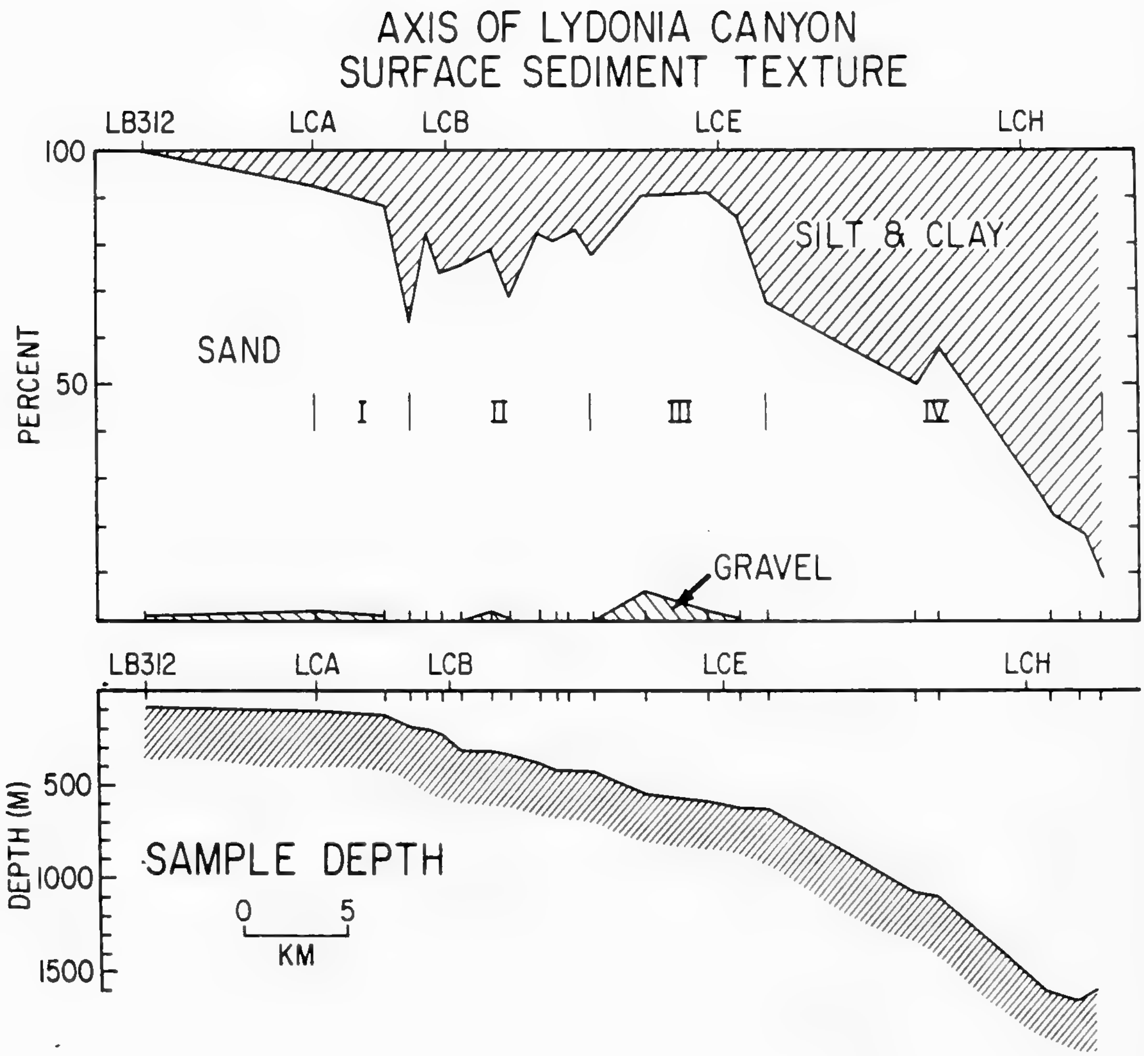

Figure 9. Surficial sediment texture along the axis of Lydonia Canyon. Percentages of fine (silt-plus-clay), medium (sand), and coarse-grained (gravel) sediments along the axis of Lydonia canyon and the adjacent shelf (upper panel). The lower panel shows the depths of the samples. Note the increased fines near the head of Lydonia Canyon (station LCB) and the coarser sediments near LCE where the currents are slightly stronger. The fine sediments near the head are where Bothner measured accumulation rates of about 50 cm/1,000 yr. The mean Eulerian current measurements suggest a convergence of the flow toward the head.

QUESTIONS

Teal asked why Oceanographer and Lydonia Canyons are so different. Butman responded that the current strength in the canyon depends on geometry (wall slope and bottom slope) and the density structure in the water column. These parameters control the propagation and intensification of energy near the bottom. In some canyons, the bottom slope and water density may intensify currents toward the canyon head. In other cases energy will be reflected back out of the canyon. In Oceanographer Canyon and Lydonia Canyon there appears to be a difference. It is a complex oceanographic problem, and there has been little attempt to model the propagation of energy through the canyon using realistic topography and density.

Boehm asked why silt gets deposited around the canyon head on the shelf. Butman responded that he didn't know. The thickness of the silt-plus-clay near the canyon head is relatively thin.

Teal asked whether there were any severe events during the study. Butman answered no and that, for the two year observational period, any two-to-four months were representative of the remaining months. There was very little variability in low frequency energy fluctuations but a large change in the high frequencies. There was some correlation between the occurrence of warm-core rings at the canyon mouth and the strength of the current fluctuations at the canyon head. Flow in the canyon was generally not correlated with flow on the shelf.

Kraeuter asked where the sediments were coming from. Butman responded that they apparently come from the shelf. Some sediments from the middle part of the canyon may be transported toward the head. This is a rate problem. However, the present study has been process-oriented and does not specifically address rates, though rates are important to the hypotheses in question.

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SEDIMENTARY ENVIRONMENTS IN SUBMARINE CANYONS AND ON THE OUTER SHELF - UPPER SLOPE OF GEORGES BANK

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Sedimentary environments have been identified on the southern margin of Georges Bank in the depth range of 150 to 600 m on the basis of sedimentary texture, bedforms, and direct current measurements. Dominantly erosional vs. depositional environments are identified for the outer shelf, upper slope, and submarine canyons along the southern margin of Georges Bank. Studies conducted in Oceanographer, Lydonia, and other canyons suggest that it is possible to predict sedimentary environments in unstudied canyons based on overall canyon morphology and by analogy with the known distribution patterns of canyon sedimentary environments.

SHELF ENVIRONMENT

Georges Bank is an isolated shoal, separated from continental sediment sources by the Northeast Channel, Great South Channel, and the Gulf of Maine. The mean regional flow field is clockwise around Georges Bank. The bank surface is erosional; fine sediments winnowed from the bank top are delivered to bank-edge environments. Coarse sands and gravels found near-bottom current maxima on the bank grade to finer sands and mud along the southern margin.

At the shelf edge, rippled sand gives way to smoother and finer-grained sand deposits as water depth increases on the upper slope. Submarine canyons of varying size and wall steepness incise the Georges Bank shelf and contain such sedimentary facies as pavements of ice-rafted gravel, bioeroded and collapsed Pleistocene silt outcrops, mobile sands, and almost featureless silty sands.

SLOPE ENVIRONMENT

The upper slope east of Oceanographer Canyon, to a depth of 200 m demonstrates normal downslope textural gradients related to bottom current energies. By contrast, the upper slope between depths of 200 to 300 m is erosional in nature with little silt or clay present. Below 300 m, silt and clay content increases steadily downslope to the heads of small gullies found at 500 m. The interval below 300 m is depositional and includes the floors of small slope canyons such as Filebottom Canyon, which is covered with silty sand. The lack of deposition in the 200- to 300-m interval is attributed to strong, northeastward-flowing bottom currents of Gulf Stream warm-core rings that intersect the upper slope environment. Nineteen warm-core rings impinged on the Georges Bank margin in the Oceanographer-Lydonia Canyon region between 1976 and 1983. The upper slope was influenced by the clockwise flow of these eddies for a total of 17 months during this 8-year period. Current velocities of 50 to 60 cm/s (about 1 kt) effectively removed most fine sediment during this interval.

CANYON ENVIRONMENTS

Sedimentary facies related to bottom currents were investigated in and around several canyons on the southern margin of Georges Bank. These facies are related to the overall morphology and energetics of the two canyons and the sediment sources. The most extensive observations have been made in Oceanographer and Lydonia Canyons. Gravel deposits and mobile sands are found along the eastern rims of both canyons, and they are best developed along the northeastern side of Oceanographer Canyon. A strong bottom current of unknown origin flows westward at about 50 cm/s across the rims of both canyons at depths of 150 to 200 m, transporting shelf sand across deposits of ice-rafted gravel onto the east canyon walls.

Oceanographer Canyon walls are steep in places, with extensive bioeroded outcrops of Pleistocene silt. Sediment that is spilled over the canyon rim combines with silt eroded from the canyon walls and is transported downslope to the canyon floor. The floor is covered by coarse sands which are mobilized into both large and small asymmetric bedforms. Ripples, megaripples, and sand waves are present in the axial area down to at least 750 m. Analysis of bedform shape indicates that sand is moved both up and down the canyon axis with no net transport direction for sand. Silt and clay is winnowed by the strong currents. Maximum current velocities measured in the axial area of Oceanographer Canyon range between 75 and 100 cm/s. The floor of Oceanographer Canyon is predominantly nondepositional with regard to fine sediments.

The depositional facies of Lydonia Canyon are more complex but generally contain silt and clay deposits both on the canyon walls and in the axial area. Current velocities within this canyon are reduced relative to Oceanographer Canyon.

Small, shallow canyons such as Heeltapper are relatively tranquil, and like the upper slope, canyon floors are covered by silting sand.

CANYON MORPHOLOGY, CURRENTS, AND SEDIMENT TRANSPORT

The outer continental shelf and slope areas adjacent to and including Oceanographer and Lydonia Canyons can be characterized in terms of sediment transport and current strength. Areas of high sediment transport include the eastern rims of both canyons and the axis of Oceanographer Canyon down to 750 m. Areas of moderate sediment transport include the walls of both canyons and the mud-free interval of the upper slope swept by warm-core rings. Areas of low net sediment transport include most of the head and axis of Lydonia Canyon, the small canyons, and the continental slope below 300 m.

The data from the southern slope of Georges Bank suggests that the energetics of bottom currents found within the canyons are directly related to the overall canyon morphology. Large, long canyons with deep mouths at the shelf break (the 200-m isobath) and steep walls interact with the tidal flow regime to strengthen the bidirectional currents within the axial area.

Moderate size canyons with shallower mouths and less steep walls have weaker bidirectional flows. Small shallow canyons and gullies are low energy depositional environments. Because sediment transport and bottom facies are generally well-correlated with current energy, the results from studies of Lydonia, Oceanographer, and other canyons can be used to predict bottom facies, sediment transport regimes, and depositional vs. erosional areas for other canyons on the southern margin of Georges Bank (Table 1). High energy canyons include Oceanographer, Hydrographer, and Gilbert. Moderate energy canyons are Lydonia, Powell, Welker, and Veatch. Low energy canyons include Atlantis and Heeltapper.

In general, sediment movement is more rapid in a narrow band along the upper slope, along the lower walls and floors of large, high-energy canyons, and from the shelf westward across the eastern rims of large and medium canyons. Sediment movement is less rapid on the outer shelf, on most of the upper slope, including the gullies, on the floors of medium and small canyons, and on the shelf around some canyon heads. A moderately energetic canyon of medium size such as Lydonia may be accumulating sediment most rapidly. The movement and resuspension of fine-grained sediment on the floor of Lydonia Canyon is substantial. However, the canyon traps a large volume of shelf sand as well as bioeroded silt from outcrops on lower canyon walls, and sediment is accumulating on its floor.

Table 1. Sedimentary facies and sediment transport regimes for rims, walls, and floors of high, moderate, and low energy canyons along the Outer Continental Shelf of Georges Bank. LGH = canyon length landward from the canyon mouth at the shelf break (200-m isobath); DPH = depth from canyon rim to floor at the canyon mouth; ANGL = slope angle of lower canyon walls at the canyon mouth.

HIGH ENERGY CANYONS:		LGH: 13-25 KM DPH: 750-1000 M	ANGL: 15-35°
RIM:	SHELF SAND+GRAVEL, RIPPLED	SAND IN TRANSIT TO WALLS	TIDAL CURRENTS,
	GRAVEL [EAST RIM]	STATIONARY	WESTWARD CURRENT
	VERY FINE SAND	DEPOSITED AT CANYON HEAD (FROM CANYON?)	
WALLS:	MANY SILT+CLAY OUTCROPS	EXTENSIVE BIOEROSION	
	MIXED SHELF SAND AND SILT+CLAY, RIPPLED	IN TRANSIT TO FLOOR	AXIAL(?) CURRENTS
FLOOR:	SAND, RIPPLED, MANY LARGE BEDFORMS	TRANSPORTED UP-DOWN CANYON; FINES SEPARATED; SAND DEPOSITED	STRONG SEMI-DIURNAL AXIAL CURRENTS
MODERATE ENERGY CANYONS:		LGH: 8-18 KM DPH: 320-520 M	ANGL: 8-15°
RIM:	SHELF SAND+GRAVEL, RIPPLED	SAND IN TRANSIT TO WALLS	TIDAL CURRENTS,
	GRAVEL [EAST RIM]	STATIONARY	WESTWARD CURRENT
	VERY FINE SAND	DEPOSITED AT CANYON HEAD (FROM CANYON?)	
WALLS:	SILT+CLAY OUTCROPS	MODERATE BIOEROSION	
	MIXED SHELF SAND AND SILT+CLAY, RIPPLED	IN TRANSIT TO FLOOR	AXIAL(?) CURRENTS
FLOOR:	SILTY SAND, RIPPLED, FEW LARGE BEDFORMS	TRANSPORTED UP-DOWN CANYON; FINES RE-SUSPENDED; SAND, SILT, CLAY DEPOSITED	MODERATE SEMI-DIURNAL AXIAL CURRENTS
LOW ENERGY CANYONS:		LGH: 2.5-5 KM DPH: 200-300 M	ANGL: 4-7°
RIM:	SHELF SAND+GRAVEL, RIPPLED	SAND IN TRANSIT TO WALLS	TIDAL, WCR(?) CURRENTS
	?GRAVEL [EAST RIM] IF CANYON INCISES SHELF ? KM		?WESTWARD CURRENT
WALLS:	FEW SILT+CLAY OUTCROPS	MINOR BIOEROSION	
	MIXED SHELF SAND AND SILT+CLAY, FEW RIPPLES	IN TRANSIT TO FLOOR	AXIAL(?), WCR(?) CURRENTS
FLOOR:	SILTY SAND, FEW RIPPLES, NO LARGE BEDFORMS	SAND, SILT, CLAY DEPOSITED	WEAK SEMI-DIURNAL AXIAL CURRENTS

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TOMS CANYON STUDY

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Exploratory drilling activity on the Middle Atlantic OCS was at its peak during the years 1978 to 1981. Environmental concern about potential adverse impact prompted Government-mandated studies, including one at Toms Canyon. The wellsite, in Block 816, is at the edge of the continental shelf about 150 km from the New Jersey Coast and about 3.7 km northeast (up current) from Toms Canyon. The Government required the lessee, Exxon USA, to perform a monitoring study to determine if discharges from the well were entering the canyon in harmful quantities. The study was carried out by EG&G under the direction of Exxon Production Research Company.

The field study, from September 1980 to April 1981, included a pre-drilling survey, four cruises during the drilling period, and continuous monitoring of currents and sedimentation at several locations from the drilling rig to midcanyon. The pre-drilling survey included bathymetry; sediment sampling for background measurements of barium, chromium and vanadium; and grain size analysis and sampling of biota. The bilogical samples were to be analyzed only if Exxon drilled another well in Block 816 or in any other block adjacent to Toms Canyon. Since no other wells were drilled, the biological samples were never analyzed.

The sampling design included three transects, one running southwest and downcurrent from the rig site across the canyon, one along the canyon axis, and one north-south across the shelf break through the rig site. Bottom samples were taken and water properties were measured throughout the water column. Sediment traps and current meters were located near the bottom, and in the upper water column near the rig, at the canyon rim and at mid-canyon.

RESULTS

Currents on the shelf were in line with other studies: mean flow southwest along the isobaths at 10 to 21 cm/s and relatively uniform flow throughout the water column. In the canyon, the currents were decoupled from the shelf flow, running up and down the axis with a net up-canyon movement.

Sediment analysis showed up to 95 percent sand on the shelf, 50 percent at about 350 m, and around 3 percent at 550 m in midcanyon. The silt/clay ratio in most of the samples was about 2. Pre-drilling metals analysis for the upper 3 cm of sediment showed background levels consistent with earlier studies--barium at 156 to 303 ppm, chromium at 8 to 45 ppm and vanadium at 16 to 49 ppm. The higher levels were found in the canyon, reflecting the higher concentration of fine sediments. During drilling, the barium levels in the upper 3 cm of sediment were elevated to almost 5,000 ppm in the immediate vicinity of the wellsite, but were down to background levels within 1 to 1.5 km downcurrent. Chromium and vanadium levels were not elevated above background even at the wellsite.

The sedimentation rates, as measured by the traps ranged from 32 to 347 mg/m^2/day near the sea surface (20-m depth), 98 to 800 mg/m^2/day at middepth (140-m depth), and 121 to 5,792 mg/m^2/day in the canyon axis at 540-m water depth, with one anomalously high value over 1.1 million mg/m^2/day at this location. Barium levels in the sediment traps were elevated above sediment background with higher values occurring in the traps near the wellsite. However, the percentage of mud solids in the sediment traps ranged from about 10 percent at the 20-m depth and 1,500 m from the wellsite, to less than 0.1 percent in the canyon--at the 540-m depth and 7 km from the wellsite.

CONCLUSIONS

- Mud solids were transported to the canyon but not in sufficient quantity to affect the natural sedimentation rate or be detected in canyon sediments.

- Barium levels were elevated in the sediments up to 1.5 km from the wellsite. Chromium and vanadium sediment concentration's were not elevated, even at the wellsite.

- Sediments in the canyon are less sandy and more variable in composition than those on the shelf.

COMMENT

Bothner observed that the anomalously high rate of sediment collection in traps from the canyon axis may have been real as it is only about seven times those measured in the axis of Lydonia Canyon. The rate of sediment collection in traps 5 mab in Lydonia Canyon were 10 times higher during periods of strong currents than during quiescent periods.

RECENT DEVELOPMENTS IN INDUSTRY SPONSORED RESEARCH

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Preliminary results were shown from three studies, which have not yet been completed, in the vicinity of drilling operations off the coasts of California, Texas, and Alabama. The California and Alabama studies were done at single well sites. The Texas study was in a field of six development and four exploratory wells.

The California field study took place in 1984 at Molino, about halfway between Santa Barbara and Pt. Conception, about 3 mi offshore in a water depth of 73 m. The 11,000-ft well used 10,700 bbl of drilling mud containing 860 metric tons of barite.

The results are consistent with earlier studies in a number of ways; for example, plots of barium distribution in the sediments are directly related to currents in the water column. Concentrations decrease rapidly with distance away from the platform. Also, although total barium in the drilling mud ranged up to 350,000 ppm, the soluble quantities obtained by a weak acid leach technique were about two orders of magnitude lower--around 400 to 500 ppm. Background levels of barium in near shore areas along the California coast range from 700 to 900 ppm.

Other metals--zinc, lead, copper, and cadmium--follow the barium pattern. Mercury, nickel and chromium show slight increases with distance, but that is not thought to be related to drilling.

Biological studies were done on three species of bottom organisms--*Cyclocardia*, a siphon-feeding clam, and *Pectinaria* and *Nephtys*, two deposit-feeding polychaetes--to find out if the metals bioaccumulate, and where in the organism the metals are located. It turned out that more than 97 percent was in the granular pellets, the insoluble fraction, which is most probably excreted. Based on this information, the investigators hypothesize that almost all of the barium taken up is in the insoluble, barium sulphate form. Very little was found in the soluble fraction.

TEXAS

The Texas wellsite, examined in 1986 and 1987, is about 12 mi offshore from San Antonio Bay, in about 25-m water depth. Nearly 17,000 metric tons of barite were in the discharged drilling muds. A problem in this (and other areas) is that there are often multiple discharge points within a development field so that distributions are complicated. Some of the results showed very jumbled patterns of distribution; nevertheless, it is clear that maximum concentrations of metals were highest near the wells (closer than 200 m) and decreased rapidly with distance. Barium was the only element that was traceable beyond the first few hundred meters. Biological effects attributable to bottom contamination were not detectable.

Core samples in these shallow waters were taken by hand, by divers, for both fine fraction and bulk sediment analyses. The cores show bioturbation ranging up to 10-cm depth.

ALABAMA

Studies were done during 1987 and 1988 about 5 mi off the mouth of Mobile Bay, in water depth of 12 m. (Incidentally, this location is only a few miles from the area where the Army Corps of Engineers dumps in a day 6 to 7 times as much dredge spoils as the amount of material the drill rig discharges in its active life--about 8 to 12 months of drilling). Here the sampling was done in a ring pattern at varying distances from an exploratory well on four occasions: before drilling, shortly after drilling began, right after drilling stopped, and 8 to 9 months later. Again, both fine and bulk analyses were done.

The usual pattern in the bulk sediment results was a sharp increase after the commencement of drilling and a return to background or near background levels at the end of 9 months. There was little discernible change over time in the fine fractions. There appeared to be a lack of correlation between mercury and barium.

CONCLUSIONS

There is little, if any, evidence of biological effects in these three locations. Measurements of total metals in organisms can be misleading. Detailed analysis of the actual fate of metals within the organism are needed to more accurately determine biological impact.

QUESTIONS

Teal and Butman asked about the lack of mercury/barium correlation. The speaker noted that there is some evidence of a cadmium-barium correlation in tests off California but that it only appears at the stations immediately downstream, at distances less than or equal to 400 m. The regulatory agencies are interested in mercury and cadmium although mercury remains insoluble and is not bioavailable. Cadmium is slightly soluble and has shown some limited availability for uptake by organisms.

Cooper asked about effects on marine life. Ray saw no biological effects beyond the immediate wellsite. In intracellular analysis of animal tissue, the barium concentrations in the cytosol (soluble fraction) is one to two orders of magnitude below the threshold levels of calcium (Ca++), and thus probably would cause no toxic effects.

He re-emphasized the need to look at detail: the fine fraction in the sediments and the different parts of the organism--in order to come to any meaningful conclusions.

Bothner asked about the relative importance of dissolution of barium and transport in mass balance studies. Ray responded that results to date don't add up: there's not as much barium in marine sediments as one might predict. Mass balance studies on the shelf predict higher levels of barium than are actually present.

Note: The studies reviewed will be completed and available by the end of the first quarter, 1989. The California study was conducted by Jenkins et al., California State--Long Beach; the API--Texas and the Mobile Bay--Alabama Studies were by Continental Shelf Associates, A. Hart, B. Vittor, et al. Because the studies reviewed were in draft final form, the data tables presented for discussion could not be reprinted in this report.

THE FLUX AND COMPOSITION OF RESUSPENDED SEDIMENT IN LYDONIA CANYON: IMPLICATIONS FOR POLLUTANT SCAVENGING

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One of the objectives of the U.S. Geological Survey's sediment geochemistry studies in Lydonia Canyon and on the adjacent continental shelf and slope was to determine the relative potential for sediments to accumulate contaminants. The analyses of bottom and suspended sediments have provided four lines of evidence that suggest that the axis of Lydonia Canyon has a higher potential for contaminant accumulation than the surrounding areas do.

The evidence supporting this conclusion includes the following:

- The head and axes of Lydonia (and Oceanographer) Canyon has much higher fluxes of resuspended sediment than the adjacent shelf or slope. This resuspension activity provides more opportunity for particles to adsorb dissolved contaminants from seawater.

- The head of Lydonia Canyon is an area of active sediment accumulation. (This is based on carbon-14 dating of piston cores.) Therefore, some of the sediment that is recycled into the water column by resuspension is eventually buried in the bottom sediments by subsequent deposition.

- Enhanced scavenging of dissolved contaminants is suggested by the inventories of sediment-reactive isotopes lead-210 and plutonium-239, -240, which are higher in the sediments of the axis of Lydonia Canyon than in sediment from areas of comparable depth on the continental slope.

- Although trace-metal levels are low in the surface sediments along the Outer Continental Shelf and slope, the concentrations of cadmium, chromium, copper, and lead--normalized for differences in grain size--are higher in the canyon axis than in adjacent areas.

SEDIMENT RESUSPENSION

It is commonly reported in the literature that fine-grained sediments provide active surfaces which can adsorb many dissolved inorganic and organic contaminants in sea water. Resuspension of bottom sediments is one important mechanism through which the opportunity for such adsorption reactions by particulates can take place.

On each of the five current-meter deployments in and around Lydonia Canyon, discussed in a previous talk by Butman, we fixed sediment traps at various heights above the bottom in order to determine the RELATIVE intensity of sediment resuspension in different areas and heights above bottom.

We claim only to measure the relative intensity of resuspension, because the absolute efficiency of these sediment traps is unknown in a current flow that is both strong and highly variable. However, all the results have been normalized to a trap of standard dimensions and so a comparison of the collection rates for different areas is possible (Bothner and others 1986).

Figure 10 summarizes the differences in the flux of trapped sediment collected in Lydonia Canyon during the first experiment (12/1/80 to 4/29/81) when areal coverage was the most extensive.

The rate of sediment collection ($g/m^2/day$) increases greatly (almost logarithmically) as the distance above the bottom decreases. This indicates that resuspended bottom sediment is the source of the material collected.

The highest collection rates are observed near the bottom in the canyon axis at locations in 300- and 600-m water depth. There, the rates are as much

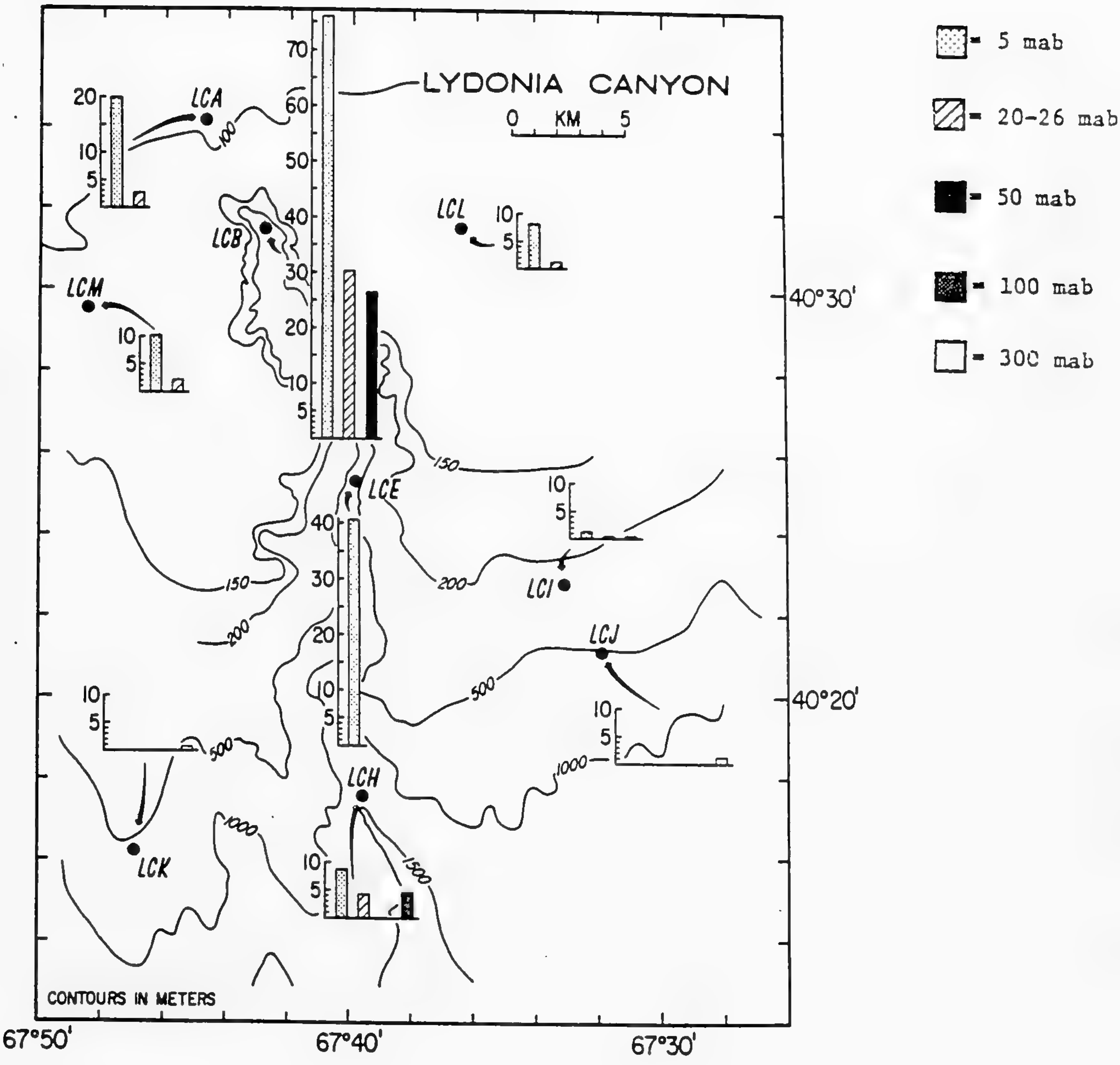


Figure 10. Histograms showing the flux of resuspended sediment (g/m^2/day) at different heights (in meters) above the bottom.

as 65 times higher than rates on the continental slope at comparable depth and seven times higher than those measured on the continental shelf.

The frequency of sediment resuspension and its variability in intensity were also indicated in the sediment-trap data. An instrument was placed in some of the traps which deposited a layer of white teflon powder on the accumulating sediment at 10 day intervals (Figure 11). The mass of sediment collected between each time interval varied by an order of magnitude. The variability in flux of trapped sediment correlated, in most cases, with high-energy current events recorded by the current meters. It is during these events that the coarsest sediment was resuspended and collected in the sediment traps.

Not only is the resuspended sediment flux relatively intense and frequent in the canyon axis, but it also influences a significant portion of the water column. Traps placed between 20 and 102 mab exhibited a similar pattern of alternating fine and coarse sediment, indicating that resuspended sediments were being exposed to at least the lower 100 m of the water column.

These same processes of sediment resuspension seem to be intensified in the axis of Oceanographer Canyon as well. During one deployment, the flux of trapped material was 30 percent higher in Oceanographer Canyon than in Lydonia Canyon at the same water depth.

RATES OF SEDIMENT ACCUMULATION AND SEDIMENT SOURCES

There is a growing body of information which suggests that the head of Lydonia Canyon is accumulating sediments and that the continental shelf contributes at least some of this material. On the basis of high-resolution, seismic-reflection and sidescan-sonar data, Twichell (1983) mapped areas of post-glacial sediment fill and suggested that accumulation of fine sediments winnowed from the adjacent shelf was probably active. The carbon-14 age of total organic carbon deposited with these sediments was determined on two

Figure 11.

A. Histogram showing the relative (%) mass of sediment collected at station LCP, 5 mab, during each 10 day interval between September 28, 1981 and January 28, 1982.

B. Schematic diagram showing position of teflon timing layers (open symbols) and layers of coarser sediment (dots). Percent sand is indicated below schematic.

C. X radiograph of the sediment trap sample showing layers of coarser (darker) and fine sediment. Top of sample is to the left.

D. Record of bottom stress (dynes per cm^2) at the station LCP.

E. Calculated flux of trapped sediment. The size distribution (%) of particles 8, 32-63, and 64-125 μm in diameter is indicated for periods of increased flux (Bothner and others 1987a).

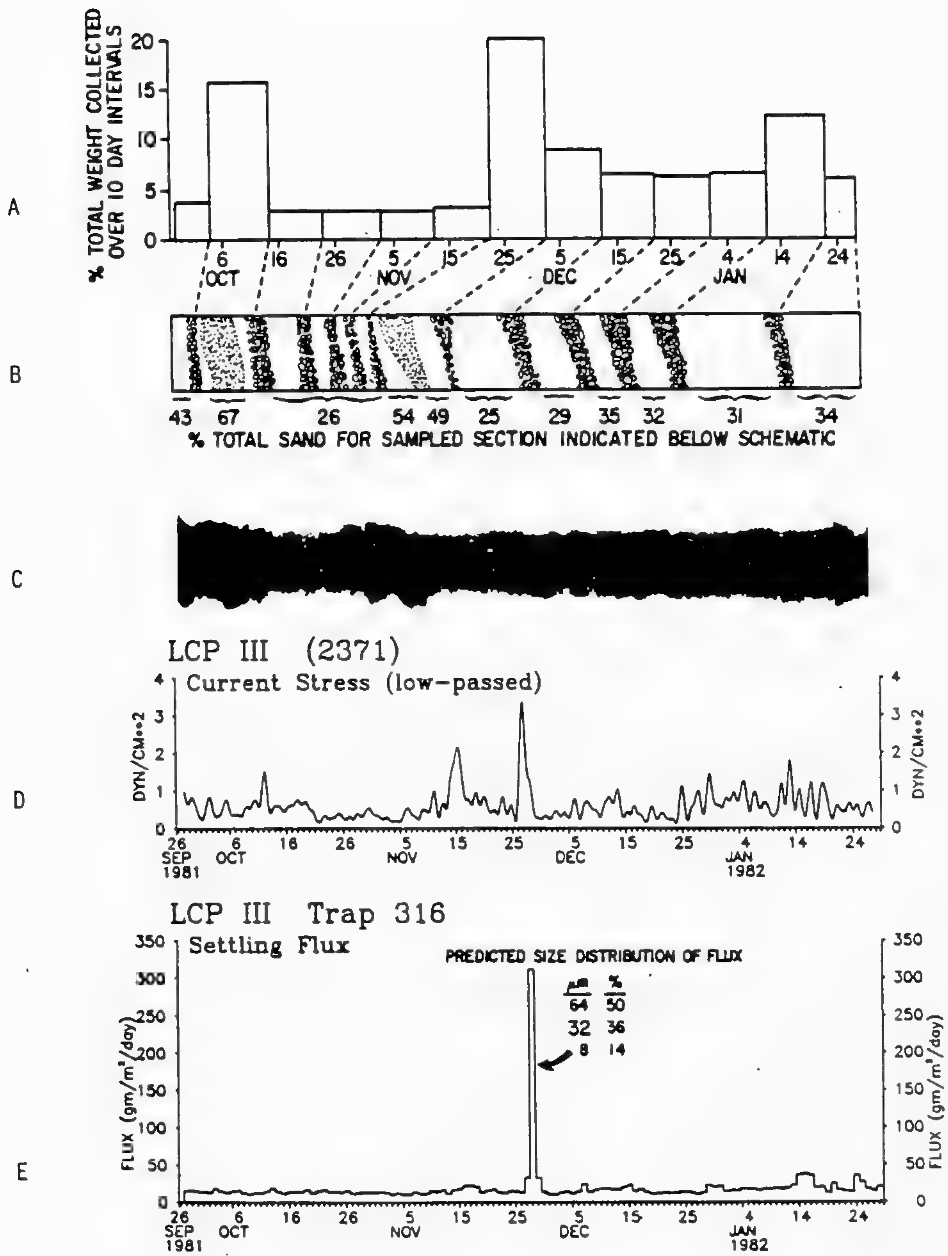

A
% TOTAL WEIGHT COLLECTED OVER 10 DAY INTERVALS
0
5
10
15
20
6 OCT
16
26
5 NOV
15
25
5 DEC
15
25
4 JAN
14
24
B
43 67 26 54 49 25 29 35 32 31 34
% TOTAL SAND FOR SAMPLED SECTION INDICATED BELOW SCHEMATIC
C
D
LCP III (2371)
Current Stress (low-passed)
DYN/CM**2
0
1
2
3
4
26 SEP 1981
6 OCT
16
26
5 NOV
15
25
5 DEC
15
25
4 JAN 1982
14
24
E
LCP III Trap 316
Settling Flux
FLUX (gm/m²/day)
0
50
100
150
200
250
300
350
PREDICTED SIZE DISTRIBUTION OF FLUX
μm %
64 50
32 36
8 14
26 SEP 1981
6 OCT
16
26
5 NOV
15
25
5 DEC
15
25
4 JAN 1982
14
24

Figure 11.

piston cores collected from the head of Lydonia; the data show a near-linear increase of age with depth, which suggests a constant and ongoing accumulation of sediments at these locations over the last few thousand years (Figure 12). The mean accumulation rate is 60 cm/1,000 yr or about 2 $g/m^2/day$.

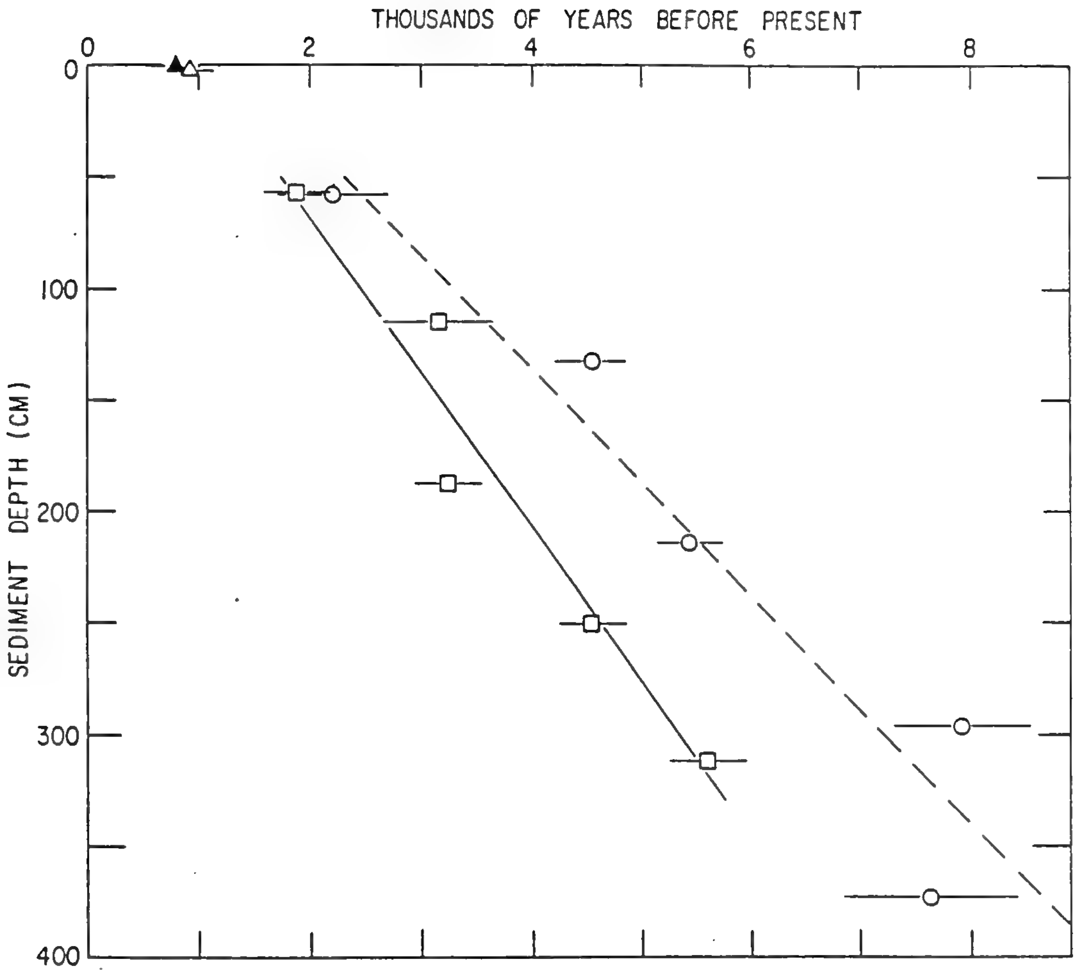
The carbon-14 age of the surface sediments is about 900 years, which reflects the slow exchange of atmospheric and oceanic carbon dioxide and bioturbation of the surface sediments.

The calculated rate of sediment accumulation from piston cores is at least an order of magnitude less that the rate of sediment accumulation in traps. Although the efficiency of the traps is not known, this implies that canyon sediments are subjected to numerous cycles of resuspension and deposition before final burial. These cycles are thought to increase the opportunity for scavenging of dissolved contaminants by particles.

The rates of sediment accumulation have not been determined on the open slope adjacent to Lydonia Canyon. The closest carbon-14-dated core on the slope was taken south of Martha's Vineyard in 1,100 m of water, where a rate of 13 cm/1,000 yr was reported (Anderson and others 1988). The rates of sediment accumulation on Georges Bank are assumed to be nil. Redistribution of materials is occurring, but because of its present isolation from continental sources of sediment, the Bank as a whole is considered erosional.

Transport of material from the continental shelf into the axis of Lydonia Canyon is directly evidenced by the systematic increase with time in the concentration of barium in sediment trap samples (Figure 13). The first mooring deployment predated the exploratory drilling on Georges Bank and the remaining four deployments included the period when eight wells were drilled, the closest about 9 km away from mooring LCB.

The barite component of drilling mud, the source of this barium increase, was highly diluted by the time it was collected in Lydonia Canyon. It was measurable only in the fine fraction (finer than 60 microns) of the trapped



▲ = Grab OC122-46, △ = Grab OC124-7A, □ = piston core OC122-43, ○ = piston core OC122-45. Linear regressions indicate accumulation rates of 51 cm/1000 years for OC122-45 and 69 cm/1000 years for OC122-43.

Figure 12. Carbon-14 age of organic carbon in marine sediments from the head of Lydonia.

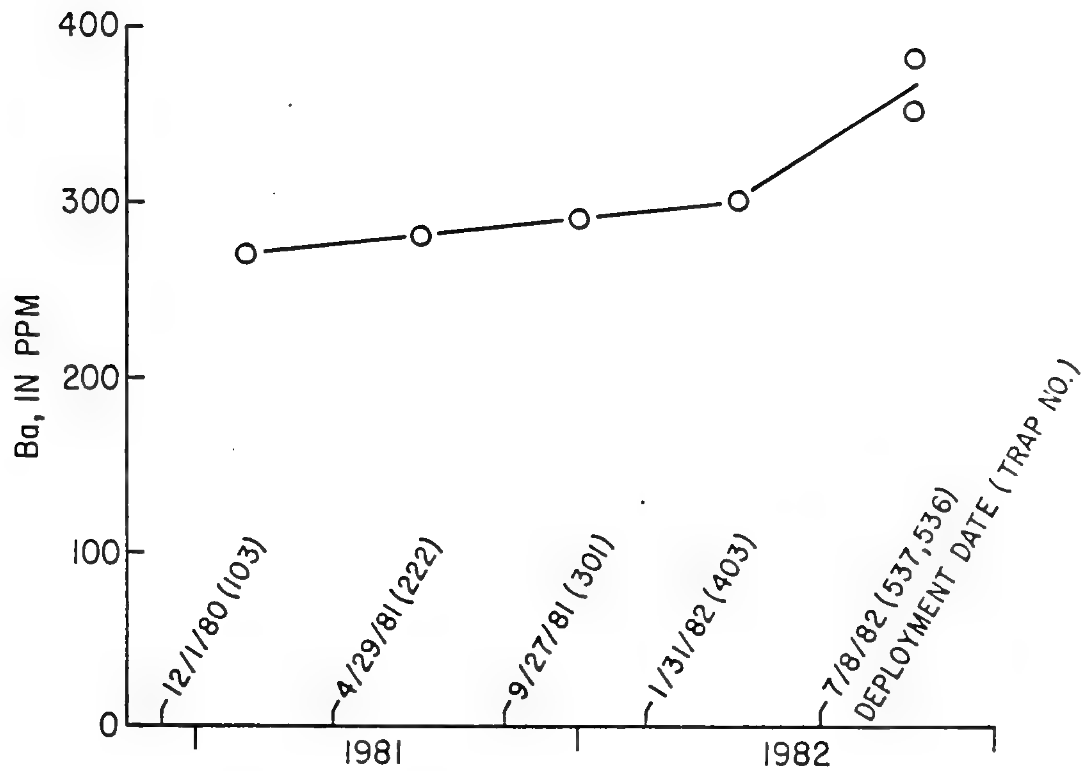


Figure 13. Concentration of barium in the fine fraction of material collected in sediment traps deployed at the head of Lydonia Canyon on different deployment dates. Traps were recovered just prior to the next deployment.

sediment, where barium concentrations increased only about 35 percent above pre-drilling levels; maximum concentrations were 380 ppm. Near the drilling rig in Block 410, the barium concentrations in the fine fraction of bottom sediments reached 10,000 ppm in post-drilling samples.

TRACE METALS AND RADIONUCLIDES

Twelve metals were measured in bottom sediments at 15 stations on the continental slope off Georges Bank, and all were found at levels expected for uncontaminated fine grained sediment (Bothner and others 1987b). Lead was the only metal showing slight enrichment in the surface sediments within the cores, compared to deeper sediments. This trend is seen in many off-shore areas and is thought to reflect the use of lead in gasoline and industry.

The metal concentrations in sediments from a station in Lydonia Canyon and from the adjacent slope (both at 550-m water depth) were compared as a test for differences in scavenging. The analysis was carried out on only the sediment fraction finer than 60 microns. The heavy metal concentrations were divided by Aluminum concentrations in order to normalize for textural variability (Figure 14). For perspective, the resulting concentration ratios were compared to those in world average shales (Krauskopf 1967).

Four metals (Figure 15) showed a consistently higher enrichment factor in the canyon axis compared to the slope in each of the three sampling periods. This is taken as supportive evidence, although certainly not dramatic, that the potential for scavenging is greater in the canyons.

The hypotheses for greater scavenging in the canyons is more clearly supported by the distribution of radioisotopes plutonium-239/-240 and lead-210. Plutonium has been introduced to the ocean surface from nuclear weapons testing in the atmosphere, and had a peak fallout about 1963. Lead-210 is continuously generated from the natural decay of uranium. It has a half-life of 22.3 years and is introduced to the ocean both from the atmosphere and from in situ decay of dissolved radium-226.

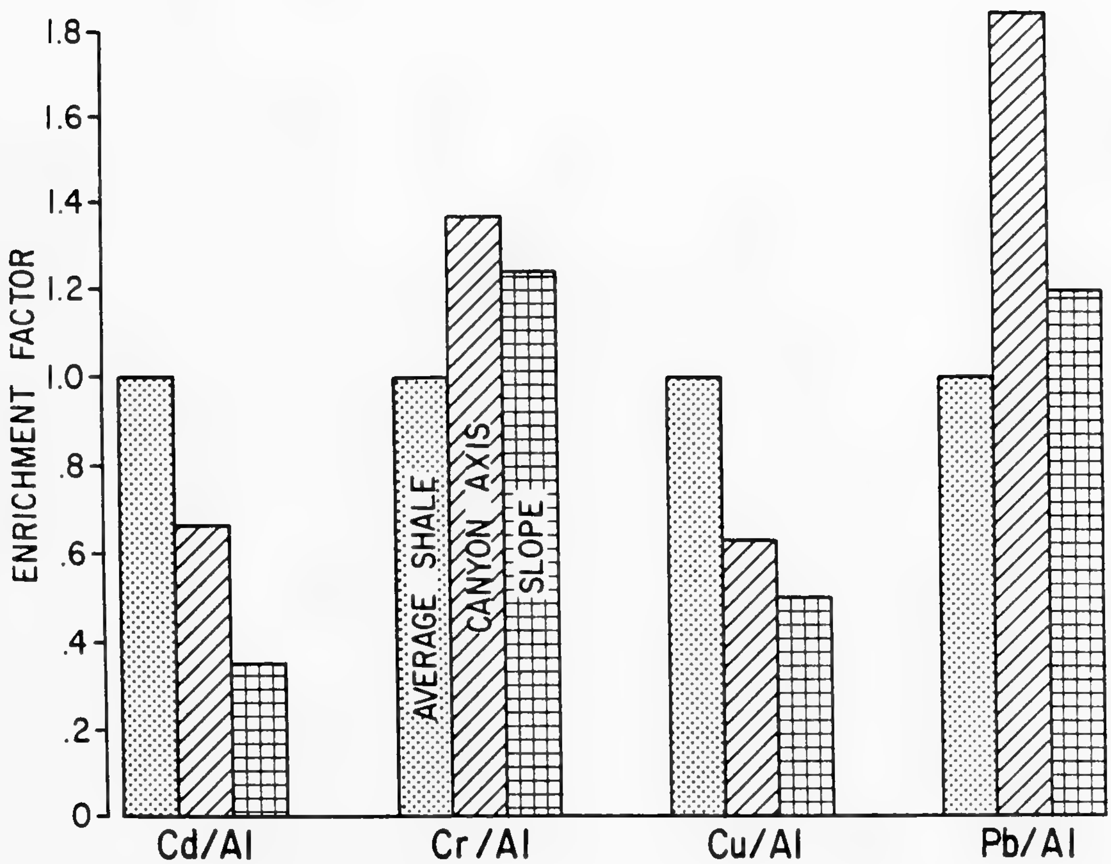


Figure 14. Histogram showing the abundance of metals in the canyon axis and on the slope relative to world average shales (world averages from Krauskopf 1967). Samples used in the calculations are the fine fraction (finer than 60 microns) of the upper 2 cm at 550-m water depth in the axis of Lydonia Canyon and at the same depth on the adjacent continental slope (Stations 7 and 4 in Bothner and others 1987b). Metal concentrations have been divided by Al to correct for differences in sediment texture.

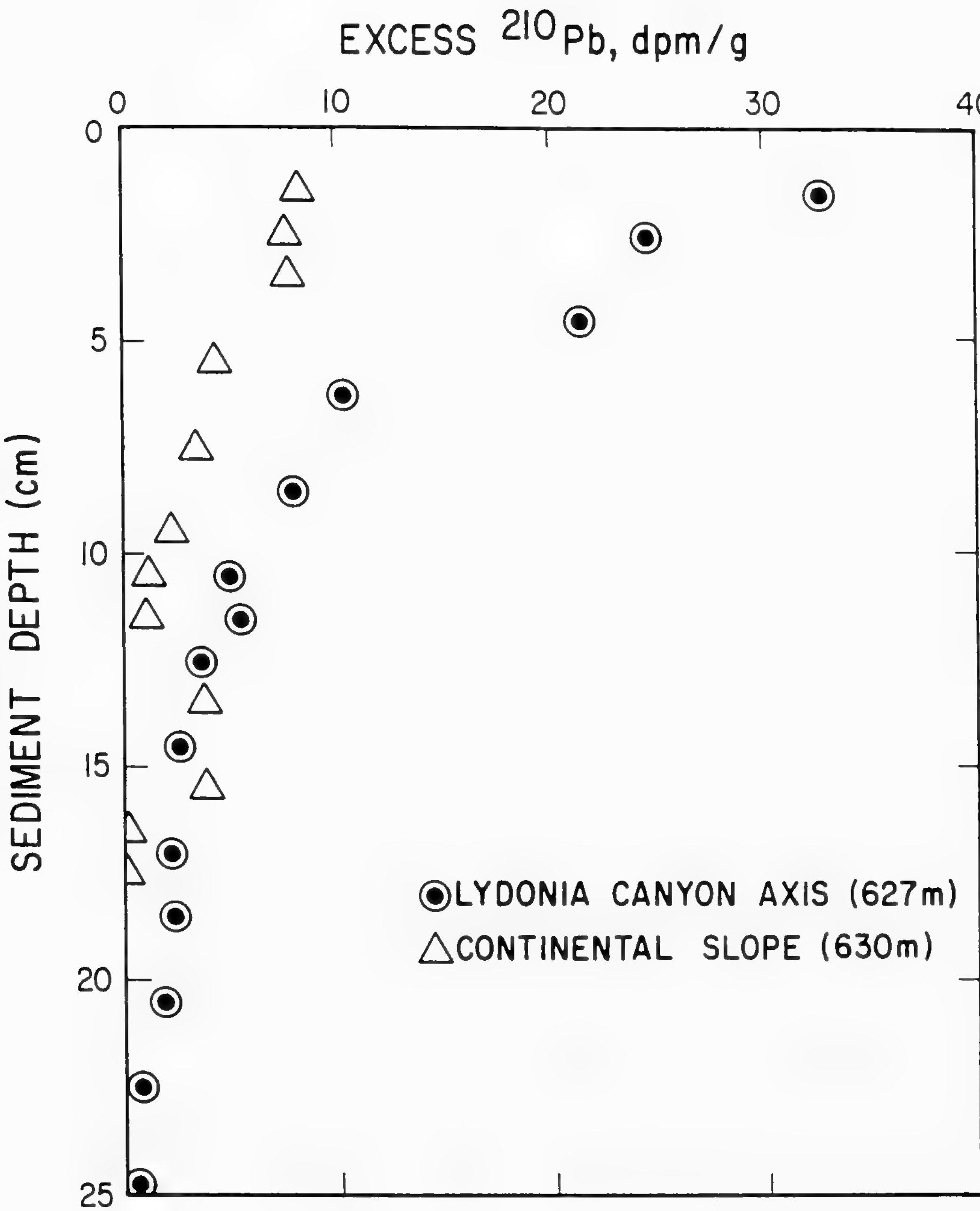


Figure 15. Isotope data suggest active processes in the canyon axis. Activity of excess lead-210 with depth in sediment cores from the axis of Lydonia Canyon and from the continental slope (canyon core 4769, 40° 23.87′N, 67° 40.13′W; slope core 4772, 40° 09.43′N, 68° 20.12′W). Inventories are 223 dpm/g and 86 dpm/g respectively.

Data from two box cores show that the inventories of these isotopes (activity/cm^2) are 2.5 times higher in the sediments of the canyon axis than they are on the open slope. The specific activities (activity/g) are much higher in the canyon axis as shown in Figures 15 and 16. These observations are a clear indication that the sediments in the canyon axis are accumulating more of these sediment-reactive isotopes as a result of the collectively more active processes operating in the canyon. If a correction were made for the percentage of fine sediment, the relative enrichment in the canyon would be even greater.

The depth of penetration of these isotopes is a result of extensive bioturbation in these sediments. This conclusion is based on the slow rates of sediment accumulation in both areas and the presence of measurable plutonium and excess lead-210 activities at depths much greater than can be explained by the sedimentation rate. Preliminary estimates of the rates of sediment mixing by organisms suggest nearly the same mixing coefficients for both locations (about 1 cm^2/yr; Bothner and others 1987a). Biological mixing of the sediments is another mechanism that influences the retention of contaminants in sediments.

SUMMARY

The data we have collected in Lydonia Canyon suggest that it has higher potential as a sink for contaminants than adjacent areas of the continental shelf or slope. The most compelling evidence for greater scavenging in this canyon is found in the limited data showing inventories and specific activities of plutonium and lead-210. The possible mechanisms for the enhanced scavenging are higher rates of sediment accumulation and more intense and frequent sediment resuspension.

Of the canyons in the North Atlantic OCS study area, Lydonia is the best studied in terms of physical and geochemical measurements. While additional information is needed in Lydonia Canyon to confirm some of the processes

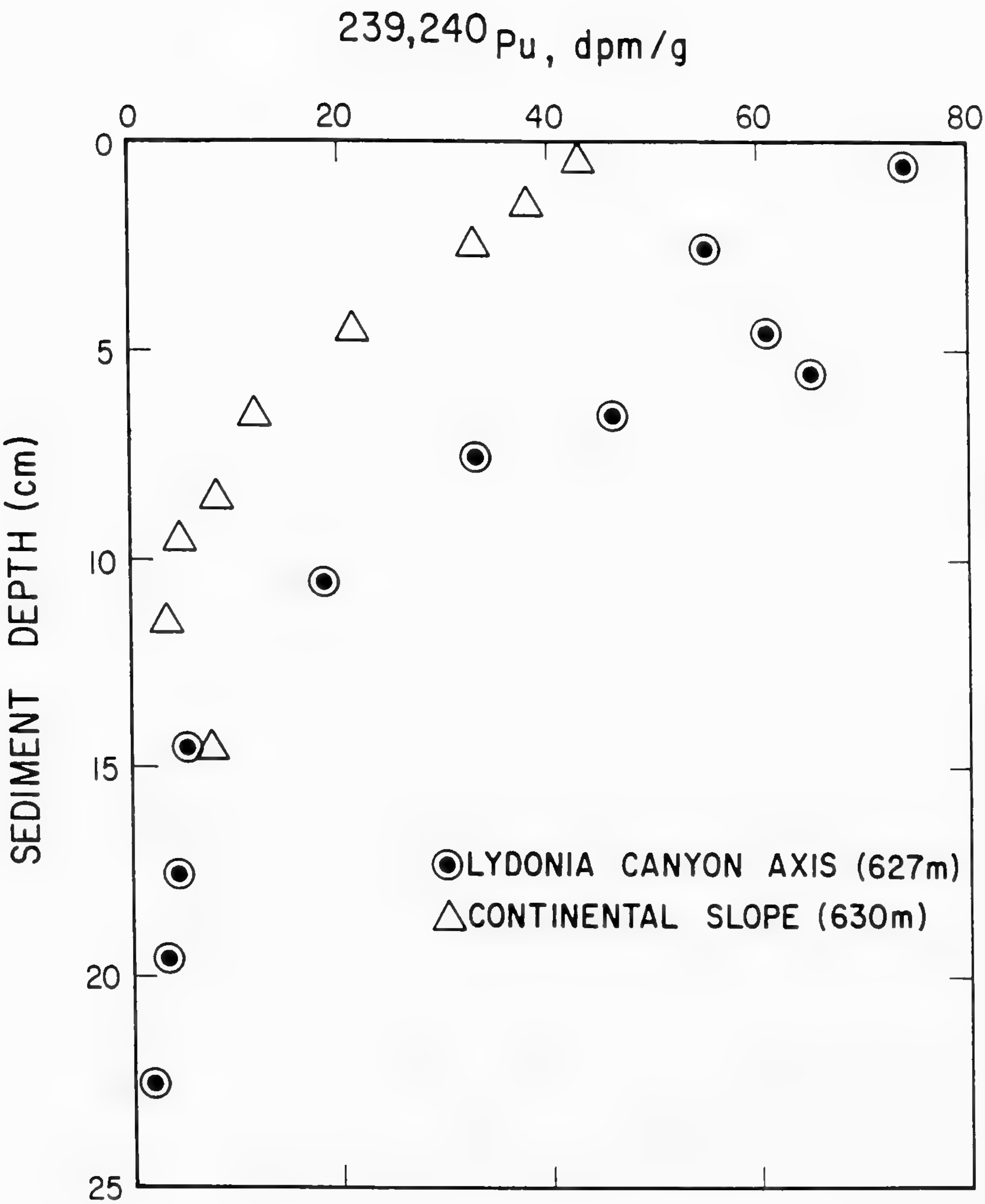


Figure 16. Activity of plutonium-239/-240 with depth in sediment cores from the axis of Lydonia Canyon and from the continental slope (canyon core 4769, 40° 23.87'N, 67° 40.13'W; Slope core 4772, 40° 09.43'N, 68° 20.12'W). Inventories are 3.2 mCi/km^2 and 1.3 mCi/km^2 respectively.

suggested by our limited data, a full effort is needed in some of the other canyons of this area as well.

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OVERVIEW OF THE BIOGENIC AND ANTHROPOGENIC HYDROCARBON DISTRIBUTIONS IN SEDIMENTS ALONG THE NORTH ATLANTIC MARGIN

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Georges Bank and the adjacent slope, rise, and submarine canyon areas are characterized by highly dynamic sediment transport, deposition, and resuspension cycles. Important questions concerning the hydrocarbon story for this area are:

- What are the overall concentrations of hydrocarbons in the sediments?
- What is the composition of the hydrocarbon assemblage?
- What is the distribution of both total hydrocarbons and individual hydrocarbons?
- What are the sources and sinks of hydrocarbons?
- What processes control distributions and concentrations?

HYDROCARBON DISTRIBUTION

Results of five MMS, National Oceanic and Atmospheric Administration (NOAA), Bureau of Land Management, and Department of Energy studies show that pollutant and biogenic hydrocarbons distributions follow the general trends of those for fine sediments. Total hydrocarbons and polycyclic aromatic hydrocarbons (PAH) are found at very low levels in the central bank area where sediments are coarse. Total hydrocarbon values are 0.5 to 5 ppm for Georges Bank with PAH values of 5 to 20 ppb. Elevated levels are found in the depositional areas of the "mud patch" on the shelf south of Martha's

Vineyard (10 to 15 ppm and 100 to 2,000 ppb), at canyon heads, and along the slope and rise (10 to 30 ppm and 50 to 500 ppb). In general, the PAH compounds are of a nonfossil source indicating combustion as a likely origin.

SEASONAL TRENDS

Seasonal trends are different for total and PAH hydrocarbons. Total hydrocarbons and terrigenous plant materials do not vary seasonally and appear to be in an overall steady state (Figure 17). Pristane (a marine biogenic hydrocarbon) does vary seasonally from a spring high to a winter low (Figure 18). This seasonality is presumably determined by seasonal cycles of erosion and deposition. Pristane is eventually transported to depositional areas to the west and southwest of Georges Bank. Sporadic incidence of petroleum residues (e.g., tar balls) are observed but are relatively short-lived. Indirect evidence (hydrocarbon chromatograms in conjunction with sediment textural data) suggests that anthropogenic hydrocarbons are associated with the easily resuspended fine sediments while biogenic hydrocarbons associate with the coarser fractions (Table 2). It has been estimated that 40 to 50 percent of the organic matter is resuspended and removed from the shelf to the slope during fine-grained sediment transport.

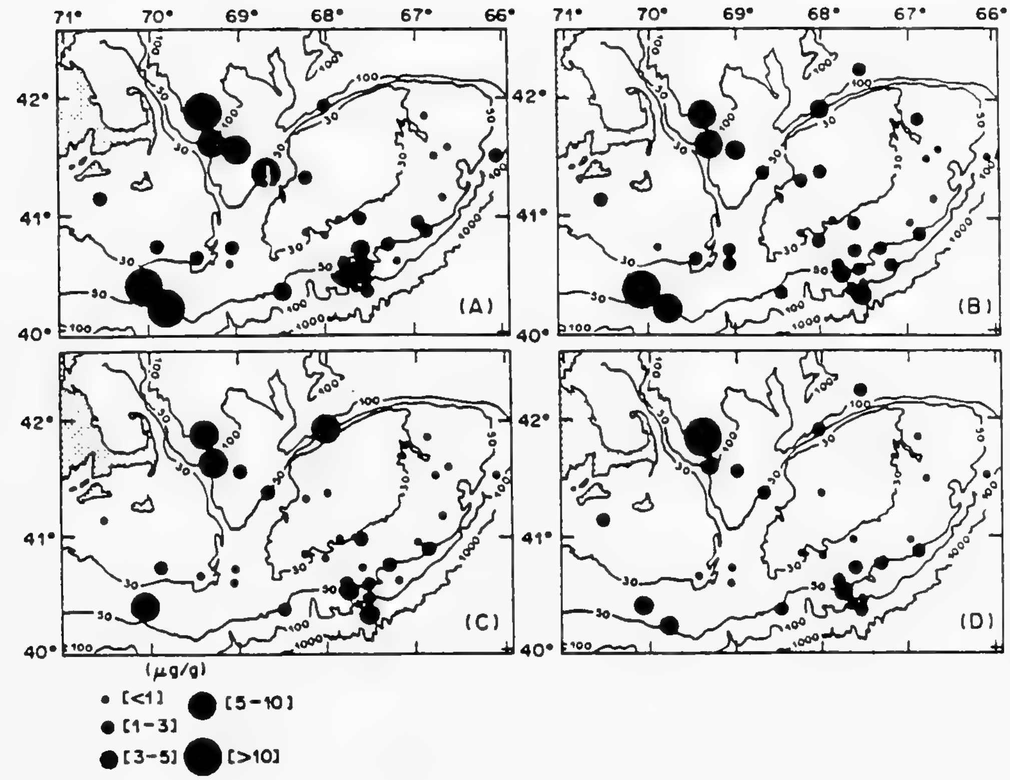

Figure 17. Seasonal variations in total hydrocarbon concentrations in sediments from Georges Bank and Nantucket Shoals. (A) Winter; (B) spring; (C) summer; (D) fall.

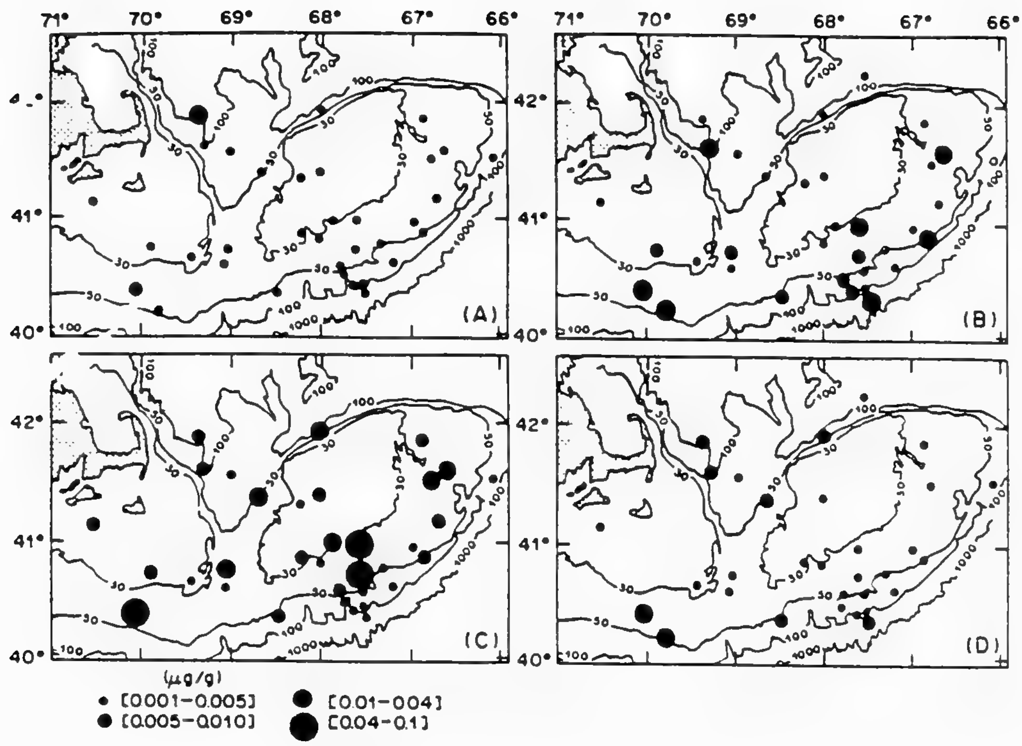

Figure 18. Seasonal variations in pristane concentrations in sediments from Georges Bank and Nantucket Shoals. (A) Winter; (B) spring; (C) summer; (D) fall.

Table 2. Comparison of mean silt-clay content and PAH concentrations in sediments collected in April 1985 (Cruise North-2).

Station	Station Depth (m)	Percent Silt/Clay	Percent Carbon	PAH[a]
11	255	30.6	0.47	49
7	560	9.0	0.20	15
4	550	29.4	0.27	39
12	550	58.9	0.86	121
10	1220	68.4	0.80	122
3	1350	75.6	1.18	132
9	1220	88.7	1.41	183
13	1250	93.6	1.24	141
5	2065	29.8	0.28	28
8	2180	42.0	0.52	49
14	2105	47.6	0.54	59
15	2155	53.4	0.70	73
6	2115	54.0	0.43	39
2	2100	87.1	1.06	123

[a]ng/g dry weight

RELATION TO TOTAL ORGANIC CARBON

Both the saturates and the PAH compounds are strongly associated with total organic carbon (TOC) in the sediments. While the absolute concentration of total hydrocarbons ranges from 0.2 to 20 ppm and of PAH compounds ranges from about 0.01 to 1.0 ppm, the respective ratios to TOC are relatively constant, suggesting a well-mixed geochemical area. Saturated hydrocarbons of a terrigenous plant wax origin dominate the overall assemblage and covary strongly with TOC and the clay content of the sediment (THC = 0.96 (TOC) + .29; r=.88). PAH also covaries strongly with TOC (PAH = 2.2 (TOC) - 0.027; r=.93). The PAH distributions are similar to those originating in the combustion of fossil fuels, with distributions dominated by the higher molecular weight (i.e., 4- and 5-ring compounds) rather than petroleum-sourced PAH. PAH also covaries strongly with terrigenous plant material (r=.93) and is considered to be either sourced onshore and distributed with the plant wax residues or is introduced via aerial transport and is mixed and distributed with other fine-grained material. The PAH/TOC ratios are very similar to those found in sediments from other geographical areas well removed from the North Atlantic outer continental margin.

IMPLICATIONS FOR FATE OF POLLUTANTS

The distributions of hydrocarbons in the shelf and slope areas have important implications for predictions of the fate of pollutants which may originate through outer continental shelf development. Sedimented hydrocarbons associated with fine-grained sediments will be redistributed from their point of origin rapidly (weeks to months) and will be transported to depositional areas which include canyon heads, deeper slope areas, and shelf basins such as the "mud patch." In particular, canyon heads are likely sites for the accumulation of total and PAH hydrocarbons. Although much of the present data suggests that introduced pollutants will be deposited in canyon heads and transported down the canyons, hydrocarbon data from muddy lobes found on the shelf near the heads of Oceanographer and Lydonia Canyons suggest a canyon source for this mud. Present data are thereby also consistent with the possibility of up-canyon transport of fines to the canyon head with spill-over onto the shelf.

POTENTIAL EFFECTS OF DRILLING EFFLUENTS ON MARINE ORGANISMS

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Of more than 25,000 offshore wells drilled in U.S. waters in the past 90 years, more than 10,000 are still in production. During drilling and production, there are several possible discharges to the ocean and physical alterations of the bottom that may have adverse effects on the marine environment. Some discharges are authorized by permit; others are accidental. The permitted discharges of greatest environmental concern are drilling muds, drill cuttings, and produced water. The most important accidental discharge is petroleum through operational spills or blowouts. Physical impacts may be caused by the mere presence of the platform or by emplacement of pipelines on the bottom. The major concern in this report is the impact of drilling muds and cuttings discharges.

Such discharges are diluted very rapidly by dispersion and fractionation. The heavier solids (representing about 90 percent of the mass of the mud) settle rapidly to the bottom, usually within 200 to 1,000 m of the rig, depending upon water depth and current speed. The liquids, soluble materials, and fine clay-sized particles are carried away from the rig in a near-surface plume and are diluted rapidly by mixing with seawater. In a typical current of around 10 cm/s, a dilution of ten-thousand fold--well below toxic or even sublethal levels--is accomplished within 200 m of the rig in less than half an hour. Small wonder the National Academy of Science report concluded there is essentially zero likelihood of any adverse effect within the water column.

The ingredients of greatest concern in drilling muds on the sea floor are metals, notably barium, chromium, lead, and zinc. Cadmium and mercury are regulated by the Environmental Protection Agency but are found above background levels only in association with high concentrations of barium. Minor ingredients sometimes added to drilling mud that may contribute to its impact include diesel fuel or mineral oil, surfactants, and biocides. Many hundreds of acute toxicity bioassays have been performed with drilling muds, and nearly 90 percent of the samples were found to be nontoxic or practically nontoxic to marine organisms.

LABORATORY STUDIES

To test bioavailability, experiments were conducted with juvenile lobsters and with flounder species. The animals were kept in aquaria with either uncontaminated or highly contaminated bottom sediments and were fed either uncontaminated or highly contaminated food over a period of 99 days--long enough to consume 4 to 5 times their own body weights. Sufficient drilling mud solids were added to sediment to increase the concentrations of barium in sediment by 10,000 mg/kg. Flounder and lobsters were examined for bioaccumulation of barium and chromium and for growth rate and mortality. In both types of animals, there were no visible effects from eating contaminated food; however, there were some problems from elevated levels of drilling mud solids in the sediment. There was some bioaccumulation of barium, but not chromium, from sediment. It was concluded that minimal bioavailability is associated with sediments and none with food.

FIELD STUDIES

Review of many field studies in many regions points to three conclusions:

- Effects on the benthic community are found only in the immediate vicinity of oil rigs, usually in tranquil environments, and most recover fully in less than a year after drilling stops.
- Bioaccumulation of metals is limited to barium and chromium, with small increases immediately after the discharge.
- There has been no demonstrated effect of hydrocarbon contamination.

GEORGES BANK STUDIES

Two stations on the bank, close to exploratory drilling rigs, were sampled quarterly for 3 years, with 29 stations in a ring pattern around one rig, and 3 stations near a second rig. The sites were both on the south flank of the bank, one in 80-m water depth, the other at 140 m. Chemical analyses by Bothner showed five- to seven-fold increases in barium concentrations in the bulk sediment, much higher in the fine fraction, and some drill cuttings. There was a tendency for the barium to migrate as a result of reworking and resuspension of sediments. There was little or no evidence of hydrocarbon accumulation.

Biological effects were examined down current from the rigs. At the shallower station, a strong seasonal signal was found in both diversity and abundance, but no real biological impacts were attributable to the discharges. At the deeper site, there was a smaller seasonal signal, but no other discernible change occurred except a gradual increase over time in both diversity and species abundance. The increase was attributed to an accident of timing, as it was also seen at the control sites. Two species of amphipods virtually disappeared when drilling began, but that was attributed to a severe winter storm. In short, if there were any effects at all, they were small and transitory.

DISCUSSION

Several questions concerned the laboratory experiments. Vild asked about signs of stress in lobsters; there was slight elevation in mortality and slight decreases in growth. Ray asked for barium concentrations in the aquaria sediments; they were field muds from Gulf of Mexico rigs, and barium concentrations were increased above background by 5,000 to 10,000 ppm. Cooper noted that lobsters are very vulnerable to zinc and copper; Neff responded that those metals are in forms that are not bioavailable.

Maciolek asked about water depths where the most significant impact occurs; it appears to be around 100 m on the Middle Atlantic shelf, 50 to 100 m in the North Sea. Ray described experiments at 35 feet and 75 m in the Gulf of Mexico that showed no significant impact. There is no information on possible impact at significantly greater depths, 500 m or more.

MEGAFAUNAL POPULATIONS IN LYDONIA CANYON WITH NOTES ON THREE OTHER NORTH ATLANTIC CANYONS

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Lydonia Canyon is a relatively narrow canyon that incises Georges Bank approximately 11 mi north of the shelf-slope break. It has a narrow sediment-covered axis flanked by steep walls with massive exposures of outcrop and talus-strewn slopes.

Megafaunal populations in Lydonia Canyon were surveyed photographically during 16 camera sled tows and 17 *Alvin* dives between May 1979 and September 1982. Nearly 115,000 square meters of sea floor, between 130- and 2,330-m depth, were analyzed. More than 750,000 animals were identified. The analysis included data on water depth, surficial geology, current indications, species identification, and abundance. The area viewed was estimated for most of the pictures since flat terrain was rarely encountered. The *Alvin* dives were used to obtain data in very steep regions and collect "voucher" specimens for better taxonomic identification.

RESULTS

Faunal abundance was much greater in the canyon than at comparable depths on the slope. Total megafaunal abundance in the canyon was very high (up to 30 individuals/m^2) at shallow depths, and intermediate at mid-slope (5 individuals/m^2) and lower slope (7 to 8 individuals/m^2) depths. Highest concentrations were along the canyon axis, but abundance was also high on the flanks, especially in areas of outcrops or boulders. Between 350 to 450 m in the axis there were very high concentrations of a sea pen (*Pennaula aculeata*) and brittle stars (*Ophiura* spp); other high concentrations were at 800 to 1,000 m (mostly hard-substrate corals) and below 1,600 m (a different brittle star (*Ophiomusirium lymani*)).

The "percent similarity" index was used as a mathematical indication of faunal similarity. The resulting cluster structure was a function of both depth and location within the canyon. Clusters grouped at relatively low percentages (15), an indication that many of the taxa were patchily distributed.

Geographical mapping of the cluster results shows 5 broad faunal zones (using the word "zone" loosely since clusters were usually a result of high abundances of few species and clusters only grouped at 15 percent similarity) on the walls and flanks of the canyon. The faunal distributions within the canyon axis at depths of less than 1,500 m were extremely patchy and complex, reflecting the substrate heterogeneity and active physical regime.

Cluster 1 consists of areas that are centered on the 200-m isobath around the canyon rim. Species common to all areas in this cluster are crabs (*Cancer* sp.), black-bellied rosefish, the anemone, *Actinauge longicornis*, and the starfish, *Sclerasterias tanneri*.

Areas in cluster 2 range from 300 to 475 m but do not extend into the canyon past the upper flanks. Common species are *Bolocera tudiae*, *Hyalinoecia artifex*, *Actinauge verilli*, and long-finned hake.

Areas in cluster 3 are between 500 and 1,000 m and have a mud to cobble substrate, with *Synaphobranchus kaupi*, *Geryon quinquedens*, *Glyptocephalus cynoglossus*, and *Asbestopluma* sp.

Areas in clusters 4 and 5 are the deepest, with *Distichoptilum gracile* and a *cerianthid* anemone in both and *Ophiomusium lymani* in 5.

In contrast, the clusters consisting of axis areas (clusters 7, 8, 9) are typified by a variety of corals and sponges, in addition to the background fauna of clusters 1-5.

GENERAL OBSERVATIONS

The canyon has a higher diversity than does the slope, reflecting the addition of sessile filter feeders to the background slope fauna. At mid-slope depths, carnivores predominate on the slope, while filter feeders are preeminent at all depths in the canyon axis. In both regions, diversity is higher on hard substrate than on soft. Diversity also increases with the size of the hard substrate, being lowest in cobble areas, and highest on cliffs.

OTHER CANYONS

In 1977 *Alvin* made three dives in Oceanographer Canyon, three in Heezen Canyon, and one in Corsair Canyon. The same kind of cluster analysis used in Lydonia Canyon shows disparity among the three canyons, possibly reflecting the disparity in their morphology and corresponding differences in their physical regimes: Oceanographer Canyon is wide, with low stepped cliffs and comparatively heavy sediments; Heezen is very narrow and deeply incised, with large Eocene chalk cliff flanking the axis. Corsair is mostly sediment covered with limited exposures of hard substrate. Only some of the faunal differences among the canyons could be attributed to availability of hard substrate.

CONCLUSIONS

- Distributions of megafaunal assemblages in the Georges Bank canyons are complex with a high degree of patchiness in many of their faunal constituents.

- The canyons are marked by high concentrations of sessile filter feeders (corals and sponges).

- The different patterns reflect substrate heterogeneity, enhanced current speeds within the canyons, resuspension events, and probably the concentration of fine particles in the axis.

- The increased sediment load in the water column may stress filter feeders through tissue abrasion, clogging of filter apparatus and decreased larval settling. There may also be indirect effects through changes in the substrate itself.

DISCUSSION

Bothner asked if the sled is remotely controlled. The answer is no; it takes a picture every 15 seconds. There is too much tendency for an operator to introduce bias by increasing coverage where the fauna is abundant.

BENTHIC INFAUNA OF LYDONIA CANYON AND THE ADJACENT SLOPE ENVIRONMENT

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The Georges Bank Benthic Infauna Monitoring Program was carried out between 1981 and 1984, and a deep-water characterization study (Study of Biological Processes on the U.S. North Atlantic Slope and Rise) was made from 1984 to 1986. In both programs, the benthos was sampled quantitatively at several stations including stations in Lydonia Canyon and on the adjacent slope. The canyon/slope stations were at three water depths: approximately 150, 550, and 2,100 m. Stations were sampled from 3 to 8 times. Sampling was conducted seasonally, but because we did not see pronounced seasonal effects, the results are presented as an overview for each station.

COMMUNITY STRUCTURE

To assess community structure of the infaunal benthos, we recorded species composition and abundance, and then determined which species were numerical dominants at a station on a given sampling date and over all sampling dates. We also looked at diversity using the Shannon-Wiener information index and the Hurlbert rarefaction method. Similarity among samples and stations was also evaluated using the NESS similarity measure, followed by cluster analysis.

150-Meter Stations

One of the two 150-m stations in Lydonia Canyon was sampled four times and then relocated, because at the first site we were sampling the wall of the canyon where sediments were highly variable. In general, sediments at this first site were very coarse, with less than 1 percent silt-plus-clay. At the new station location where sediments were finer, the average silt-plus-clay was about 30 percent. The slope station outside the canyon had fine sandy sediments, with about 2 percent silt-plus-clay.

Faunal Composition and Dominance

Species composition was strikingly different between the two canyon stations. Of the top 20 numerically dominant species, 8 were shared between the two stations, but none of the top 10 dominants at one station were among the top 10 at the other.

The dominant species at the coarse-sediment canyon station was a polychaete, *Lumbrineris latreilli*, which accounted for 7 percent of the fauna. The rank of several of the subdominants at the coarse-sediment station varied widely over the four sampling dates, probably because the same sediment type was not sampled each time.

At the fine-sediment canyon station, the top dominant was the amphipod *Ampelisca agassizi*, which accounted for about 12 percent of all individuals. This species consistently ranked either first or second, except once when it ranked fourth.

At the adjacent slope station, this same amphipod was the top dominant on each of 12 sampling dates. Here, however, *Ampelisca* accounted for 35 percent of all individuals. Comparing dominants between the canyon stations and the slope station, there were more in common between the coarse-sediment station and the slope station than between the fine-sediment canyon station and the slope station. Of the top 20 dominants at the coarse-sediment canyon station, 13 were also dominant at the slope station. Of the top 20 dominants at the fine-sediment canyon station, only 4 were also dominant at the slope station. Density was highest at the fine-sediment canyon station, followed by the coarse-sediment canyon and slope stations.

Diversity

We measured diversity using both the Shannon-Wiener information index and the Hurlbert rarefaction method. The coarse-sediment canyon station had the highest Shannon-Wiener diversity (5.41), followed by the fine-sediment canyon station (4.72). The slope station had the lowest diversity (4.25).

For the rarefaction method, we calculated the number of species expected for a given number of individuals. This method allows us to compare samples of unequal sizes by reducing them to a common sample size. According to this measure, the two canyon stations were less diverse than the slope station.

Similarity

Based on this analysis, we found that none of the three 150-m stations were really very similar to each other. The canyon station with fine sediments was seen to be most similar to a station in the "mud patch" located far to the west (on the shelf south of Martha's Vineyard). The coarse-sediment station was similar to a station near the head of Oceanographer Canyon, and the slope station was most similar to other slope stations near the drill site in Block 410, several kilometers away. Despite the dominance of *Ampelisca* at both the slope and fine-sediment canyon stations, the remaining faunal composition at the two stations was very different.

550-Meter Stations

There were two stations at 550 m, one inside the canyon and one on the adjacent slope. Sediment texture--a muddy sand--was very similar at the two stations.

Faunal Composition

As at the 150-m stations, faunal composition was very different between canyon and slope stations at 550 m. The same small polychaete, *Tharyx baptisteae*, was the top dominant at both stations, but it accounted for 32 percent of total individuals at the canyon station and only about 6 percent at the slope station. In all, of the top 20 dominant species, only 6 were dominant at both stations.

Many species occurred at both stations but in significantly different densities. We used analysis of variance to test for significant differences in mean densities of individual species found at both stations: in almost all cases, differences between stations were highly significant. For example, abundance of the bivalve *Nucula subovata* was significantly higher at the slope station, whereas the polychaete *Cossura longocirrata* was significantly more abundant at the canyon station. As at 150 m, total densities were much higher in the canyon than on the slope.

Diversity

Using either the Shannon index or Hurlbert rarefaction, the canyon station had lower diversity than the slope station. The Shannon H′ values were 4.66 in the canyon and 6.00 on the slope.

Similarity

We compared the 550-m stations among themselves and with all other stations sampled in the program. Cluster analysis of the 550-m stations showed the slope station near the canyon to be more similar to another 550-m slope station several kilometers distant than it was to the nearby canyon station. The same pattern was seen when all stations were analyzed together.

2,100-Meter Stations

We sampled three stations at 2,100 m: one in the canyon and two on the adjacent slope. At this depth, the story was very different from that at 150 or 550 m. At 2,100 m, the fauna at all three stations was very similar. The top dominant species at all three stations was the polychaete *Aurospio dibranchiata*, the dominant infaunal species at 2,100 m along the east coast of the United States at least as far south as Cape Hatteras. This species accounted for 8 to 11 percent of all individuals at each station. At shallower stations, the percentage contribution of the top dominant species to each community was very different.

Of the top 20 dominants at the 2,100-m stations, 11 or 12 were shared between the slope and canyon stations, compared to 4 or 6 species shared between canyon and slope stations at the shallower depths. Total densities were similar at all three 2,100-m stations.

Diversity

Also in contrast to the situation at the shallower stations, diversity was higher at the canyon station than at either of the 2,100-m slope stations, whether measured by Shannon-Wiener or Hurlbert rarefaction.

Similarity

At 150 and 550 m, the canyon stations were clearly different from the adjacent slope stations. At 2,100 m, the canyon station was highly similar to the slope stations.

SUMMARY

In conclusion, we see that major differences in community structure occur between canyon and slope stations at 150 and 550-m depth, but differences at 2,100 m are minor. Most interestingly, it appears that although subtle differences in sediment texture may account for faunal differences at 150 and 2,100 m, at 550 m the current regime may be more important than sediment texture.

At 550 m, the sediment texture was similar at both the canyon and slope station, but there is evidence that currents may cause much sediment resuspension (presentation by Butman).

There appear to be differences in epifauna on the slope and in the canyon at 550 m (presentation by Hecker). The red crab (*Geryon quinquidens*) is common on the slope and may cause greater predation pressure on the infaunal communities there.

RECOLONIZATION

Rates of recolonization were investigated using two designs of a free-vehicle sediment tray, which were used to expose defaunated sediments at 2,100 m. The sediment was frozen and thawed to kill all living organisms before being used in the trays. Based on field data, results from both designs were found to be comparable.

Sediment trays were placed at three stations at 2,100 m on the slope. Two were on the slope near Lydonia Canyon and one was several kilometers to the west. Trays near the Lydonia Canyon stations were exposed for 7 months, and those at the third station for 14 months. Average density at the 7-month stations was 35 individuals/m^2. At the 14-month station, after twice as long an exposure, density was about 12 times as great: 416 individuals/m^2. However, this still was far lower than the normal density of about 4,000 individuals/m^2. From these results, it is likely that deep-sea benthic communities would take years to recover from a catastrophic impact.

MASSACHUSETTS' PERSPECTIVE ON SUBMARINE CANYONS AND DRILLING AROUND THESE CANYONS

Ms. Patricia E. Hughes
Massachusetts Coastal Zone Management Office
Boston, MA

In late 1983 and through 1984, the Minerals Management Service, along with the National Marine Fisheries Service and the U.S. Geological Survey, worked on the development of a stipulation that prohibited drilling within 200 m of the submarine canyons in the North Atlantic OCS planning area. A further part of the stipulation required monitoring of exploratory drilling activities within 4 mi of the submarine canyons. This no-drilling stipulation was established for three reasons:

- to protect the unique biological habitats of the canyons (presentations by Dick Cooper, Barbara Hecker, and Nancy Maciolek discussed this aspect of the canyons. Dick called the canyons a very unique habitat and indicated that the canyons are important nursery areas for a number of species. Brad described the canyons as a complex environment.)

- to protect the important biological resources (Dick Cooper highlighted the variety of species using the canyons that are subject to the commercial fishery.)

- to avoid spatial exclusion of fishing activity and minimize conflicts between fishing (particularly pot fishing for lobsters and red crab and long-line fishing for tilefish and swordfish) and petroleum activity

Five years after the no-drilling stipulation, it is my opinion that the information we've heard today reinforces the original no-drilling stipulation. If the stipulation did not exist, the canyons would be viewed as areas of special biological significance, and stipulation 2 (the biological stipulation) would be invoked. There would likely follow debate on whether drilling should be allowed. If drilling were allowed, discharges might be prohibited. If not prohibited, it is likely that discharge restrictions would be required, as well as monitoring. The MMS has traditionally taken the position of conditioning activity, and placing restrictions on drilling activity in order to avoid deferring areas from leasing.

The MMS has taken this approach in some controversial areas, and in many areas it has been a sensible method. But, in the North Atlantic, the information argues for no drilling in submarine canyons, and further argues whether, in fact, the 200-m exclusionary zone is sufficient.

I will close by noting that, although the present focus is exploratory drilling, the potential impacts of development and production are what most people are concerned about. The reasons include:

- transport of materials
- pollutants attached to fine-grained sediments
- question of the fate of fine-grained materials in the canyons
- recognition of the unique canyon habitat

All four argue for preventing these areas from being leased in the first place.

THE RHODE ISLAND PERSPECTIVE ON SUBMARINE CANYONS

Mr. Bruce F. Vild
Division of Planning
Rhode Island Department of Administration
Providence, RI

Even though this workshop and the studies program focus on science, I hope everyone recognizes that science is only one facet of the controversy over submarine canyons. Politics, economics, and public opinion enter strongly into the policy equation--and influence the governors' decisions, in Rhode Island and elsewhere.

In New England, public opinion favors the fishermen. New Englanders are suspicious of the oil companies, and by extension, the Department of the Interior. Both are seen as a threat to fisherman. Attitudes displayed at public hearings demonstrate this clearly. Some of the notions held by the general public about fishermen and the environment may seem romantic, but they must be not be ignored. They have an impact.

Supporting offshore drilling is unpopular in New England. Any policy that a governor makes endorsing OCS exploration has to be tempered, not only by environmental and scientific considerations, but also by political ones. For my governor, or any governor, to support drilling in submarine canyons, it will require far more than a statement that such activities are relatively benign--assuming that such a statement is defensible. (Rhode Island is on record opposing leasing and drilling in the canyons.)

On the economics side, the governors have to ask this about OCS exploration: what's in it for New England? Are the oil companies willing and able to make any long-term commitment to the economic health of the region that will balance the risk (perceived or actual) of allowing drilling--especially in such controversial areas such as the submarine canyons? Since there have been eight dry holes on Georges Bank, there is no direct evidence that New England is going to benefit by its governors supporting offshore drilling. Because the odds are against finding oil and gas in the North Atlantic, the oil companies simply can't make any guarantees that would make a governor's policy-making easier if he or she decides to endorse a drilling program.

The voters know the fishermen and the environmentalists. They don't know the oil and gas explorationists. The oil and gas explorationists don't have a permanent presence in New England. When criticisms of the industry are made or issues arise, there is no spokesperson for them to provide a counterpoint to advocates for the fishermen and environmental groups. Public opinion responds accordingly.

These are the political realities. And decisions are made by elected officials--who are very sensitive to public opinion.

So, although I hope science will continue to play an important role in the submarine canyon controversy, we have to keep in mind that science is not the only thing that will be considered if the canyons are ever offered for lease.

DISCUSSION

Aurand: Considering that exploratory drilling on Georges Bank didn't cause any damage, why has this fact been unsuccessful in reducing tension?

Vild: I'm not convinced that opposition hasn't lessened, at least from some of the fisherman's groups, but there seems to be a consolidation of interest around certain points--the submarine canyons, for example.

Hughes: For various reasons, including increased public awareness of the Georges Bank fishery with passage of the 200-mi limit, research funded by DOI that has helped to better define the Georges Bank system (for example, described features that make Georges Bank "special"), reduction in resource estimates, and now, shared jurisdiction with Canada, and different national philosophies on petroleum development and fisheries management, there is heightened interest in the region. And, to most people, Georges Bank means "fish."

Ray: I see some hypocrisy here. There should be an environmental impact statement on the different fisheries. In truth, there are many tradeoffs involved with the fish that goes on your dinner table. Fishing tears up the environment and, because of the by-catch, is often very wasteful.

People aren't being honest with themselves. On the one hand, they're talking about hypothetical impacts, and on the other, they're overlooking actual impacts and damages that are quite routine.

Hughes: The science of fisheries management is as inexact as is the predicton of the effects of oil and gas activities. The public is realizing that there are questions about the conduct of the fisheries and on conservation and management efforts.

Vild [on the subject of trying to avoid conflicts between the industries or with the environment]: How about directional drilling in canyon areas?

Ray: Industry prefers straight drilling in the exploratory phase, but development could use directional drilling.

Cooper: Looking at the fisheries in general, the likely impact (negative) of oil and gas drilling operations on the commercial fisheries of submarine canyons is greatly overshadowed by living resource losses. These losses are due to man's inability to wisely manage the fisheries, the industry, or the ocean-floor environments that support a major portion of the fishery, for example the groundfish (flounder, hake, cod, lobster, etc.) fishery. At some point in the future, when oil prices rise, and our production is lower than it is now, what will we do then? The issue now is a relatively easy one--compared perhaps to the future.

Vild: Jim Ray, what are the prospects of direct industry-to-industry talks...that address topics like space restriction and gear loss? Can the two industries come to a consensus?

Ray: There has been progress along this line in Alaska and California, for example. There is a liaison office in California that provides a good model to build on.

Teal: I suggest that exploration be decoupled completely from development and production. Then, exploration could assess the resource, without an automatic follow on. Decisions on production and development could be made with the knowledge of the value of the resource present.

Vild: That wouldn't work unless the government was willing to subsidize exploration.

Ray: Industry would object to the government getting into the exploration business. Competition and sharing of information would be factors.

Teal: I'm not saying that it's easy or even possible, but to decouple the process would allow the public to know the value of the resource prior to leasing for development.

ROUNDTABLE DISCUSSION:
SUMMARY AND SYNTHESIS
GEOLOGY AND GEOCHEMISTRY OF NORTH ATLANTIC SUBMARINE CANYONS

Dr. Bradford Butman, Chairperson
U.S. Geological Survey
Woods Hole, MA

Following the first day's scientific presentations, a roundtable discussion of existing information on submarine canyons was held with an eye toward producing a consensus summary document. The focus for consensus was to be on mechanisms and not necessarily impacts. Agreement on mechanisms is necessary to assess potential impacts of drilling from routine operations and discharges, accidental spills, and "worst case" events.

GENERAL DESCRIPTION OF CANYONS

The submarine canyons that incise the southern margins of Georges Bank vary in size, shape, and length. In some cases, they extend for long distances past the shelf break onto the continental slope. Studies have been conducted both in shallow- and deep-water parts of the canyons (see background papers given on Day 1 of the workshop). These studies have shown that canyons exhibit widely different sedimentary environments. Characteristics which differ from canyon to canyon include sediment texture, bottom currents, and intensity of erosional and depositional processes.

The workshop conclusions focus on the shallow parts of the canyons,* defined as the area from the canyon head to the point where the canyon crosses

*See also reviewer comment in Appendix A.

the shelf-slope break (200-m isobath). These canyon areas (enclosed on three sides by the shelf) are those most likely to be impacted by drilling on the shelf, on canyon rims, and on the uppermost slope near the canyons.

Butman offered a series of general statements based on the concept of a "typical" canyon, with a length of 10 to 20 km, a depth of 500 to 1,000 m, and a width at the mouth of approximately 5 km (Figures 19 through 22 illustrate a variety of canyon types in the Georges Bank region). Although the axis and rim areas comprise a small portion of the total area of canyons, most of the biological and geological sampling has been done in these areas. In contrast, many of the visual observations made by submersibles in canyons have come from the canyon walls. Nearly all the information to date has been obtained from the upper portion (less than 700 m) of a very few canyons.

PHYSICAL FEATURES OF CANYONS

Many statements presented in the workshop were largely applicable to the large, deep canyons such as Oceanographer, or the generic canyon presented in the preceding figures (Figures 19 to 22). These statements were progressively amended during discussion to include conditions and mechanisms found in other, generally smaller canyons such as Lydonia. Throughout the workshop the question was posed, in a number of different forms, as to just how applicable many of the broader statements were to canyons in general.* The heterogeneity of canyons was widely recognized.

There was consensus on the fact that canyons are unique habitats and environments--as compared to slopes at comparable depths.

The general categories by which canyons could be defined as unique were:

- Topography and features: canyon shape, substrate type, and patchiness;

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*See also reviewer comment in Appendix A.

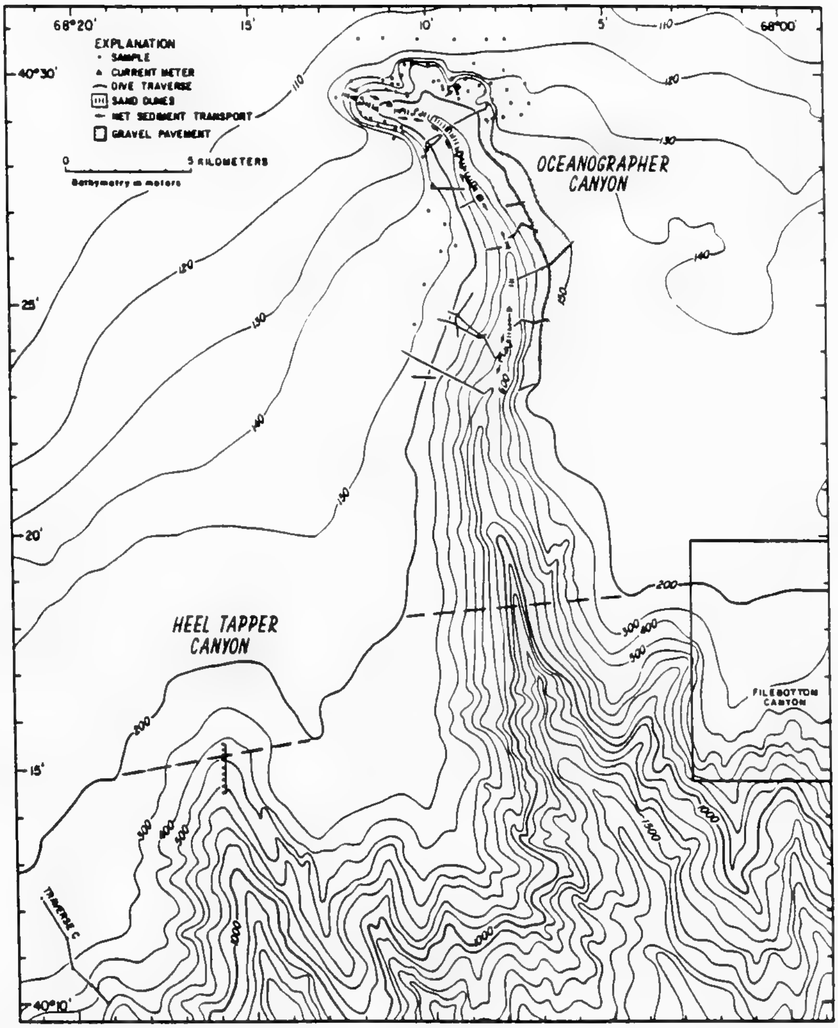

Figure 19. Map of Oceanographer, Heeltapper, and Filebottom Canyons located on the southern margin of Georges Bank. Oceanographer is a large canyon, and its shallow northern part incises the continental shelf for 25 km. By contrast, Heeltapper is a small canyon that incises the shelf north of the 200-m isobath for only 3 to 4 km. Filebottom canyon is a slope canyon that does not cut into the shelf. Dashed line is location of section in Figure 11 (adapted from Valentine 1987).

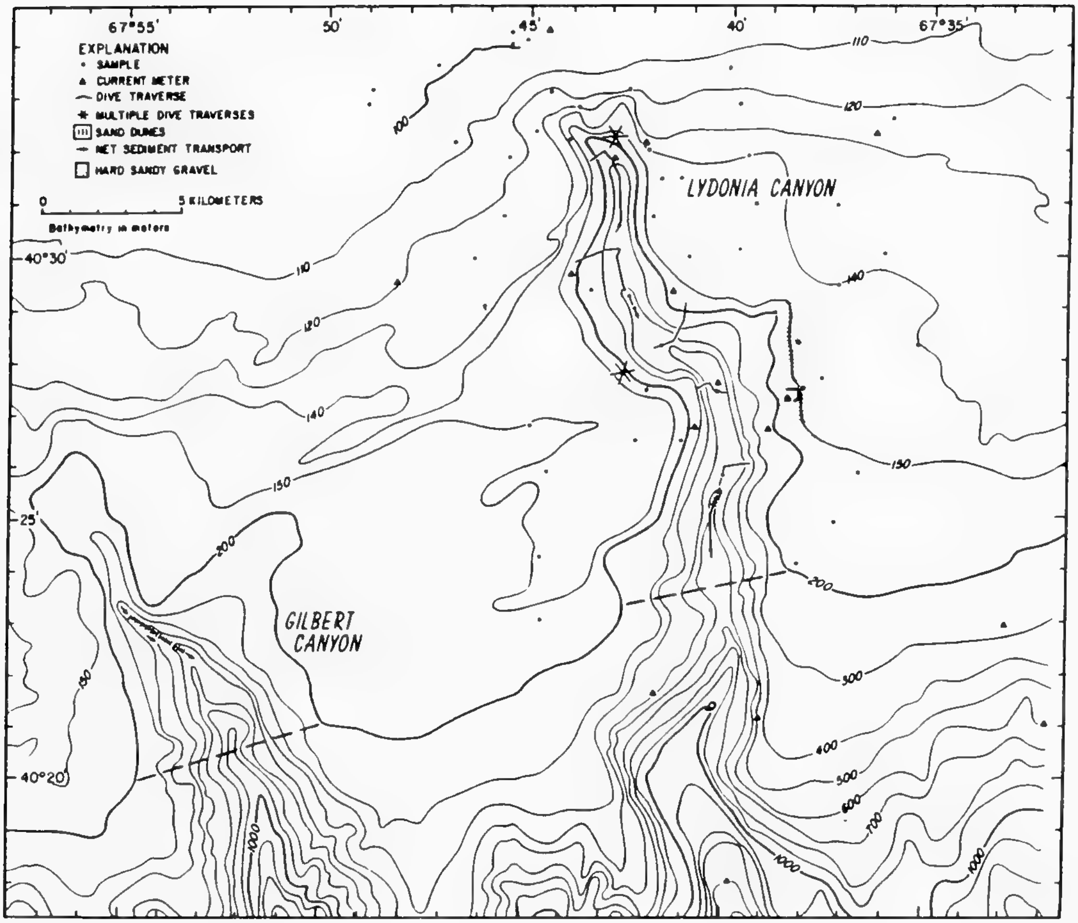

Figure 20. Map of Gilbert and Lydonia Canyons located on the southern margin of Georges Bank. Gilbert, a large canyon, has greater volume and relief than Lydonia, a median-size canyon, which is longer. Dashed line is location of section in Figure 11 (adapted from Valentine 1987).

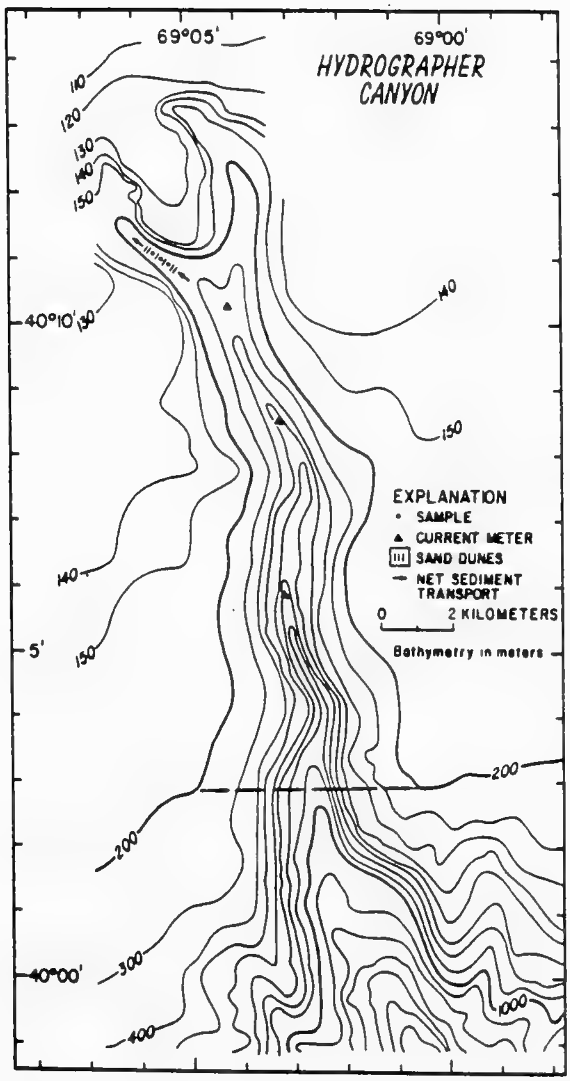

Figure 21. **Map of Hydrographer Canyon, a large canyon located on the southern margin of Georges Bank.** Dashed line is location of section in Figure 11 (adapted from Valentine 1987).

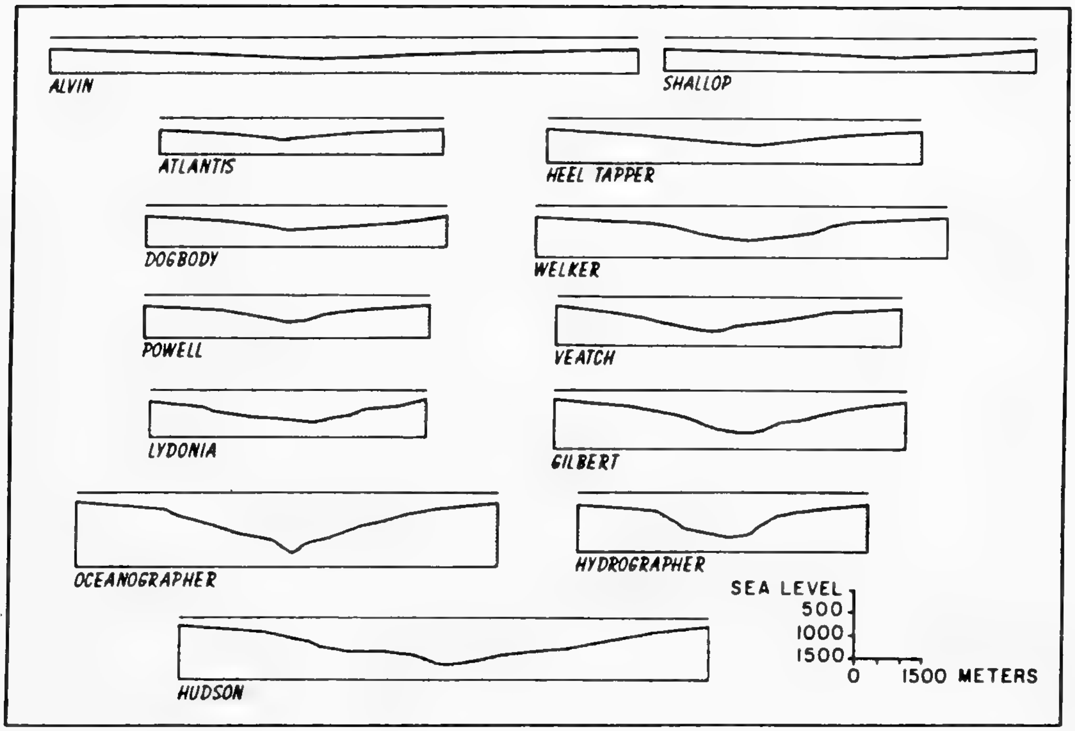

Figure 22. Cross section of 12 Georges Bank (North Atlantic) canyons and Hudson Canyon (Middle Atlantic) at the 200-m isobath (see dashed lines in Figures 8 to 10). Horizontal line above each section is sea level. No vertical exaggeration. (Figure from Valentine 1987).

- Currents: decoupled from the shelf flow; stronger or weaker; extremes in current speed: net and oscillatory flows;

- Resuspension of fine-grained sediment: intensity and frequency;

- Species diversity and density: epifauna and infauna; different trophic structure and feeding strategies;

- Role in fisheries: largely untrawled areas; nurseries for shelf fisheries; refuge sites; stock populations;

- Different geochemical environment and potential for pollutant scavenging as expressed by different lead-210 and plutonium-239/-240 inventories;

- Sediment accumulation rates: higher or lower.

QUESTIONS

To match scientific questions with supporting data, a list of questions was developed in the general area of the geology and geochemistry of submarine canyons. Each question was followed by a short list of data categories. Each category is assessed as to whether the data support the idea (Y or N in the first column); and which canyon(s) provided the data (second column: O=Oceanographer; L=Lydonia; A=Atlantis; H=Hydrographer.)

- Do particles (sand and fine-grained sediment) enter canyons from the shelf, based on:

	Y/N	C
1. Flow regime and calculations?	Y	L
2. Barium concentrations?	Y	L

3.	Submersible observations?	Y	O,L,A,H
4.	Sediment texture?	Y	O,L,A,H
5.	Seismic surveys?	Y	L
6.	Accumulation rates?	Y	L

Sources: Butman for flow regime, Bothner for barium and accumulation rates, Valentine for submersible observations and textural analysis, and Twichell for high-resolution seismic data.

This information as presented met with general agreement.

- Does fine-grained sediment accumulate on canyon floors (over last few thousand years)?

		Y/N	C
1.	Measured accumulation	Y	L
2.	Texture and bedforms	Y	L
	Texture and bedforms	N	O
3.	Seismic surveys	Y	L
4.	Convergent transport	Y	L

Sources: Butman for convergent transport data, Bothner for measured accumulations, Valentine for texture and bedforms, and Twichell for seismic data.

There was general agreement that fine-grained sediment accumulates on the floors of canyons of moderate size and energy, such as Lydonia, but not on the floor of the best known large, deep, and high-energy canyon, Oceanographer.

■ Is there evidence of contaminant accumulation, based on:

		Y/N	C
1.	Sediment resuspension (stripping, scavenging)?	Y	L,O
2.	Lead-210 and plutonium-239/-240 inventory?	Y	L
3.	Lead-210 and plutonium-239/-240 concentration?	Y	L
4.	Trace metals?	Y	L
5.	Hydrocarbon concentrations?	N+	

+except Hudson canyon, where sludge dumping occurs

Sources: Bothner is source for the first four data categories, Boehm for hydrocarbon data.

It was generally agreed that there is a high potential for contaminant accumulation in canyons where fine-grained sediments are accumulating. This is most clearly the case in Lydonia Canyon where resuspension of sediment augments contaminant scavenging by fine sediments.*

*See also reviewer comment in Appendix A.

DATA NEEDS

A few of the limitations of the available data were discussed, and several areas of scientific information needs were listed:

- Physical processes: largely confined to water depths between 100 and 750 m, mostly in two canyons (Lydonia and Oceanographer)
- Lead-210 and plutonium-239/-240 data as an indicator of sediment stripping efficiency
- Rates of sediment accumulation and transport: canyons are possibly "leaky systems"
- Radioisotope studies limited to one canyon (Lydonia)
- Biological processes, including mechanisms controlling species diversity: variable substrate, limited exploitation, and temperature controls
- Geochemical data: walls vs. axis
- Textural data: none below 750 m

Aurand observed that agreement on things known was more useful for MMS purposes than agreement on things unknown.

ROUNDTABLE DISCUSSION:
SUMMARY AND SYNTHESIS
BIOLOGICAL COMMUNITIES OF NORTH ATLANTIC SUBMARINE CANYONS

Dr. Barbara Hecker, Chairperson
Lamont Doherty Geological Observatory
Palisades, NY

Barbara Hecker assumed the chair for the discussion of biological communities in submarine canyons. In somewhat the same format as Butman, she presented a series of statements for discussion, amendment, and consensus.

- Do biological characteristics of canyon populations differ from those of the outer continental shelf/upper slope in the following ways?

	Megafauna (all canyons)	Infauna (Lydonia only)
1. Higher Biomass	Y	Y
2. Higher Density	Y	Y
3. Faunally mediated contaminant concentration via filter feeding strategies (inferred)*	Y	Y
4. Nurseries for commercial species	Y	-
5. Higher concentration of commercial species	Y	-

*See also reviewer comment in Appendix A.

6. Species composition shifts	Y	Y
7. "Distinctiveness" of canyon species	Y	?

"Distinctiveness" was expressed in a number of different forms: "canyon indicator" species and communities, "unique" species and communities, and commercially important species "typically" found in canyons. Although it was agreed that no species is unique to canyons, a number are particularly diagnostic of canyon environments. These include the white hake, tilefish, lobster, and various corals and sponges. Further discussion dealt with various aspects of canyon populations including: migratory species vs. permanent residents; mobile vs. attached (sessile) forms; and juvenile forms that use canyons as nursery sites. Cooper stated that canyons are unique for lobsters in that they serve as a major nursery site as well as home grounds. Valentine said distinctive bottom communities such as the "pueblo villages" (burrowed outcrops of Pleistocene silt that harbor a diverse fauna of fish and crustaceans) are found in some larger canyons but not in small, shallow canyons or gullies such as Heeltapper, Filebottom, and Dogbody. It is difficult to agree on a generic "canyon" classification when present data suggest there are at least three types of canyons along the Georges Bank shelf. Butman suggested that the biological characteristics could be applied on a canyon-by-canyon basis. Teal pointed out that the people presently discussing the issues were best qualified to do that.

POSSIBLE BIOLOGICAL IMPACTS

Hecker continued with a series of questions on possible impacts of drilling on canyon communities.

- What are the "stock" populations in canyons and how are they influenced?

- What controls settling success in benthic communities? What are the cues in settling? Are they physical? Are they chemical? What concentrations of what contaminant may interfere with the cues?

- Are there different impacts at different life stages for the same organism?

- What are short-term impacts vs. long term impacts?

Teal expressed the opinion that very often it takes at least a 10 percent change in the physical environment before an animal perceives it. Offering a very conservative opinion, he suggested that a 1 percent change in an environmental parameter to which animals are particularly sensitive would have no impact on an organism or a community. If the parameter starts at a value well below that to which the animal is sensitive, a much larger change would have no effect.

Cooper asked what specifically were the real dangers of drilling? Are direct impacts such as suffocation by cuttings and drilling mud adjacent to rigs more important or of greater concern than (as an example) impacts related to the uptake of heavy metals? Ayers suggested that immediate impacts are restricted to within a few hundred meters of the drill site and no significant heavy metal impact has ever been seen. Most drilling mud metals are very insoluble and the only ones present in concentrations significantly higher than concentrations found in marine sediments are barium and sometimes chromium. There is no evidence to suggest that barium, when present as barium sulfate as it is in drilling mud, is a "bad actor" when introduced to healthy marine populations. Ayers stressed that barium (as barium sulfate) is the only drilling-mud component that is elevated in the sediments at distances greater than a few hundred meters from the wellsite.

Cooper suggested that, under conditions of normal drilling operations, there would be no measurable impacts. He then suggested that, in a "worst case" scenario (a major oil spill), there may still be only short-lived impacts. Since most commercially valuable species in the canyons are mobile and fast and grow to maturity at a young age,* most populations would be capable of bouncing back from even a major oil spill.

Neff stated during this discussion that the major impact would be to surface waters, possibly eggs and larvae of fish, and that may include cod, haddock, and others. Neff further stated that he did not know of a mechanism to transport enough oil to the bottom to cause any serious long-term impacts. For example, with cod fish, the eggs are on the bottom, they rise to the surface, and then gradually sink back down again. So there is a period where they are in the top meter or two. The fishing modelers hypothesize that the period at the surface is the only opportunity for serious impact. Teal suggested that a major oil spill was not the only "worst case" scenario. For example, if one could imagine an event that transported a large amount of long-lasting, toxic materials to the bottom in a localized area such as a pueblo village, that might have a much grater effect than oil spilled on the surface, little of which would even reach the bottom near canyons.

IMPACTS ON SESSILE ORGANISMS

Hecker stated that since commercial species are mobile and have rapid growth, one would expect primarily short-term effects. But with sessile species, effects are more likely to be long term. In a worst-case scenario, where one would wipe out a local population, there would be concern about the sessile organisms. If you wipe out a population in one canyon, have you wiped out the entire "stock" population of that species, or is there substantial transport and recruitment between canyons? She said that her instincts are that the effects will be longer term, because the sessile organisms can't

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*See also reviewer comment in Appendix A.

"walk in" and repopulate an area. This leads to the question of how much of the stock population are you wiping out? It will be a much higher percentage for the sessile organisms that inhabit the canyons. Ayers and Hecker agreed that the deeper one goes, the longer recolonization would take, and the more sensitive the organisms become.

GEOGRAPHIC EXTENT AND AREA OCCUPIED BY CANYONS

Cooper stated that 20 percent of the upper continental slope off Georges Bank is occupied by submarine canyons.* Hecker questioned whether the small "noncanyons" should be subtracted. Teal summarized by saying that there seems to be general agreement that the canyons occupy a substantial portion of the upper slope.

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*See also reviewer comment in Appendix A.

FINAL SUMMARY SYNTHESIS AND CONCLUSIONS

CHARACTERISTICS OF CANYONS

To best summarize the information presented in a full day's scientific presentations and nearly a full day of roundtable discussions, "information capsules" were prepared on the principal topics that seemed to underlie the conclusions and recommendations of the scientific panel. These capsules follow on the next several pages.

Submarine Canyons - Special Environments

Submarine canyons support a higher concentration (numbers, biomass, and diversity) of large, bottom-dwelling animals than adjacent environments on the continental shelf. The high biomass and diversity of commercially important species such as lobsters, crabs, shrimp, flounders, hake, ocean pout, cusk, and tilefish at the heads of canyons is primarily due to the wide variety of substrate types. These substrates provide three-dimensional shelters, including burrows and grottos excavated by the animals. Such shelters are frequently utilized by juveniles, making the canyons important nursery grounds. At greater depths along the canyon axis, and down the walls, are a variety of corals and sponges. Many of these corals and sponges, along with the cleaner shrimp, black-bellied rosefish, and tilefish from the shallow regions of the canyon heads, are found only in canyons. Also, several species that are common on the continental slope, such as brittle stars, long-nosed eels, rattail fish, and sea pens, are found in much higher abundances in canyons. The specific species composition varies from canyon to canyon, probably reflecting physical differences among canyons. The sessile species in the deeper canyon axis may represent an important proportion of the total local population. These stock populations may be necessary for future recruitment to other areas. The submarine canyons of the northwest Atlantic that fit this characterization are the following:

Corsair	Heezen
Powell	Lydonia
Gilbert	Oceanographer
Hydrographer	Veatch
Atlantis	Block
Hudson	Norfolk

There are other, smaller canyons and gullies, but they more closely resemble habitats on the continental slope, or have not been studied.

Submarine Canyon Morphology and Sedimentary Environments

Submarine canyons on the southern margin of Georges Bank exhibit wide variability in size and shape. Canyon morphology modifies axial current flow that, in turn, is linked directly to variability of sedimentary environments. The largest canyons incise the shelf 13 to 25 km and have 750 to 1,000 m of relief at the shelf break (200 m). They are characterized by strong currents and heterogenous sedimentary environments that include large areas of gravel, rippled and duned sand, and bioeroded Pleistocene silt and clay outcrops. Medium-size canyons (8 to 18 km length, 320 to 520 m relief) and small canyons (2.5 to 5 km length, 200 to 300 m relief) exhibit proportionally less textural variability and lower energy levels. The smallest canyons are broad embayments of the shelf edge, and sediment texture is similar to the homogeneous silty sand that covers the upper slope. Source areas of sediment for the canyons are the continental shelf and bioerodable Pleistocene silt and clay that veneers canyon walls.

Erosional processes on the bank margin include (a) sand transport from the shelf edge and canyon rims to the upper slope and canyon walls, respectively; (b) winnowing of fine sediment from sand on the upper slope in the 200 to 300 m depth interval; (c) bioerosion of Pleistocene silt and clay outcrops on canyon walls; and (d) winnowing and re-suspension of fine sediment from sand, silt, and clay deposited on canyon floors.

Deposition of sediment occurs as follows: (a) sand, silt, and clay on the upper slope below 300 m; (b) fine sediment around canyon heads; (c) sand (containing little fine sediment) on the floors of large canyons; and (d) sand, silt, and clay on the floors of medium and small canyons.

The physical environment of the canyon is reflected in the fauna. The largest canyons contain the most heterogenous bottom (habitat) types, and the epibenthic fauna there exhibits the highest diversity and greatest biomass. Medium canyons are less diverse, and the fauna of the smallest canyons resembles that of the upper slope due to the absence of hard substrate for attached organisms. However, at deeper depths, these smaller canyons may support high concentrations of "canyon indicator" taxa. This is true, for example, in Heezen Canyon off Georges Bank and Hendrickson Canyon off New Jersey.

Sediment Resuspension and Potential for Pollutant Transport on Particles

The processes of sediment resuspension are more frequent and much more intense in the axes of Lydonia and Oceanographer Canyons than on the adjacent continental shelf, or at comparable depths of the continental slope. Sediment traps placed 5 m above the bottom in the canyon axis collected about 8 and 60 times more sediment than on the continental shelf and slope, respectively. This greater resuspension activity in canyons increases the opportunity for particles to adsorb and transport dissolved contaminants from the water column to the bottom sediment. Measurements of lead-210 and plutonium-239/-240 distributions in sediment cores from the axis of Lydonia Canyon and from the open continental slope (both locations at the 630-m water depth) support this hypothesis. The behavior of these isotopes in the marine environment, by virtue of their affinity for particulates, is analogous to the behavior of many contaminants. Both isotopes have inventories (disintegrations per minute per cm^2) that are 2.5 times higher in the canyon axis than on the slope.

Specific activities (dpm/g) are also much greater in the canyon axis, indicating that enhanced scavenging rather than preferential deposition of particles containing these isotopes accounts for these differences. The greater inventories of isotopes found in Lydonia Canyon suggest that this environment has a greater potential for scavenging dissolved contaminants than noncanyon areas.

Canyon Fisheries

Several commercial species (lobster, Jonah crab, red crab, witch flounder, four-spot flounder, white hake, squirrel hake, ocean pout, and tilefish) are found in high abundance in the heads of submarine canyons, due in part to the wide variety of low relief, three-dimensional habitats. Fishing methods directed toward these species include traps and long- line (baited hooks) gear. Mobile gear (trawls, dredges) is not used in the canyons, so there is no physical damage to the habitats as has occurred in historic fishing areas on the shelf and slope. Submarine canyons therefore function as refuges ("home territory") for a number of commercial species and their food organisms. All of these species are mobile and, with the exception of tilefish which are very faithful (endemic) to a given tunnel or grotto shelter, are likely to move out of the canyon head or along the rim or wall if subjected to any stress. The most mobile (migratory) of these species, the lobster, is known to undergo extensive seasonal migrations inshore, offshore, and along the shelf. Approximately 75 percent of the offshore lobster catch and 95 percent of the tilefish catch emanates from the submarine canyon populations.

POSSIBLE IMPACTS

As in the previous section, information capsules are presented for topics that are likely to be considered in relation to environmental impacts of petroleum activities.

Estimating Impacts

One approach to estimating how much of an impact oil and gas activities could have is to make a simple calculation (following an earlier suggestion to consider worst-case scenarios). To do so, we assume a reasonable discharge of contaminants that are transported into a small area at the canyon head or axis. The accumulation is then assumed to be evenly distributed into a thin layer of surface sediment and the resulting concentration is compared with background concentrations.

We assumed the contaminants would not settle disproportionately near the drill site, but would be spread evenly throughout the 1 km^2. We also assumed that the materials would be mixed into a 1-cm thick surface area. (Biological mixing of materials within sediments is often deeper than this, and in regions of high current velocities, physical processes can mix sediments deeper than 1 cm.

All three assumptions (area covered, depth of mixing, and amount transported) yield a worse-case result--because the area covered and depth of mixing is less then actually expected, and the amount transported is greater than actually expected.

Based on these worst-case assumptions, however, we can consider the potential elevation of the metal chromium present in drilling mud at a concentration of 200 mg/kg. If we assume a total discharge of 1 million kg of drilling mud/well, evenly distributed over 1 square km of canyon floor, and mixed to a depth of 1 cm, that would add 20 ppm to the chromium content of the top centimeter of sediment. Background values average 45 ppm (ranging from 35 to 80 ppm) in Lydonia Canyon, so the increase is on the order of 45 percent. However, this increase assumes that all of the drilling mud reaches the canyon, and all of it is deposited in 1 square kilometer. For perspective, consider that the world average chromium concentration in crustal rocks is 100 ppm.

The same hypothetical worst-case scenario can be used to estimate the potential changes to the physical nature of the sediments. The deposition of this drilling mud would contribute at most 10 percent to the mass of natural sediment in the upper 1 cm over the 1 square km area. Barium sulfate, the only component of drilling mud with significantly higher density than natural sediment, represents a variable fraction (one half to two thirds) of the total drilling mud by weight.

Generally, deposition of particulates from drilling muds beyond the wellsite should be at a relatively low rate: 0.1 cm/yr, compared with 0.06 cm/yr for natural deposition (also a low rate, based on measurements near the canyon head).* Such deposits are unlikely to threaten megafauna, including commercial fish and invertebrate species, except possibly in their early life stages. At the expected low rate of deposition, material derived from drilling muds should be quite thoroughly mixed into natural sediments by physical and biological processes. Moreover, depositions from the drilling mud represent only a fraction of total depositions from all sources in a highly active environment. Thus the physical effects on the substrate beyond 500 m should be quite small.

Because, at least in some canyons, some turbulence and resuspension occurs normally, some or most canyon fauna are not particularly sensitive to sediment in the water. Therefore, the principal effect of the drilling muds on the biota, beyond the near-field blanketing of the bottom, is likely to be chemical. Although chemical constituents of drilling muds may not cause direct mortality, there may nevertheless be an effect upon sensitive organisms. Chemical cues may affect larval settlement or behavior and hence recruitment.

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*See also reviewer comment in Appendix A.

Life Stages and Sensitivity

Larvae are more sensitive than adults to contaminants and early juvenile stages are particularly sensitive to physical disruption. Inhibition of larval settlement on sediments whose attractiveness is affected by contaminants could result in reduced recruitment of commercial species. Any disturbance that drives juveniles from their nursery habitat will expose them to more predation.

Drilling Muds

Assuming a wellsite 1 km from a canyon rim, the available information suggests that very little biological impact due to drilling can be expected within the canyon. The main concern during the exploration phase is drill muds and cuttings, most of which would initially accumulate within 200 m of the platform.* Some quantities can be expected to drift into the canyon, especially if it is downcurrent from the platform. However, there is little or no chance of burial of organisms or of chemical contamination of the sediments, much less bioaccumulation of harmful materials at distances greater than a few hundred meters from the wellsite. The metals found in drilling muds are virtually all insoluble, and thus not available to animals. Furthermore, barium, the most plentiful metal in drilling muds, is not toxic to marine organisms when present as barium sulfate. In general, drilling-mud metals are present in chemical forms that limit their bioavailability to marine organisms.

Produced Water

Produced water is usually a saline brine with constituents similar to those in seawater, as well as some hydrocarbons (including aromatics) and metals. The metals may be concentrated up to three orders of magnitude above

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*See also reviewer comment in Appendix A.

seawater levels but all the constituents of produced water are diluted very rapidly and would pose no problem in a canyon 1 km from the source. Even in a worst-case situation in shallow water in the Gulf of Mexico over a period of several years there is very little evidence of any effect of hydrocarbons from normal drilling and production operations. The same is true of radionuclides--there is some radium (radium-226 and -224) in produced water, but there is little signal beyond the immediate discharge site. Bioaccumulation of radium is possible, but there is no evidence to date suggesting that it has occurred.

Amounts of produced water are highly variable; the average per platform in the Gulf of Mexico is around 2,000 bbl/day. Volume increases with the age of the well. There is little produced water associated with gas production. A calculation illustrates the small effect of the produced water. At 50 ppm X 2,000 bbls/day, 16 L of oil and grease are discharged daily in the produced water.

Physical Obstructions

Anchors could be used to secure a semi-submersible drilling platform during exploration; for production, bottom-mounted rigs with no anchors would be used. Anchors could extend radially up to 1 mi from the platform, but there would be no need to locate one close to a canyon rim. Anchor impact on the bottom is small. It was estimated that even if full production were to take place on Georges Bank there would be no more than 30 platforms*--the number in the much more productive North Sea. Current shear like that found at the shelf edge, even with warm-core rings, would not present an engineering problem for drilling given the expected water depths.

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*See also reviewer comment in Appendix A.

Blowouts

Environmental impact due to accidental blowout is predominately a problem only on the surface, where the impact would depend on timing and presence of fish eggs and larvae.

Gas Blowouts

There are few studies of gas blowouts reported. There has been one report for a gas blowout in the North Sea, and perhaps two studies of gas blowouts in Canadian waters--one in the Arctic and the other in the Canadian Atlantic.

Most of the gas blowouts occur on the platform itself, so there is a combination of sand, rocks, gas, and water blown into the air. Very few of the situations actually happen subsurface, so high volumes of gas are not generally injected directly into the water. The exception may be with shallow-water gas blowouts, where there are ruptures outside the casing. The gas is volatile and would disappear quickly.

Hydrocarbons

Increased particulates scavenge hydrocarbons from the water column during spring bloom conditions. The settlement of this material to the bottom could produce impacts. From this source, a gradual increase in hydrocarbon accumulations in surficial sediments from produced water are likely to be undetected, and because the rate is low, it may be substantially offset by breakdown processes. However, net hydrocarbon accumulations, if they occur, would likely be due mostly to other sources, such as accidental spills from ships, etc.

CONCLUSIONS

After nearly two full days of reviewing the scientific facts, as recorded in this report, a workshop consensus was reached on several findings and recommendations.

- No rig should be closer than 500 m to the boundary of a canyon, as defined by NOAA, because:*

    1. It would prevent disturbance to the boulder fields and "pueblo villages" that are important nursery areas.

    2. It would exclude accumulation in the canyon of any rapidly settling material (cuttings, a major fraction of the drilling muds, and debris dropped off the rig);

    3. Direct burial and smothering of organisms in the canyon would be avoided;

    4. There would be greater opportunity for increased dilution of waterborne contaminants; and

    5. This setback would appear to have little impact on the feasibility of exploration or production drilling.

- Dilution of metals in the water column indicates that they are unlikely to cause biological problems, although some increases might be measurable.*

- Barium accumulation is expected, but because of its low toxicity,* it is unlikely to have a measurable biological effect.

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*See also reviewer comments in Appendix A.

- It is unlikely that settlement of fine material from drilling would alter the physical characteristics of the canyon sediment enough to preclude settlement by larvae of benthic organisms.* This conclusion was based on a worst-case order-of-magnitude calculation similar to that for the metals.

- Given a 500-m setback, it is unlikely that drilling muds and cuttings would produce any measurable effects on the commercial species in the heads of canyons.

- Given the low volume and high dilution, deck drainage and sewage discharges are minor contaminants, and therefore are expected to have no measurable input--compared to other discharges.

- Produced water must meet the current Environmental Protection Agency discharge standard, presently no more than 48 mg/L (ppm) of oil and grease.

- Information on the concentrations of hydrocarbons and metals in produced waters suggest no effects are expected in the water column. Benthic effects are not expected but gradual accumulation of hydrocarbons on the bottom has been shown in shallow water. If production were to occur without further study of this benthic hydrocarbon accumulation, discharge of produced water should be monitored. It is more likely that hydrocarbon buildup would be related to spills and blowouts.

- During oil spills and blowouts, there is a possibility of higher accumulations of hydrocarbon in canyons than on the adjacent slope (for example, in krill, or due to sedimentation and resuspension processes).* However, the major short-term impacts would occur in the surface layer and at the shelf water/slope water front. Benthic

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*See also reviewer comments in Appendix A.

impacts, if they occur, are likely to be the result of oil adsorbed on the particles accumulating on the bottom over a long period of time.

Major short-term impacts will occur in the sea-surface layer, especially at the shelf water/slope water front.

For major short-term impacts, planktonic eggs and larvae of canyon fauna, especially commercial species, would be most vulnerable; however, the magnitude of the impact is too dependent on a specific situation to quantify.

- Insufficient information exists to evaluate the possibility of impacts from gas blowouts.*

- Canyons represent a large fraction of the fishing grounds for some species. The 500-m setback should minimize a portion of this space conflict. Anchor lines could occupy a large fraction of the preferred fishing area near a canyon; however, some accommodation could be achieved by industry-to-industry cooperation.

*See also reviewer comments in Appendix A.

RESEARCH NEEDS

- Data on the vertical particle flux, sediment transport, and rates of sediment accumulation (processes that influence the fate and effects of contaminants) are needed in the canyons of the North Atlantic area. The lack of this basic information inhibits our ability to make definitive conclusions.

- More information is needed to specify which canyons have fisheries or other special biological characteristics, and which do not.

- Sedimentological, geochemical, and physical oceanographic information is only available for one or two canyons, primarily on the canyon heads. Hypotheses based on this limited data have been proposed to explain environmental processes and patterns in the canyons. Comprehensive studies in a variety of canyon types would improve the ability to predict potential impacts on canyon biota.

- If drilling activity is to occur close to a boundary of a submarine canyon in the mid- or North Atlantic areas, the processes associated with potential impacts should be studied.

APPENDIX A

COMMENTS SUBMITTED BY WORKSHOP PARTICIPANTS BASED ON REVIEW OF THE FINAL SUMMARY REPORT

These comments are appended separately rather than incorporated into the body of the report as they reflect individual input and not necessarily a workshop consensus.

Page	Reviewer	Comment
79	James Ray	Although the workshop focuses on the shallower parts of canyons because of the amount of oceanographic information available, the discussions of probable impacts were a little broader.
80	James Ray	There was a specific point made that many of the smaller "canyons" weren't really canyons, but small embayments of the shelf. This delineation is important with regards to the number of areas that people perceive as truly unique canyons.
87	James Ray	This [regarding statement on potential for contaminant accumulation in canyons with fine-grained sediments] is a little misleading. To say that this is an accumulation zone is questionable, especially with deposition of all similar size particles from shelf and slope co-depositing. The "scavenging" theory is based on limited data. There is virtually no data to support the suggestion that ionic species of contaminants above background levels would be drifting in the water mass at any significant distance downstream from a platform. The possibilities of this being a mechanism for concentrating rig pollutants in a canyon seems questionable based on the present information.
89	James Ray	[Regarding contaminant concentration by filter feeders.] The concept of "contaminant concentration" by coelenterates, e.g., corals and gorgonians, is much different than the accumulation process in bivalve mollusks, which are for the most part missing in the canyons. [There is some question about] the above theory, and [there may not be] any data to support it. I believe it is a nonmechanism for canyon concentration of contaminants. [Pages 218 and 219 of the verbatim transcript for February 8, 1989 address this topic.--Ed.]

Page	Reviewer	Comment
92	Pat Hughes	[Disagrees with Cooper's statement about commercial species' ability to recover relatively quickly due in part to growth to maturity at a young age]...lobsters take 6 1/2 to 7 years before they are sexually mature.
93	Page Valentine	[Disagrees with Cooper's statement that 20 percent of the upper continental slope off Georges Bank is occupied by submarine canyons]...no data to back up this statement.
99	Robert Ayers and Nancy Maciolek	[Both reviewers questioned the 0.1 cm/yr deposition of particles from drilling mudsbeyond the wellsite compared to 0.06 cm/yr for material deposition--either the actual values or the ratio caused question.] In addition, in the Toms Canyon study (in the mid-Atlantic), Ayers reports that sedimentation rates from drilling mud varied from as high as 10 percent of the natural sedimentation rate 1,500 m from the wellsite (20-m depth) to about 0.1 percent of the natural sedimentation rate in the canyon, 7 km from the wellsite (540-m depth).
100	Robert Ayers	[Drilling muds and cuttings] produce no water column impact. They can cause a temporary decrease in abundance levels of immobile macrobenthos in the immediate vicinity (about 200 m) of the wellsite. There is usually no change in diversity. Also, there is usually no detectable impact in high-energy environments.
101	James Ray	[Questions the accuracy of the statement, "...even if full production were to take place on Georges Bank, there would be no more than 30 platforms--the number in the much more productive North Sea."] [page 266 of the verbatim transcript for February 8, 1989 states that because of the large number of wells able to be drilled from one platform, the number of platforms used would be smaller--and that the number of platforms in the North Sea was thought to be about 20, rather than 30--Ed.]

Page	Reviewer	Comment
103	Pat Hughes	[Suggests expansion of statement on the 500-m setback] No drilling should occur within the heads of submarine canyons nor within 500 m of the boundary of a canyon....This statement should include a list of the special features of the canyons that have led this group to recommend that drilling be prohibited within 500 m: 1. Canyons are complex environments, 2. Species diversity and abundance are greater in canyons than on the adjacent slope, 3. Canyons do trap sediments from the adjacent shelf, and 4. Active resuspension of sediments in canyons results in a higher potential for the adsorption and removal of sediment-reactive pollutants.
103	Brad Butman	[Questions the recommended 500-m setback for rigs, and suggests]...a larger distance to meet the objectives listed. Especially around Lydonia Canyon, the depositional region extends several km onto the shelf around the rim.
103	Robert Ayers	[Suggests expansion of the statement regarding dilution of metals in the water column. Additions or modifications are underlined.] ...dilution <u>and settling</u> of metals (<u>they are essentially 100 percent in particulate form or adsorbed on particulates</u>) indicates that they are <u>not</u> a biological problem. [Suggests deletion of the phrase]..."although some increases might be measurable." [Adds] They are also unlikely to be a significant problem in the canyon sediments.
103	Brad Butman	[While it is true that because of] dilution, metals are unlikely to be a problem, the report should explicitly state that exploratory drilling would probably not present a problem. The simple calculations assume one well is drilled, potentially increasing the chromium concentration 20 ppm in a region where the background is about 50 ppm. Thus, while one

Page	Reviewer	Comment
		well may not be a problem, if 25 to 50 wells are drilled from one platform, the metals could be a problem.
103	James Ray	[Questions use of description "low-toxicity" for barium, since elsewhere in the workshop, barium has been described as nontoxic.]
103	Brad Butman	[Comments on the effects of barium] Although the concentrations from one well may be low, multiple wells may provide significant concentrations in confined areas. Although apparently nontoxic, the physical effects of barium (it is heavier and finer than the natural sediments) may influence the benthic communities in subtle ways. For example, in the MMS-supported California Area Monitoring Program (CAMP), careful laboratory experiments have shown that feeding rates (as indicated by fecal-pellet production) of polychete worms (*Mediomastus ambeseta*) decreased with barium concentrations on the order of 0.1 to 1 percent. (Personal communication, Dr. Cheryl Ann Butman, Woods Hole Oceanographic Institution, Woods Hole, MA). More details of the barium calculations should be presented (volume, area of distribution, mixing depth, number of wells, etc.).
104	Pat Hughes	[Expands on statement that settlement of fine material from drilling would be unlikely to alter physical characteristics of canyon sediment so as to preclude larval settlement of benthic organisms. Points out that the data are]...inconclusive as to the potential risk of chemical impacts to larval settling, etc.
104	Page Valentine	[Suggests that the role of krill in possible hydrocarbon accumulation in canyons is through fecal pellets, recalling the workshop statement that "the feeding activity of krill in surface waters results in the production of rapidly settling large fecal aggregates."]
105	James Ray	Because of the nature of gas blowouts, it is very unlikely that there would be significant environmental [effects].

Page	Reviewer	Comment
105	Robert Ayers	[Suggests modification to the statement on gas blowouts--modifications and additions are underlined] Less information exists on possible impacts from gas blowouts. However, since the hydrocarbon gases rise into the atmosphere rather than remain in the water column or settle, it appears that impacts would be significantly less than if crude oil were spilled.

APPENDIX B

ABSTRACTS

PRE AND POST DRILLING BENCHMARKS AND MONITORING DATA OF OCEAN FLOOR FAUNA, HABITATS, AND CONTAMINANT LOADS IN THE GEORGES BANK SUBMARINE CANYONS

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ABSTRACT

The biology and geology of submarine canyons of the northwest Atlantic was investigated by diver scientists, using manned submersibles, from 1973 through 1984. This effort entailed in-situ studies in eighteen canyons ranging from Corsair, Georges, Nygren, Powell, Lydonia, Gilbert Oceanographer, Filebottom, Hydrographer, and Veatch off Georges Bank to Atlantis, Block, Hudson, Toms, Wilmington, Baltimore, Washington and Norfolk off southern New England and the Mid Atlantic Bight. From 1980 through 1984 scientists from several New England research institutions (NMFS, USGS, and NURC) conducted a before, during, and post-drilling study of the species abundance, community structure, animal-substrate relationships and body-substrate burdens of trace metals, PCB's, and hydrocarbons within and downstream of oil and gas exploration areas on the south central portion of Georges Bank. There was no evidence of impact from drilling on the megabenthic fauna and the quality of their ocean floor habitats within the Georges Bank Canyons (Lydonia, Oceanographer, and Veatch). The five-year "benchmark" and monitoring study, conducted from the research submersible Johnson-Sea-Link, was supported by NOAA's Office of Undersea Research (OUR) and the National Marine Fisheries Service, Woods Hole, MA.

Site specific stations were established in Lydonia Canyon (head of canyon and west wall) in 1980 and in Oceanographer and Veatch Canyons in 1981 and 1982. Photo and video transects were made in July, along transects oriented north, south, east, and west of the station marker. Estimates of species abundance and community structure were made by habitat type.

We hypothesize that submarine canyons function as refugia for many bottom-oriented species, where there is little, if any, impact from active fishing gear. Species diversity and abundance are greater in canyons than in non-canyon areas at comparable depths. Canyons also function as important nursery grounds for a wide variety of megabenthic fauna such as shrimps, Cancer crabs, American lobster, white hake, cusk, ocean pout, conger eel, tilefish, and black-bellied rosefish etc., and provide three-dimensional

shelter, rarely occurring in noncanyon areas of the outer shelf and upper slope, for the adults of some 20 species. Our combined canyon studies show that these large geologic features represent unique ecosytems, largely because of their highly varied, three dimensional habitats.

Examination of the benchmark data on annual variations in species abundance, specifically for the fourteen designated key "indicator species," suggests that no one species is likely to clearly reflect anything other than a major impact from production drilling. We suggest that community composition be examined by habitat type and specific location for defining faunal benchmarks in terms of future oil and gas explorations.

Surficial sediments at each benchmark station were analyzed for trace metals (Ba, Cd, Cu, Cr, Hg, Pb, and Zn), hydrocarbons (aromatic and aliphatic), and PCB's. Scallops (muscle and viscera), cancer crabs (hepatopancreas and claw tissue), lobsters (hepatopancreas, claw/tail tissue, and eggs), and tilefish (dorsal musculature) were subjected to the same analyses. Sediment and animal bound PCBs were below the levels of detection (0.005 ppm) prior to drilling; subsequent analyses were not made. Concentrations of petrogenic hydrocarbons (FI, FII) were all non detectable prior to and after drilling. Trace metal concentrations in the surficial sediments and in crabs and lobsters remained relatively constant over time.

Since no impacts were identified with regard to exploratory drilling, this 5-year data base is considered an appropriate "benchmark" for future drilling operations.

THE LYDONIA CANYON EXPERIMENT: CIRCULATION, HYDROGRAPHY, AND SEDIMENT TRANSPORT

by

Bradford Butman

U.S. Geological Survey
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A field program was conducted to study the circulation and sediment dynamics in Lydonia canyon, located on the southern flank of Georges Bank, and on the adjacent continental shelf and slope. The program included (1) insitu measurements by an array of moored current meters, bottom tripods, and sediment traps maintained between November 1980 and November 1982; (2) synoptic observations of the hydrography and suspended sediments; (3) sidescan-sonar and high-resolution seismic reflection surveys; (4) samples of the surficial sediments; and (5) direct observations of the sea floor from the submersible ALVIN.

The distribution of surficial sediment and the high-resolution seismic reflection data suggest that very fine sand and silts and clays accumulate in the head of the canyon and on an area of the shelf adjacent to the canyon. However, the current measurements show that the surficial sediments are reworked and resuspended along the canyon axis to a water depth of at least 600 m. Thus, although fine sediments may be accumulating, the axis is not tranquil. Maximum hour-averaged current speeds 5 meters above bottom (mab) were greater than 60 cm/s at about 300 and 600 m in the canyon axis. No evidence of sediment movement was observed at 1,380 m. The current observations suggest down-canyon transport of sediment along the axis near the head at a water depth of about 300 m and up-canyon transport at about 600 m, implying a convergence in the transport of sand as bedload toward the head. Qualitatively, the sediment distribution along the axis mirrors the strength of the near-bottom currents (finer sediments in areas of weaker currents).

The mean Eulerian (measured at a fixed point) current was southwestward on the shelf adjacent to Lydonia Canyon and above the level of the canyon rim which is consistent with previous studies of the mean circulation on Georges Bank. On the continental slope, the mean flow was strongly influenced by Gulf Stream warm core rings. Several rings passed to the south of Lydonia Canyon during the observation period; the strong clockwise flow around them caused eastward flow along the edge of the shelf as strong as 80 cm/s. On the slope, the influence of the rings in the water column extended to at least 250 m, but not to 500 m. The influence of the rings did not extend onto the Continental Shelf to water depths of 125 m. Over the slope, there was a persistent off-shelf and downslope component of flow near the bottom of a few centimeters per second. There is some evidence that the warm core rings affect flow in the canyon by generating packets of high-frequency current fluctuations.

Within the canyon, the mean Eulerian flow near the bottom was complex. Near the head of the canyon, net Eulerian flow 5 mab was down-canyon, at about 3 cm/s, and weak at 50 mab. At 550 m, the near-bottom flow was up-canyon. At 600 m the near-bottom flow was weak; the flow 100 mab was up-canyon. These observations suggest a convergence of the mean Eulerian flow between 300 and 600 m and possibly several cells of recirculation along the canyon axis. However, because of the energetic, non-linear, high-frequency motion observed in the canyon and the small spatial scales, the mean Eulerian current may not indicate the actual Lagrangian water-particle motion. Further analysis is required to determine the Lagrangian circulation pattern. Measurements made on the eastern rim of the canyon at about 200 m show westward flow directly across the canyon axis. Measurements on the eastern wall of the canyon, just a few km away at comparable depths, show northward inflow along the eastern wall. Measurements on the western wall show southward outflow. The mean Eulerian currents in the canyon thus suggest a complex vertical Eulerian circulation along the axis and horizontal exchange along the canyon walls.

The current fluctuations within the canyon are aligned with the canyon axis. The strength of the high-frequency fluctuations (motions with periods shorter than about one day) increase toward the bottom and the head of the canyon. The low-frequency currents (motions which fluctuate at periods longer than about 2 days) were strongest over the slope and weakest in the canyon. Alongshelf current fluctuations over the shelf were correlated with cross-shelf flow over the canyon mouth (offshelf for southwestward flow), suggesting enhanced cross-shelf exchange in the region of the canyon. The fluctuations at semidiurnal periods dominate the current spectra; near the canyon head their strength changes substantially with time, indicating random generation of internal wave packets.

Similar studies in nearby Oceanographer Canyon show that the currents are dominated by the tidal currents and are stronger than in Lydonia. Net Eulerian down-canyon flow was observed at both 200 and 600 m.

SEDIMENTARY ENVIRONMENTS IN SUBMARINE CANYONS AND ON THE OUTER SHELF-UPPER SLOPE OF GEORGES BANK

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Sedimentary environments have been identified on the southern margin of Georges Bank at depths of 150-600 m on the basis of texture and bottom current patterns. At the shelf edge, rippled sand gives way to smoother and finer-grained sand deposits as water depth increases on the upper slope, which is dissected by steep-walled gullies. Submarine canyons of varying size and wall steepness incise the Georges Bank Shelf and contain such sedimentary facies as pavements of ice-rafted gravel, bioeroded and collapsed Pleistocene silt outcrops, sand accumulations surfaced with large and small bedforms, and almost featureless silty sand.

Patterns of strong bottom currents are attributed to Gulf Stream warm-core rings, tidal currents, and an unknown source. (1) Gulf Stream warm-core-ring currents flow northeastward at about 50 cm/s, winnowing very fine sand, silt, and clay from the upper slope between 200 and 300 m water depth. (2) Regional tidal currents are weak on the upper slope. However, canyon morphology appears to affect tidal flow. At depths of 150 to 600 m in large canyons having steep walls (Oceanographer Canyon), tidal currents are strong, attaining speeds of 75 to 100 cm/s. The canyon floor is covered by coarse sediment and large bed forms. By contrast, small, shallow canyons (Heel Tapper Canyon) are relatively tranquil, and, like the upper slope, canyon walls and floors are covered by silty sand. (3) A strong bottom current of unknown origin flows westward at about 50 cm/s across the rims of Oceanographer and Lydonia Canyons at depths of 150 to 200 m, transporting shelf sand across deposits of ice-rafted gravel onto the east canyon walls.

Sediment movement is more rapid in a narrow band northeastward along the upper slope, along the lower walls and floors of large, high-energy canyons, and from the shelf westward across the east rims of large and medium canyons. Sediment movement is less rapid on the outer shelf, on most of the upper slope, including the gullies, on the floors of medium and small canyons, and around some canyon heads. A moderately energetic canyon of medium size such as Lydonia may be accumulating sediment most rapidly. It traps a large volume of shelf sand as well as bioeroded silt from outcrops on lower canyon walls.

TOMS CANYON STUDY

R. C. AYERS, JR. AND J. E. O'REILLY

EXXON PRODUCTION RESEARCH COMPANY

DURING THE PERIOD 1978-81 EXPLORATORY DRILLING ACTIVITY ON THE MID-ATLANTIC OCS WAS AT ITS PEAK. ALSO, DURING THIS PERIOD, ENVIRONMENTAL CONCERN OVER THE IMPACT OF DRILLING IN THIS FRONTIER AREA WAS QUITE HIGH. TO ADDRESS THE ENVIRONMENTAL ISSUES, GOVERNMENT MANDATED STUDIES ON DRILLING DISCHARGE IMPACTS WERE CONDUCTED BY INDUSTRY. THE TOMS CANYON STUDY WAS ONE OF THESE. THE WELLSITE IN BLOCK 816, LOCATED APPROXIMATELY 150 km FROM THE NEW JERSEY COAST, WAS ALSO LOCATED APPROXIMATELY 3.7 km NORTH EAST AND UPCURRENT OF TOMS CANYON. THE MID-ATLANTIC BIOLOGICAL TASK FORCE RECOMMENDED TO USGS THAT THE LESSEE, EXXON USA, BE REQUIRED TO PERFORM A MONITORING STUDY TO DETERMINE IF DISCHARGES FROM THE WELL WERE ENTERING THE CANYON IN HARMFUL QUANTITIES. EXXON USA AGREED TO FUND THE STUDY WHICH WAS CARRIED OUT BY EG&G ENVIRONMENTAL CONSULTANTS UNDER THE DIRECTION OF EXXON PRODUCTION RESEARCH COMPANY.

THE MONITORING STUDY, CONDUCTED IN 1980-81, CONSISTED OF A PRE-DRILLING, SEDIMENT SAMPLING SURVEY AND THREE DRILLING PHASE SURVEYS. IT INCLUDED MEASUREMENTS OF CURRENTS, WATER PROPERTIES, PHYSICAL AND CHEMICAL CHARACTERISTICS OF BOTTOM SEDIMENTS AND MATERIAL COLLECTED IN SEDIMENT TRAPS, A BATHYMETRIC SURVEY, AND THE COMPOSITION AND QUANTITY OF DISCHARGED MATERIAL. BARIUM (FROM BARITE) WAS USED AS A CONSERVATIVE TRACER OF THE DRILLING DISCHARGES. IT WAS FOUND THAT ELEVATED BARIUM LEVELS COULD BE DETECTED IN MATERIAL DEPOSITED IN SEDIMENT TRAPS AT THE RIM OF THE CANYON. HOWEVER, THE DEPOSITION RATES FROM THE DISCHARGES WERE TOO LOW TO MEASURABLY INCREASE CONCENTRATIONS OF BARIUM IN SEDIMENTS LOCATED FURTHER THAN 1-1.5 km FROM THE WELLSITE.

RECENT DEVELOPMENTS IN

INDUSTRY SPONSORED RESEARCH

J.P. RAY
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This presentation will introduce and summarize several industry sponsored projects relating to drilling fluids and cuttings that have been conducted over the past two years. Some of this work has been submitted for journal publication, some will be relegated to the gray literature.

Included in this summary are near and far-field rig monitoring programs conducted in the Gulf of Mexico off Alabama and Texas. These include fate and effects monitoring relating to both exploratory and development drilling. Sediment contamination (metals and hydrocarbons) were considered in several of the studies in addition to benthic community analysis. One location monitored exploratory discharges prior too, immediately after, and one year post-drilling, in water depths of 10 m. Another assessed impacts due the discharges from 10 wells into in a water depth of 28 m.

The industry, as part of their data gathering for comment submission on the proposed EPA offshore effluent guidelines, have developed an extensive database on drilling mud composition and acute toxicity from systems in field use for the past two years. Generalizations regarding the <u>*general*</u> *toxicity of field muds can be extracted from this database and will be presented. This information is relevant to hazard assessment considerations for the North and mid-Atlantic, and the related canyon areas.*

A brief overview will be given of a major study conducted in California which quantified sediment metals contamination, and their bioaccumulation and intra-cellular fate in three different species of benthic infauna. Based on over 100,000 metals analyses, the data suggests that barium is being accumulated as barium sulphate, and not the more soluble and toxic barium ion. All sediment and faunal samples were taken from a discharge site in water depths of > 70m.

Recent laboratory studies have explored the solubility and bioavailability of trace contaminants, especially mercury and cadmium, from barite (the primary weighting agent used in drilling muds). Because barite is the only mud component measurable in marine sediments at distances beyond a few hundred meters, these studies have special relevance to hazard assessments.

THE FLUX AND COMPOSITION OF RESUSPENDED SEDIMENT

IN TWO SUBMARINE CANYONS FROM THE WESTERN NORTH ATLANTIC:

IMPLICATIONS FOR POLLUTANT SCAVENGING

by

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ABSTRACT

Sediment traps were used to estimate the flux of resuspended sediments in Lydonia and Oceanographer Canyons and on the adjacent U.S. North Atlantic continental shelf and slope. The axes of both canyons are sites of much more resuspension activity than are areas of comparable depth outside of the canyons. The highest resuspended flux (157 $g/m^2/day$) was measured in Lydonia Canyon axis 5 m off the bottom at 300-m water depth. At the head of Lydonia Canyon, in water depths of 100 to 125 m, the variability in the flux and texture of the trapped sediment correlates with the timing and strength of major storms. Sediments trapped deeper along the canyon axis show textural differences over time that are similar to those observed at the head of the canyon, but the record is more complicated. The greater variability in sediment textue at deep sites suggests that additional processes, such as internal waves, cause resuspension in the canyons.

The hypothesis that shelf-derived material is being transported into Lydonia Canyon is supported by two recent data sets. First, the concentration of barium, a major element in drilling mud, increased in the resuspended sediment collected in Lydonia Canyon during the period in which eight exploratory wells were drilled on Georges Bank. Second, carbon-14 dating of piston cores from the head of Lydonia Canyon indicates that sediment is accumulating at an average rate of 60 cm/1,000 yr. The core locations are down gradient and down current from the southern flank of Georges Bank.

The more intense resuspension and higher accumulation rates in this canyon, as compared to those on the adjacent continental slope, suggests that the canyon sediments have a higher potential for the adsorption of sediment-reactive pollutants. This hypothesis is based on the observations that sediments in the canyon axis have higher specific activities and higher inventories of lead-210 and plutonium-239, 240 than sediments on the continental slope. In addition, concentration ratios of Cd/Al, Cr/Al, Cu/Al, and Pb/Al are higher in surface sediments of the axis of Lydonia Canyon than they are on the adjacent slope.

Frequent resuspension of fine-grained sediments in canyons increases the opportunity for particulates to adsorb dissolved materials and strip them from the water column. This process may make some canyons a more effective sink for pollutants than the open slope.

OVERVIEW OF THE BIOGENIC AND ANTHROPOGENIC HYDROCARBON DISTRIBUTIONS IN SEDIMENTS ALONG THE NORTH ATLANTIC MARGIN

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Technical Director

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Georges Bank and the adjacent, slope, rise and submarine canyon areas are characterized by highly dynamic sediment transport, deposition and resuspension cycles. Pollutant and biogenic hydrocarbon distributions follow the general trends of those for fine sediments. Saturated and polycyclic aromatic hydrocarbons are found at very low levels in the central bank area where sediments are coarse and are found at elevated levels in the depositional areas of the "mud patch" , at canyon heads, and in fine grained sediment areas further offshore.

Hydrocarbons of a biogenic, terrigenous nature appear to be in overall steady state, while marine biogenic hydrocarbon distributions are deposited and then eroded from the surface sediments, eventually being deposited in depositional areas to the southwest and west. Indirect evidence suggests that anthropogenic hydrocarbons are associated with the easily resuspended fine sediment fraction, while the biogenics associate with the coarser fractions. It has been estimated that 40-50% of the organic matter is resuspended and transported to the slope from the shelf.

Both the saturates and the PAH compounds are strongly associated with total organic carbon in the sediments. Saturated hydrocarbons of a terrigenous plant wax origin dominate the overall hydrocarbon assemblage. While the absolute concentration of total hydrocarbons range from 0.2 to 20ppm, and PAH compounds range from about 0.01 to 1.0 ppm, the respective ratios to TOC are relatively constant, suggesting a well mixed geochemical area. The PAH/TOC ratios are very similar to those found in sediments from other geographical areas, well removed from the North Atlantic OCS. The PAH distributions are similar to those originating in the combustion of fossil fuels, with distributions dominated by the higher molecular weight PAH (i.e. 4- and 5-ring compounds) rather than petroleum-sourced PAH.

The distributions of hydrocarbons in the shelf and slope areas have important implications for predictions of the fate of pollutants which may originate through outer continental shelf (OCS) development. Sedimented hydrocarbons associated with fine grained sediments will be redistributed from their point of origin rapidly (weeks to months) and will be transported to depositional areas which include canyon heads, deeper slope areas and basins such as the mud patch area. Data suggest that although introduced pollutants may be deposited at these canyon heads and be transported down the canyons, the data also suggest the possibility of up-canyon transport and deposition of pollutants at canyon heads, as well.

POTENTIAL EFFECTS OF DRILLING EFFLUENTS ON MARINE ORGANISMS

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During drilling and production from an offshore platform, there are several possible discharges to the ocean and physical alterations of the bottom that may have adverse effects on the marine environment. Some discharges are authorized by permit; others are accidental. The permitted discharges of most environmental concern are drilling muds, drill cuttings, and produced water. The most important accidental discharge is petroleum through operational spills or blowouts. Physical impacts may be caused by the mere presence of the platform and by emplacement of pipelines on the bottom. The focus of this talk will be on impacts of drilling mud and cuttings discharges.

When discharged to the ocean, drilling muds and cuttings are diluted very rapidly by dispersion and fractionation. The heavier solids (representing about 90 percent of the mass of the mud) settle rapidly to the bottom, usually within 200 to 1000 meters of the rig, depending on water current speed and water depth. The liquids, soluble materials, and fine clay-sized particles in the drilling mud are carried away from the rig in a near-surface plume and are diluted rapidly by mixing with seawater.

Because of the rapid dilution of drilling mud in surface waters, significant biological impacts have not been detected in the water column. However, drilling mud and cuttings solids may cause adverse impacts in bottom living (benthic) biological communities wherever the mud and cuttings solids accumulate on the bottom. These impacts could be due to physical burial, changes in sediment texture making the habitat less suitable for some species, or chemical toxicity of some drilling mud ingredients.

The ingredients in water-based drilling muds of greatest environmental concern are metals. The metals most likely to be present in drilling muds at concentrations significantly higher than their concentrations in marine sediments are barium, chromium, lead, and zinc. Minor ingredients sometimes added to drilling muds that may contribute to its impact include diesel fuel or mineral oil, surfactants, and biocides. Many hundreds of acute toxicity bioassays have been performed with water-based drilling muds. Nearly 90 percent of the samples were found to be non-toxic or practically non-toxic to marine organisms.

Several large field studies have been performed in this country and abroad by the oil industry and the government (in the United States, usually the Minerals Management Service of the Department of the Interior) around offshore platforms. The objective of these monitoring programs was to assess the impacts of drilling mud and cuttings discharges on the benthic environment. Accumulation of drill cuttings and of some drilling mud ingredients, particularly barite, in sediments has been detected near offshore exploratory rigs and production platforms. On Georges Bank, elevated concentrations of barite derived from drilling mud discharges were detected in sediments near two exploratory rigs. The excess barite was washed out of the sediments and diluted to background within one to two years after cessation of drilling.

On the Mid-Atlantic outer continental shelf, but not on Georges Bank, accumulation of drilling mud and cuttings solids was accompanied by changes in benthic community structure. Such benthic impacts, when they have been detected, usually were restricted to a radius of about 200 meters from an exploratory rig from which only one well was drilled. In the North Sea, impacts on the benthos around multi-well development platforms sometimes extended out to 1000 to 3000 meters from the platform. Impacts were much more severe if oil-based drilling muds were used and oily cuttings were discharged (not permitted in U.S. waters) than if water-based muds were used and discharged. Recovery of benthic communities impacted by solids from water-based drilling muds usually began within one or two years after completion of drilling.

MEGAFAUNAL POPULATIONS IN LYDONIA CANYON, WITH NOTES ON THREE OTHER NORTH ATLANTIC CANYONS

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Megafaunal populations in Lydonia Canyon were photographically surveyed during 16 camera sled tows and 17 ALVIN dives conducted between May 1979 and September 1982. A total of 114,742 m^2 of the seafloor, between 130 and 2330 m depth, was analyzed for this study. Lydonia Canyon is a relatively narrow canyon that incises Georges Bank approximately 11 miles north of the shelf-slope break. It has a narrow, sinuous sediment-covered axis flanked by steep walls. The walls on both sides of the canyon exhibit massive exposures of outcrop and steep, talus-strewn slopes.

Total megafaunal abundances in Lydonia Canyon are very high (up to 30 individuals per m^2) at shallow depths, and intermediate at mid-slope (5 individuals per m^2) and lower-slope (7 to 8 individuals per m^2) depths. Megafaunal distribution patterns within the canyon are complex and faunal similarities among areas within a depth range are low. These low faunal similarities reflect: patchy distributions of several of the dominant shallow water taxa, substrate heterogeneity on the canyon walls, and differing physical regimes in various parts of the canyon. The megafauna inhabiting the axis and lower walls is usually dominated by filter-feeding corals and sponges, and these taxa frequently comprise assembleges that are quite distinct from those inhabiting the upper walls and the nearby slope.

Three other North Atlantic canyons (Oceanographer, Heezen, and Corsair) were surveyed during 7 ALVIN dives conducted in September 1977. Megafaunal populations differ substantially among the canyons, and between the axis and wall within a canyon. While most of the taxa are widely distributed, localized high abundances of individual taxa account for much of the observed differences. This patchiness can only partialy be attributed to differences in sustrate requirements, since several of the dominant taxa are not restricted to hard substrate. However, as was the case in Lydonia Canyon, the fauna in all three of these canyons is heavily dominated by sessile filter feeders.

While these filter feeders require threshold currents and suspended particles for their livelihood, they may also be susceptible to stresses associated with increased sediment loads such as: tissue abrasion in regions of strong current flow, clogging of filtering apparatuses in tranquil regions, or decreased larval settling success. Additionally, concurrent physical studies show enhanced current speeds and resuspension in the vicinity of canyons. This indicates that the canyon system may well serve a role in transporting and concentrating pollutants in the vicinity of these communities.

BENTHIC INFAUNA OF LYDONIA CANYON AND THE ADJACENT SLOPE ENVIRONMENT

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Among several stations sampled as part of programs funded by the Minerals Management Service, stations were positioned at approximately 150, 550, and 2100 m in Lydonia Canyon and on the adjacent slope.

At 150 m, two stations were sampled inside the canyon and one on the adjacent slope. Of the two canyon stations, one had silty sediments and was dominated by the amphipod Ampelisca agassizi. The other canyon station had coarser sediments and a much different suite of dominant species. The slope station was also dominated by A. agassizi, but a much higher percentage of the fauna at the slope station (35%) than at the canyon station (12%) was accounted for by this species. Of the next 19 dominant species, however, only two occurred in common, indicating a major difference in faunal composition between the slope and canyon station, even though both were dominated by A. agassizi. Diversity was lower at both canyon stations than at the slope station. Similarity analysis showed that none of the three stations had a high level of similarity to any of the other three, but each was most similar to other stations sampled in the program. Subtle differences in sediment texture appear to affect benthic community composition.

At 550 m, the top dominant at both stations was the polychaete Thayrx annulosus, but this species accounted for 32% of the fauna at the canyon station and only 6% of the fauna at the slope station. Of the next 19 dominant species at the canyon station, five were also among the top dominants at the corresponding slope station, but generally ranked lower and did not dominate the slope community to the same extent. Diversity was lower at the canyon station. The slope-station fauna was more similar to the fauna at another slope station more than 200 km distant (but also at 550 m) than it was to the adjacent canyon station. Because sediment texture was similar at the canyon and adjacent slope station, it is suggested that the current regime at this depth controls the benthic community.

Fewer faunal differences were evident at 2100 m, and these were not of the same magnitude as those seen at shallower depths. The polychaete Aurospio dibranchiata was the top dominant at both the canyon station and two adjacent slope stations, where it accounted for 8 to 10% of the total fauna. Of the next 19 dominant canyon species, 10 or 11 were among the top dominants at the two slope stations, respectively. These dominants often held similar ranks at the canyon and slope stations. Unlike the situation at the shallower stations, diversity was higher at the 2100-m canyon station than at either of the corresponding slope stations. Sediment texture was similar at all three stations.

Infaunal biomass was measured on up to 12 sampling dates at the 150-m stations and on one sampling date at the 2100-m stations. At both depths, the mean biomass, reported as ash-free dry weight (AFDW), was higher at the canyon station than at the slope station. Mean AFDW was 2.4 times higher at the 150-m canyon station and 2.0 times higher at the 2100-m canyon station than at the corresponding slope stations.

DRILLING WAS PROHIBITED IN SUBMARINE CANYONS IN 1984

Patricia E. Hughes, OCS Coordinator
Massachusetts Coastal Zone Management Office

Research conducted along the North Atlantic continental shelf and slope over the last fifteen years has contributed greatly to our understanding of the physical, chemical, and biological processes of this region. Research focused on the submarine canyons indicates that the processes at work in them have created habitat that supports unique biological communities in comparison with the adjacent shelf and slope environments. Whether the canyons are erosional or depositional environments, they support biological communities not found elsewhere.

The fundamental question underlying the two hypotheses being examined at this workshop is: should oil and gas activities be permitted in or adjacent to submarine canyons? In 1984, the Minerals Management Service (MMS) answered this question by developing a lease stipulation for proposed sale 82 that prohibited oil and gas drilling activities within 200 meters of the geographical boundaries of submarine canyons, as defined by the National Oceanic and Atmospheric Administration. Further, the lease stipulation included restrictions on drilling activities within 4 miles of the submarine canyons.

It is assumed that this drilling prohibition was based on the scientific community's current understanding of the canyons' oceanographic processes and biological communities. This presentation will discuss some of the factors believed to be important in the development of this lease stipulation and relevant to the discussion of the hypotheses.

NORTH ATLANTIC SUBMARINE CANYONS: MAINE'S PERSPECTIVE

Katrina Van Dusen

Maine State Planning Office

Maine has long been concerned about oil and gas activity in canyon areas because of the unique and varied habitats and diverse and abundant species found there. These areas deserve special attention because they are a nationally significant natural resource and because they serve as nursery areas and refuge for commercially important fish and shellfish. Our concern has focussed on the potential harm to these habitats that could be caused by routine and accidental discharges from drilling activities, as well as the bottom disturbance caused by the presence of drilling rigs and the exclusion of fishermen from canyon areas.

Maine's interest in the canyons may not be as great as in some of the other North Atlantic states because fewer of our fishermen make the long trip to the southern edge of Georges Bank. However, some of the species that spend part of their lives in the canyons migrate inshore at other times, especially lobsters, making the canyons important to Maine fishermen even as they fish at a distance.

We are open to working together in this forum with the hopes of acheiving some consensus on the viability of drilling activity in and near submarine canyons. Prior to Sale 82 we worked with the MMS on a canyon stipulation, an indication of our openness to creative solutions. However, I am very concerned about the scope of this workshop. The workshop agenda appears to focus solely on "what happens" in canyons with no time allocated for discussing whether what happens is acceptable; the workshop hypotheses talk about "low probability of serious environmental impact" and an absence of "serious environmental risks." The stated hypotheses can not be tested without consensus on what are acceptable risks. Although this judgement can and should be made with full consideration of the available scientific information, it is ultimately a policy decision.

THE SUBMARINE CANYONS: DRILL OR DEFER? (A RHODE ISLAND PERSPECTIVE)

by

Bruce F. Vild, Principal Planner
Rhode Island Department of Administration, Division of Planning

The author has followed the Georges Bank/North Atlantic Planning Area controversy for almost ten years, and has advised two Governors on the position the State of Rhode Island should take on issues germane to offshore drilling and habitat protection. A recurring problem, the author observes, is that of allowing oil and gas companies the opportunity to drill in the North Atlantic submarine canyons. Rhode Island traditionally has recommended that canyon exploration for oil and gas be deferred. The author believes that Rhode Island's position remains a sound judgment, in light of the findings of environmental studies, and political realities. The data collected so far do not lend themselves to hard-and-fast conclusions about the impacts of drilling on canyon habitats, making prediction difficult. The commercial fishing industry and environmental groups remain powerful constituencies. The New England governors have no assurance that the oil and gas industry is willing to invest heavily in the North Atlantic within the forseeable future, so the benefits to our states from such activity are not forthcoming. The problem of whether to allow drilling in the submarine canyons has many facets other than science. In whatever solution becomes policy, the strongest component is likely to be politics, not science.

APPENDIX C

MINERALS MANAGEMENT SERVICE
NORTH ATLANTIC SUBMARINE CANYONS WORKSHOP

PLENARY AGENDA

February 7, 1989:

8:00 a.m.....	Welcoming	Dr. Don Aurand/ Mr. Jim Lane

Chairperson: Dr. Nancy Maciolek

8:30 a.m.....	Pre and Post Drilling Bench marks and Monitoring Data of Ocean Floor Fauna, Habitats, and Contaminant Loads in the Georges Bank Submarine Canyons	Dr. Richard Cooper
9:00 a.m.....	The Lydonia Canyon Experiment: Circulation, Hydrography, and Sediment Transport	Dr. Brad Butman
9:30 a.m.....	Sedimentary Environments in Submarine Canyons and on the Outer Shelf-Upper Slope of Georges Bank	Dr. Page Valentine
10:00 a.m.....	**COFFEE BREAK**	
10:15 a.m.....	Toms Canyon Study	Dr. Bob Ayers*
10:45 a.m.....	Recent Developments in Industry Sponsored Research	Dr. Jim Ray
11:15 a.m.....	The Flux and Composition of Resuspended Sediment in Two Submarine Canyons from the Western North Atlantic: Implications for Pollutant Scavenging	Dr. Michael Bothner

*Actual presentation took place 8:15 a.m., February 8, 1989.

11:45 a.m..... LUNCH BREAK

Chairperson: Dr. Page Valentine

1:00 p.m.....	Overview of the Biogenic and Anthropogenic Hydrocarbon Distributions in Sediments Along the North Atlantic Margin	Dr. Paul Boehm
1:30 p.m.....	Potential Effects of Drilling Effluents on Marine Organisms	Dr. Jerry Neff
2:00 p.m.....	Megafaunal Populations in Lydonia Canyon, with Notes on Three Other North Atlantic Canyons	Dr.Barbara Hecker
2:30 p.m.....	Benthic Infauna of Lydonia Canyon and the Adjacent Slope Environment	Dr. Nancy Maciolek/ Dr. Fred Grassle

3:30 p.m..... COFFEE BREAK

Chairperson: Mr. Jim Lane

4:00 p.m.....	Drilling was Prohibited in Submarine Canyons in 1984	Ms. Pat Hughes
	North Atlantic Submarine Canyons: Maine's Perspective	Ms. Katrina VanDusen
	The Submarine Canyons: Drill or Defer? A Rhode Island Perspective	Dr. Bruce Vild

MINERALS MANAGEMENT SERVICE
NORTH ATLANTIC SUBMARINE CANYONS WORKSHOP

AGENDA

ROUNDTABLE DISCUSSION
(All Panelists)

February 8, 1989:*

Chairperson: Dr. Don Aurand and Dr. Tom Ahlfeld

8:00 a.m. - 10:00 a.m.

Discussion of Hypothesis: "In submarine canyons of the North Atlantic where erosional environments exist, there is a low probability of serious environmental impact to faunal assemblages from oil and gas activities in the vicinity of canyonheads."

10:00 a.m..... COFFEE BREAK

10:15 a.m. - 12:00 noon

Discussion of Hypothesis: "In submarine canyons of the North Atlantic Margin where depositional environments may exist, the rate of accumulation of drilling related contaminants is slow enough not to present serious environmental risks to faunal assemblages from oil and gas activities in the vicinity of the canyonheads."

12:00 noon - 1:00 p.m. LUNCH BREAK

1:00 p.m. - 5:00 p.m.**
(3:00 p.m. - Coffee Break)

Chairperson: Dr. Brad Butman

PANEL A - Geology and Geochemistry of North Atlantic Submarine Canyons

Panel Members:	Dr. Brad Butman	Dr. Paul Boehm
	Dr. Page Valentine	Dr. Bob Ayers
	Dr. Mike Bothner	Dr. Jerry Neff
		Mr. Bruce Vild

*Discussions of hypotheses did not take place.
**Panels A and B met jointly during the morning. Preparation of the summary synthesis and conclusions began in the afternoon.

AGENDA

ROUNDTABLE DISCUSSION
(All Panelists)

February 8, 1989

In addition to the stated hypotheses discussed during the morning session, the following topics are also suggested for related discussions:

- Effects of surficial sediment movement in canyons.
- Physical mixing processes in canyons.
- Hydrocarbon and trace metal geochemistry processes in canyons.
- Habitat types and canyon morphologies.
- Depositional versus erosional environments of canyons.

1:00 p.m. - 5:00 p.m. Chairperson: Dr. Fred Grassle
(3:00 p.m. - Coffee Break)

PANEL B - Biological Processes of North Atlantic Submarine Canyons

Panel Members:	Dr. Richard Cooper	Dr. Jim Ray
	Dr. Fred Grassle	Ms. Katrina VanDusen
	Dr. Barbara Hecker	Ms. Pat Hughes
	Dr. Nancy Maciolek	

In addition to the stated hypotheses discussed during the morning session, the following topics are also suggested for related discussions:

- Submarine canyons as nurseries for commercial fisheries.
- Benthic infauna of canyons.
- Submarine canyon species: abundance and diversity.
- Habitat types and associated fauna.
- Potential effects of varying flushing rates on canyon ecosystems.

MINERALS MANAGEMENT SERVICE
NORTH ATLANTIC SUBMARINE CANYONS WORKSHOP

AGENDA

PREPARATION OF DRAFT SCIENTIFIC PANEL
CONCLUSIONS AND RECOMMENDATIONS NARRATIVE SECTION

February 9, 1989*

(Coffee Breaks to be held at 10:00 a.m. & 3:00 p.m.)

During this final day of the workshop, the panel members are to meet to prepare written drafts of their conclusions and recommendations focusing on the workshop hypotheses discussed during the roundtable session and to summarize their comments and views developed on the issues considered during the concurrent panel sessions. This narrative section will form a consolidated summary synthesis of the conclusions and recommendations of the scientific panel members.

Rapporteurs will be available to assist in the preparation of the scientific panel members conclusions and recommendation sections.

<u>Co-chairpersons: Dr. Nancy Maciolek and Dr. Jerry Neff</u>

8:00 a.m. Scientific Panel Deliberations

10:00 a.m. Coffee Break

10:15 a.m. Dialogue

11:00 a.m. Conclusions

12:00 LUNCH BREAK

1:00 p.m. Presentations and Wrap-up

3:00 COFFEE BREAK

*Preparation of summary synthesis and conclusions continued. Workshop ended at approximately 2:30 p.m.

APPENDIX D

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