EPA 520/1-83-018

GEOLOGIC OBSERVATIONS AT THE 2800-METER RADIOACTIVE WASTE DISPOSAL SITE AND ASSOCIATED DEEPWATER DUMPSITE 106 (DWD-106) IN THE ATLANTIC OCEAN

by

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Prepared June 1978
Revised September 1983

This report was prepared as an account of work sponsored by the U.S. Environmental Protection Agency under Contract No. 68-01-3933

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Washington, D.C. 20460

FOREWORD

In response to the mandate of Public Law 92-532, the Marine Protection, Research, and Sanctuaries Act of 1972, as amended, the Environmental Protection Agency (EPA) has developed a program to promulgate regulations and criteria to control the ocean disposal of radioactive wastes. As part of that program, the EPA Office of Radiation Programs initiated feasibility studies in 1974 to learn whether present technologies could be used to determine the fate of radioactive wastes dumped in the past.

In 1975 and 1976, the advanced technologies represented by the manned deep-submergence research vehicle (DSRV) ALVIN were employed to perform an on-bottom survey at the Atlantic Ocean deepwater industrial waste dumpsite (DWD-106) and the previously-used United States low-level radioactive waste disposal site. DWD-106 is located approximately 170 kilometers (106 miles) offshore at a depth ranging between 1600-2500 meters. The low-level radioactive waste disposal site is located southwest of DWD-106 approximately 190km (120 miles) offshore at a depth of approximately 2800 meters (9300 feet). Both sites are situated south of the axis of the Hudson Canyon channel. The objectives of this survey were to describe the biological, chemical, geological and physical oceanographic characteristics of the dumpsites, with the submersible being used primarily to make direct observations of the geological and biological conditions at the two dumpsites.

The present report provides a detailed description of the geological and topographical characteristics of the two dumpsite areas. Three submersible dives were made in the 2800m low-level radioactive waste dumpsite and five dives were made at DWD-106. The sediment deposits, bottom topography, evidence of sediment avalanching, biota, currents, and the differences in these parameters between the two dumpsite areas are discussed. The presence of radioactive waste drums in the 2800m dumpsite area is analyzed in terms of the localized geological and physical processes occurring at the site. The report concludes with a general discussion of the geologic stability of the two dumpsite areas which straddle the lower continental slope - upper continental rise provinces.

The Agency invites all readers of this report to send any comments or suggestions to Mr. David E. Janes, Director, Analysis and Support Division, Office of Radiation Programs (ANR-461), Environmental Protection Agency, Washington, D.C. 20460.

Glen L. Sjoblom

Glen L. Sjoblom, Director
Office of Radiation Programs

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INTRODUCTION

The deepwater radioactive waste dumpsite addressed in this report is an area of about 100 square nautical miles (342 square kilometers) in the Northwest Atlantic which lies astride the boundary between the lower continental slope and upper continental rise of the eastern margin of North America. The dumpsite is approximately 120 nautical miles east of Cape Henlopen, Delaware. Water depths at the dumpsite range from about 2500 meters to 2800 meters. Seafloor relief is locally smooth, and the site is centered at 38°30'N, 72°06'W.

The general area which is almost contiguous to this radioactive waste dumpsite is referred to as Deepwater Dumpsite 106 (DWD-106). Baseline investigations were initiated in 1974 by the National Oceanic and Atmospheric Administration (NOAA) which is charged with the responsibility, under Title II of Public Law 92-532, to investigate the environmental effects of dumping of waste material into ocean water and onto the seabed.

Geologic field studies of the low-level radioactive waste dumpsite were undertaken by the U.S. Environmental Protection Agency in the summers of 1974, 1975, and 1976, and involved sampling and bathymetric soundings from surface vessels, and direct seafloor observation, photography, video recording and sampling by the manned submersible DSRV ALVIN.

Professor Bruce C. Heezen of Lamont-Doherty Geological Observatory had responsibility for the 1974 geological investigations at DWD-106 (Heezen, 1975) and the 1975 and 1976 geological field studies at the low-level radioactive waste dumpsite. Professor Heezen died in June 1977 prior to final analysis of the latter field studies. This report has been assembled using field notes, sketch maps, audiotape recordings made by Professor Heezen, and selected photographs from the submersible activities of the 1975 and 1976 surveys. Additional data have been added to this report data from the research files at Lamont-Doherty Geological Observatory. The assessments and conclusions reflect the authors' interpretation of the available observations and facts.

SUMMARY

During 1975 and 1976 a total of eight submersible dives with DSRV ALVIN were carried out in a relatively small region (about 2 km x 3 km) of the radioactive waste dumpsite and were centered at 38°30'N and 72°09'W. Six other dives were distributed through the northern part of DWD-106 near the boundary of the continental rise/continental slope.

The lower continental slope is incised by submarine canyons debouching into the northern side of DWD-106. Canyon walls are steep (up to 50°) and display outcrops of strata made up of calcareous marlstones, grainstones, and siliceous mudstones. The upper continental rise is incised by narrow meandering channels. One of them passes through the radioactive waste dumpsite and was surveyed in detail during the 1976 diving schedule (Heezen and Dyer, 1977).

On the upper continental rise the local terrain is relatively flat but studded with numerous tracks, trails, holes, and mounds of biological origin. The sediment carpet is composed of a gray silty-clay referred to in the pre-1970 literature as lutite. Sediment cores display bioturbation effects and appear rather homogeneous in lithology and lack distinct bedding. The carbonate in the dumpsite area ranges between 30% and 43% and averages 37%. Essentially all of the carbonate is biogenous with foraminifera characterizing the sand and upper silt-size fractions, and coccoliths characterizing the lower silt and clay-size fractions (Neiheisel, 1979).

The mineral suite averages 37% biogenous carbonate, 30% clay minerals, 2% mica, 23% quartz, 7% feldspar, 1% detrital heavy minerals, and trace amounts of glauconite and diatoms. The clay mineral suite is predominantly illite (50-60%) and generally equal proportions of chlorite and kaolinite which, when combined, range between 12% and 30%. Montmorillonite comprises between 5% and 10% of the clay minerals. The heavy mineral suite is essentially a garnet-hornblende suite with a garnet-staurolite ratio similar to the mineral province on the adjacent continental shelf (Neiheisel, 1979).

The average sediment texture of the upper and lower portions of the cores is very uniform over the dumpsite area, with most cores characterized as clayey-silts and a few as silty-clays.

Pebbles, cobbles, boulders, and large allochthonous blocks (olistoliths) were encountered on many of the dives. Some of them are interpreted as glacial erratics, ice-rafted into the area more than 14,000 years ago. Others are composed of indurated marine marls and clays of Eocene age, carried into deepwater sites by subaqueous landslides and debris flows in relatively recent times. In fact, the western part of the dumpsite is a broad slump scar which has lost tens of meters of sediment cover by creep or flowage within the time period since the last major interglacial 35,000 years before present (B.P.).

Bottom currents were detected during a majority of the dives. Five current meters deployed between August and November 1976 recorded varying oscillatory currents with a maximum speed of 40 cm/sec and a mean flow of 3-4 cm/sec. During periods of highest speeds, the currents flowed in a westerly direction (Hamilton, 1982). Ripple marks were only detected in canyons, gullies, and the thalwegs of meandering channels. Scour moats were present around rock outcrops and waste containers, and the moats were filled with distinctly coarser lag deposits.

Containers were observed in varying states of integrity. Some of the containers appeared to have been breached. Encrustations of worm tubes, anemones, and sponges were seen on the exposed concrete end of the waste containers and were also common on outcrops of calcareous substrates, indicating that the abundance of attached organisms is directly related to the solid nature of the surface of attachment. Mobile fauna (rattail fish, ophiuroids, asteroids, euphausids, and holothurians) were observed feeding upon surficial sediment surrounding the waste containers. The rattail fish in particular were attracted to sediment plumes put into suspension by the submersible. Sessile fauna such as gorgonians and pennatulids were photographed as they were deflected by near-bottom currents, the stalked animals being most abundant in flat terrain. The action of both animals and currents has partly but not totally obliterated 1- to 2-year-old ski marks made by the ALVIN during previous surveys.

On the continental rise the local terrain is partly hummocky, with relief of the hills occasionally exceeding 20-30 m. The relief is attributed to remnant mounds of sediment left behind on broad slump scars. Outcrops are common on the flanks of some of the hills and on the walls of narrow channels, but are most pervasive along the outside bends of meanders along the course of the channels. Gullies on the slope are separated by steeply sloping spurs draped with clays. Some relict cut and fill bedforms are seen in small outcrops on the canyon walls where the canyon apparently cuts through older levee deposits.

REGIONAL GEOLOGIC SETTING

The area delineating industrial waste dumpsite 106 (DWD-106) and the nearby radioactive waste dumpsite covers a diverse seascape of the dissected continental slope and the depositional terrain of the continental rise. The juncture between these two seafloor provinces is not particularly sharp because many of the slope canyons continue onto the rise as channels. Some of the channels pass entirely through the low-level radioactive waste dumpsite and reach the lower continental rise and the Hatteras Abyssal Plain.

The slope canyons are evident in the bathymetric contours of Figure 1 adapted from publications of Beatch and Smith (1939), Heezen et al. (1959), Uchupi (1965), Uchupi and Emery (1967), Pratt (1967, 1968), Holland and Bedding (1969), Schneider (1970), Emery et al. (1970), and Emery and Uchupi (1972). The DWD-106 and radioactive waste dumpsite are situated between the Hudson Canyon System to the northeast and the Wilmington Canyon (sometimes called the Brandywine Canyon (Schneider, 1970)) to the southwest. The large east-coast canyons indent the shelf edge and, where surveyed in extreme detail as illustrated in Figure 2, the canyons display a dendritic-type submarine drainage system. The dendritic fabric was first recognized by Stetson (1936). Both he and Shepard (1952) commented on the great similarity of the submarine drainage network of the east-coast margin with a subaerial "badland" type topography characteristic of North and South Dakota. Although it is widely accepted today that the submarine features are carved and kept sediment-free by exclusively subaqueous processes, one should not lose sight of the value gained by the analogies of Stetson and Shepard as relevant to the landforms of DWD-106 being sculpted by mechanisms which we do not adequately understand.

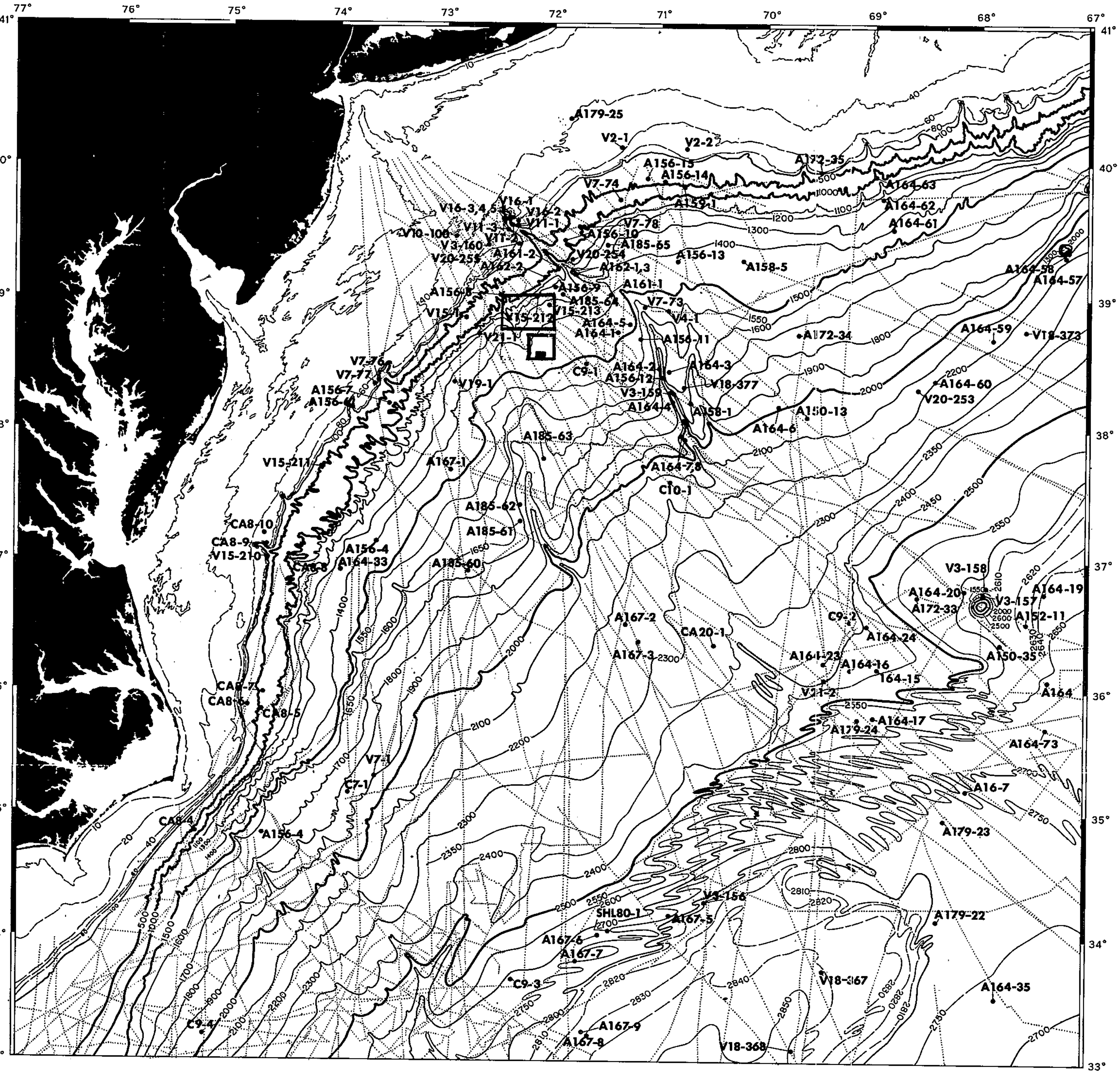


Figure 1. Deepsea core locations and bathymetric contours of the east coast continental margin. DWD-106 and the smaller contiguous radioactive waste dumpsite to southeast are outlined; the small solid square indicates the region of detailed ALVIN submersible surveys. Note the heavy incising of the continental slope by submarine canyons and the continuation of the larger canyon systems across the continental rise. Contours are in fathoms (1 fm = 6 ft = 1.8 m). The dumpsite area is bounded to the northeast by the Hudson Canyon System and to the south by the Brandywine Canyon System fed from the west by the Wilmington Canyon. Map is from Schneider (1970). Dotted lines are survey tracks, primarily of R/V Atlantis and R/V Vema cruises.

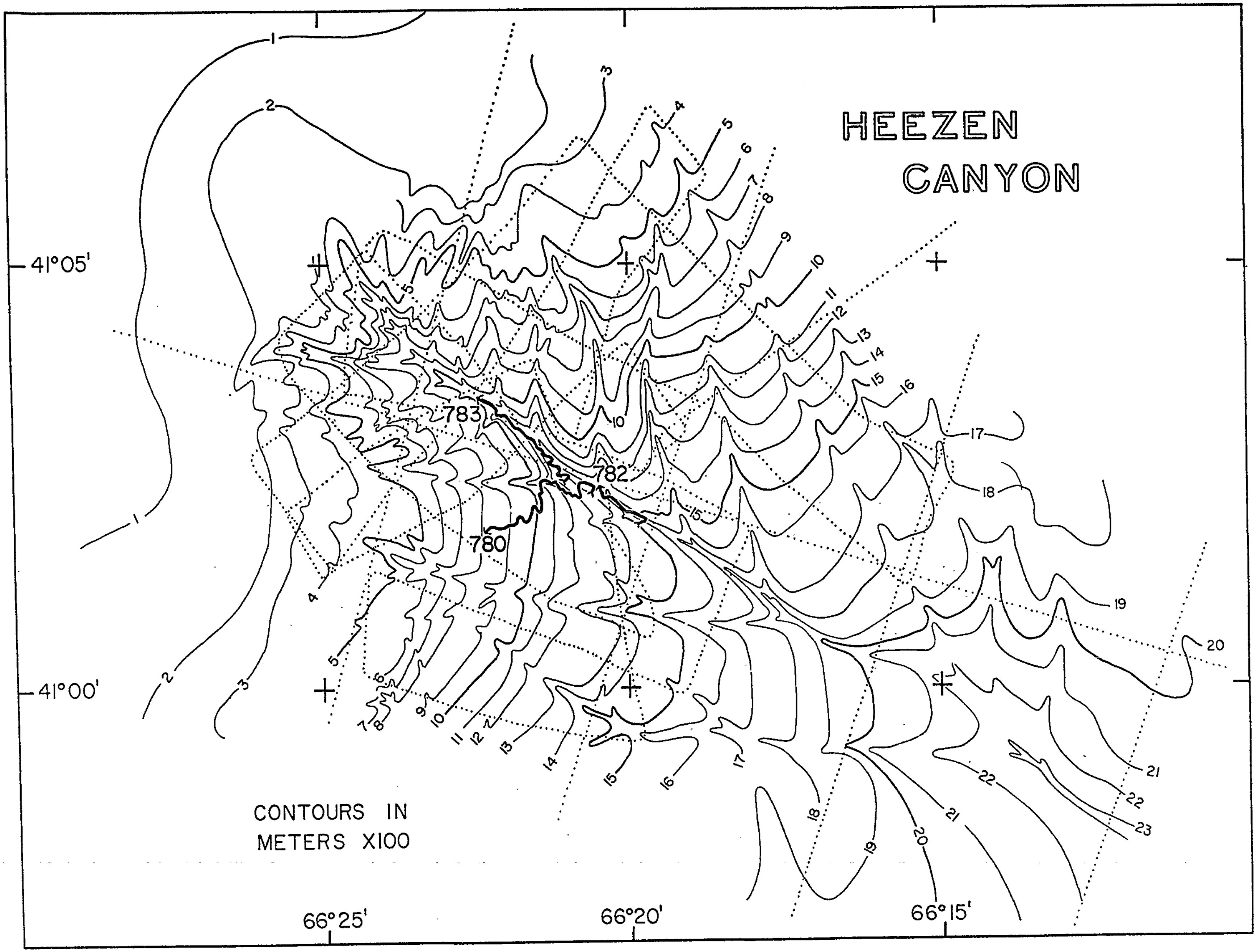


Figure 2. Dendritic-type drainage pattern in Heezen Canyon on the continental slope of New England. In 1977, ALVIN Dives 780, 782, and 783 showed that the slope canyons are routes along which sediment is actively transported downslope by debris flows and subaqueous avalanches (figure from Ryan et al., 1978b).

Continental Slope

The Atlantic continental slope is an area of active sediment denudation, especially for the region from Cape Hatteras northward to Long Island. Formations which are deeply buried beneath the continental shelf can be traced seaward by reflection profiling to outcrops along the lower slope. Strata as old as Upper Cretaceous (65-80 million years) have been recovered in shallow cores along the slope in the vicinity of Hudson Canyon and off the Carolinas (Gibson et al., 1968; Fleischer and Fleischer, 1971; Perry et al., 1975). A core (#21-38) reported by Stetson (1949) at a depth of 1565 m (855 fathoms) in the northwestern corner of DWD-106 contains material of Upper Eocene age (40 million years B.P.).

The outcropping of sedimentary layers along the slope is illustrated in Figure 3, taken from Grow and Markl (1977). This profile has been calibrated to the Hatteras Light No. 1. It shows a seaward extension of Cretaceous age layers which have been truncated by a major erosion surface (see stars on the profile) reaching deep beneath the upper wedge of sediment of the continental rise. Other erosion surfaces also appear on the U.S. Geological Survey (USGS) Seismic Line #2, passing through the northeast corner of DWD-106, and on USGS Seismic Line #5, extending southward from Martha's Vineyard.

The extent of these regional unconformities indicates that a massive amount of sediment has been removed from the former continental margin and carried basinward. One of these unconformities is traceable by reflection profiling techniques to a nearby drillsite of the Deep Sea Drilling Project (DSDP Site 106; 36°26.01'N; 69°27.69'W; 4500 m water depth) reported by Hollister and Ewing (1972a). This unconformity is called Horizon A by Tucholke and Mountain (1979). The oldest overlying strata are Miocene in age (<25 million years) indicating that the vast part of the thick continental rise prism of the western North Atlantic is remarkably youthful. The erosion surface practically crops out at the continental rise/slope transition just to the west of DWD-106. Here at DSDP Site 108 (38°48.27'N; 72°39.2'W; 1845 m water depth), Middle Eocene (45 million years) sediments have been cored at 35-75 m beneath the seabed (Hollister and Ewing, 1972b).

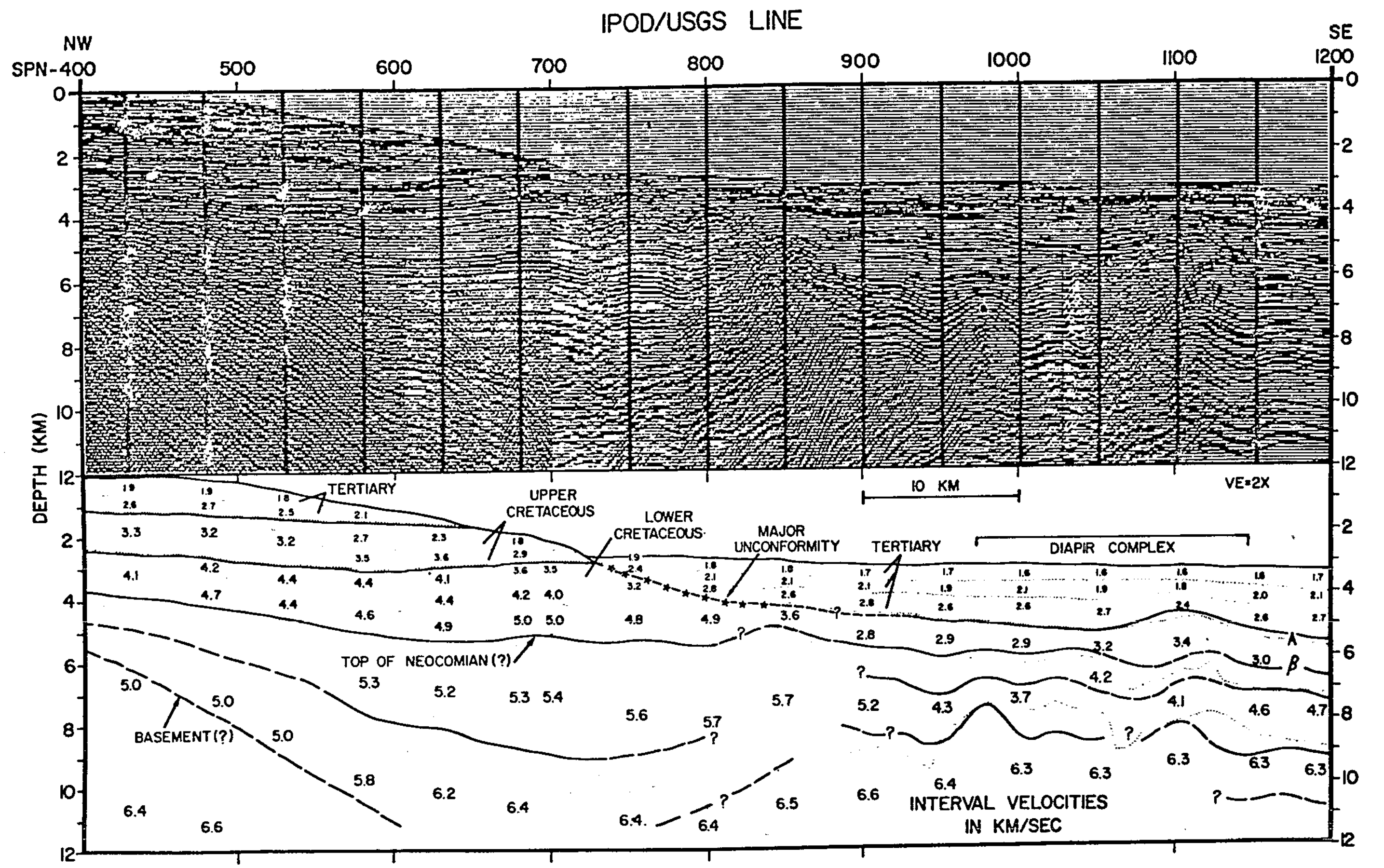


Figure 3. Sedimentary outcrops on the continental slope east of Cape Hatteras. The seismic profile and interpretation is from Grow and Markl (1977). Tertiary and Cretaceous-age strata are truncated by an erosion surface whose base (indicated by stars) is now buried beneath the upper continental rise. More than a kilometer of overburden has been denuded from the continental slope in this region. Outcrops of this type occur in the northwestern section of DWD-106.

All the aforementioned evidence emphasizes the "wasted" nature of the continental slope province. Submarine canyons obviously play an important role in the progressive landward retreat of the slope. They are not only "bypass" routes for shelf materials enroute to the continental rise and abyssal plains, but they are areas of continuing backcutting and denudation (Figure 4). Erosional processes within the canyons and on the slope which accompanied fluctuations in Tertiary sea level (to perhaps 60-70 million years B.P.) have caused a regression in the shelf edge from 10-30 km in this area (Schlee et al., 1979). Debris jettisoned into the sea as waste and landing within the confines of submarine canyons should not be expected to remain for long (geologically speaking) at the site of impact before being transported into greater depths on the continental rise apron.

Submersible explorations carried out by Bruce C. Heezen in Hudson Canyon and in Oceanographer Canyon (southeast of Cape Cod) have allowed direct observation of such erosion processes. Recent submersible fieldwork in other New England canyons (Ryan et al., 1978b) demonstrates that these features are still actively incising the slope.

The New England canyons in particular contain very narrow axial thalwegs, in places only a few meters in width, with sheer walls of polished and abraded lithified sediment. Tidal currents surge in diurnal cycles up and down the canyons, generally with a modest net upcanyon component. Sediment is carried into suspension by turbulent eddies and especially by the feeding habits of bottom dwelling organisms and grazing fish. Diagenetic dissolution, encrustation, and boring weakens exposed rock faces, eventually producing their collapse as underwater avalanches. Talus blocks are scattered throughout much of the canyon channels on the lower slope. Where sand is the dominant sediment on the adjacent continental shelf, it is fed by current gyres into the canyon heads. This abrasive material is swept back and forth along the thalweg by the cyclic tidal currents, thereby amplifying the effects of scouring and undercutting.

Where mud is the dominant lithology on the adjacent shelf, as is the case in the New York Bight, the abrasive action of tidal currents is reduced. Photography from submersibles indicates that in the New York Bight visibility is often less than 2 m due to the high degree of suspended sediment. The mud is being

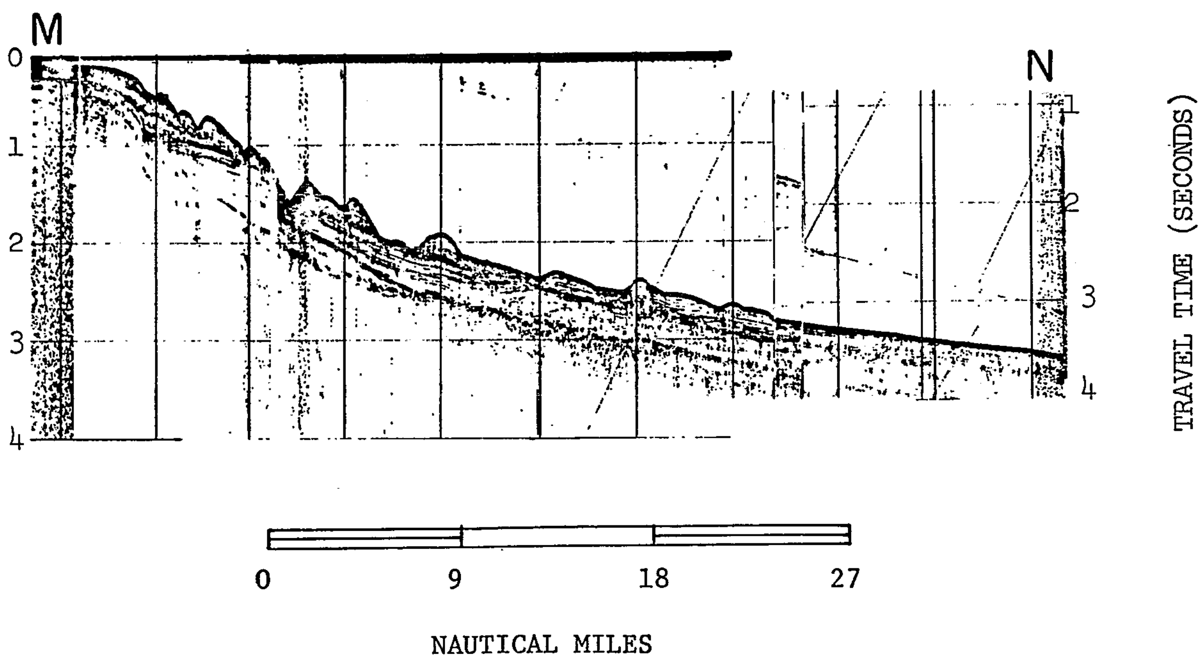


Figure 4. Seismic reflection profile extending across the continental margin from the shelf edge out onto the upper continental rise to the south of the DWD-106 and radioactive waste dumpsite region. Note how the canyons on the lower slope and upper rise have cut downward into sediment layers exposing older strata (figure from Schneider, 1970).

swept back and forth in each tidal cycle, and tidal currents in excess of 50 cm/sec have, in fact, been measured at 700 m depth in the Hudson Canyon (Heezen, unpublished). Since sizeable amounts of mud drape the canyon walls and floor, we conclude that the sediment is not being carried out of the canyon system presently at a rate greater than it is entering, and entrenchment has temporarily ceased.

The biological contribution to mass-wasting cannot be overemphasized (Dillon and Zimmerman, 1970; Warme, 1975; Warme et al., 1971; Palmer, 1976; Heezen, unpublished field notes). Animal mounds and holes are very common in the organic-rich carpet of hemipelagic marls, muds, and mudstones (Figure 5). Talus ejected from burrows is always thickest on downslope sides of mounds attesting to a prevailing gravitational migration of excavated material downslope. Vagrant benthos (crustaceans, holothurians, ophiuroids) are very abundant and they are constantly creating clouds of suspended sediment. Even the densest limestones are seen to be bored by polychaete worms and bivalves, lending to an eventual "swiss-cheese" framework that collapses from lithostatic overburden pressure and gravity.

The dendritic fabric of much of the canyon networks can be explained by abrasive activity primarily concentrated in the thalweg. The gradual sediment entrenchment results in progressive oversteepening of the local thalweg walls. The mechanical failure of the walls in turn widens the thalweg and perpetrates lateral collapse. The whole process erodes the slope leading to its retreat. The dissected regions of the continental slope are therefore only temporary storage reservoirs for contemporary sediment and/or waste dumped at sea. In summary, biological, mechanical, and gravitational processes and the prevailing current regime work in combination to transport materials arriving in the canyon network to ever greater depths on the slope and rise.

Deep sea drilling was carried out in 1975 on the west African continental margin on DSDP Leg 47. There, a deep borehole penetrated a massive erosion surface of a configuration similar to that which exists on the North American Margin. The drilling (Ryan et al., 1976; Ryan et al., 1979) and integrated geophysical site surveys (Seibold and Hinz, 1974) confirm that more than 1 kilometer of slope sediment has been removed in only a few million years

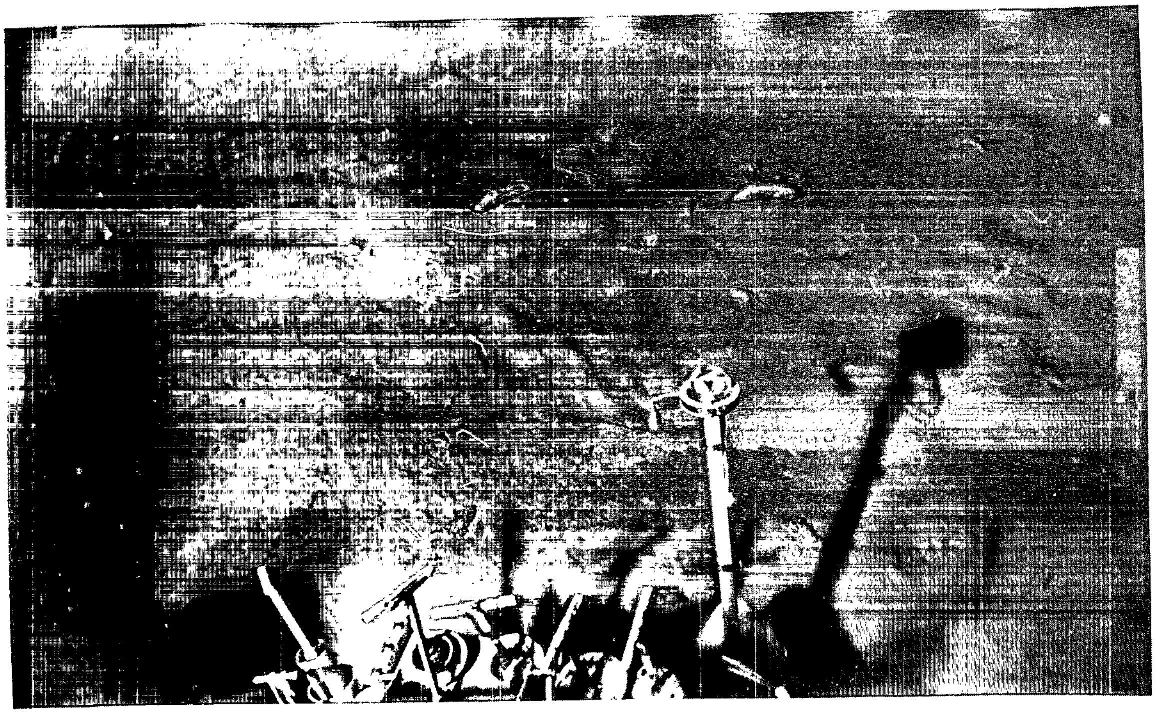


Figure 5. Holes and mounds of biological origin on the upper continental rise in the northeastern section of DWD-106 about 30 km north of the designated radioactive waste dumpsite. The holothurians (Psychropotes depressa) in background are approximately 20 cm in length. Photograph #4314 is from 1975 ALVIN Dive 591 at 38°55'N, 72°04'W, and 2460 m depth. The sample basket of the ALVIN submersible is in the foreground.

(i.e., at rates of tens of centimeters per 1,000 years). However, such mass-wasting processes are intermittent. There are relatively brief episodes when deep entrenchment takes place and longer intervals of not only little entrenchment, but even complete infilling of canyons.

Much remains to be learned about the timing of these episodes and the processes at work. Nevertheless, there is a growing consensus within the earth science community that erosive phases of the continental margin seem to have occurred coincident with times of enhanced sediment bypassing from the continental shelf to the continental rise (Rona, 1973; King and Young, 1977).

Lamont-Doherty submersible studies in New England canyons (Ryan et al., 1978a,b) reveal similar discrete episodes of "cut and fill," the earliest cutting reaching back at least 40 million years B.P.

The most recent significant entrenchment is Quaternary in age, correlating with the latest phase of northern hemisphere glaciation at approximately 18,000 years B.P. and the accompanying lowering of world-wide sea level (Flint, 1971). The magnitude of relative sea-level lowering along the eastern borderland has been estimated to be approximately 100 to 130 m (Milliman and Emery, 1968; Dillon and Oldale, 1978), an amount sufficient to move the shore line eastward to the present shelf-break (Figure 6). The Hudson Channel on the modern shelf had its origin as a subaerial stream bed (Chelminski and Fray, 1966). The regression caused large thicknesses of sediment to be removed from the shelf (Garrison, 1970) and strata as old as the Upper Cretaceous were exposed (Woodworth and Wigglesworth, 1934). Because of the proximity of the shore line to the shelf edge, rivers were no doubt capable of discharging their bedload and certainly their suspended load from major floods directly into the heads of the slope canyons. Where the shelf is narrow as along the coast of southern France, muddy water may reach abyssal depths in less than a day following river flooding (Groupe Estocade, 1978). When the heads of the canyons intersect the near-shore high-energy zone, they capture mud, silt, sand and sometimes gravel, boulders and man-made litter, whose downslope flowage, creep, and avalanching become abrasive agents for further downcutting (Dill, 1962).

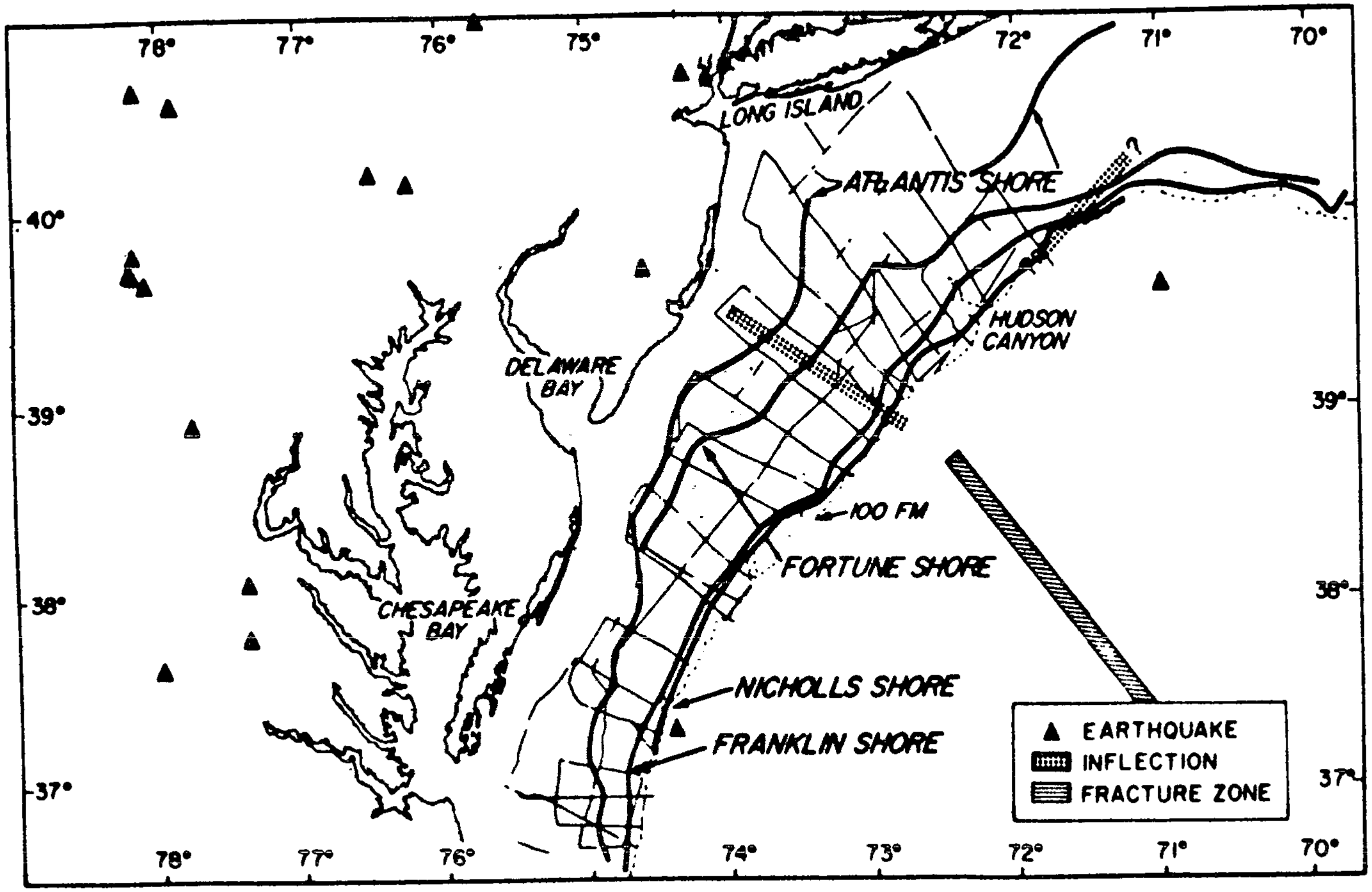


Figure 6. Position of ancient shore lines on the continental shelf east of New Jersey and Delaware. These shore lines existed at the time of lowered sea level during the last ice age. The continental slope canyons are thought to have undergone deep entrenchment when the shore line had migrated out to the shelf edge as was the case some 14,000 years ago (figure from Dillon, W.P. and R.N. Oldale, 1978).

Continental Rise

The continental rise is distinguished from the continental slope by its more gentle seaward gradient (Heezen et al., 1959). The rise is essentially a province of net sediment accumulation in contrast to the slope being a province characterized by denudation.

Off the eastern coast of North America the continental rise contains the thickest sediment of the central margin (Sheridan, 1974; Mayhew, 1974). South of Hudson Canyon, the continental rise can be subdivided into an "upper rise" with regional gradients of 1:200 to 1:600 and with a large, broad, easterly-sloping convex surface, and a "lower rise" with gradients as low as 1:2500 and an easterly-facing concave surface (Figure 7).

Groups of small hummocky hills occur in the dumpsite area in the upper portion of the upper continental rise. The seismic reflection profiles of these hills give the appearance of large allochthonous blocks (olistoliths) derived from slumps originating on the steeper continental slope. Characteristic topographic features of the upper continental rise are steep-walled slump scarps and meandering channels that cross their surfaces. The lower continental rise is a broad, nearly level terrace lying at depths generally below 4000 m (2200 fm). Directly south of Hudson Canyon the terrace is very smooth, having been created by sediment ponding behind a buried outer ridge which forms part of the lower continental rise hill complex (Asquith, 1976). The lower continental rise lies seaward of the dumpsite region and is relevant to our study because it is a site of deposition for materials which may be transported from the dumpsite region by channelized turbulent flow and/or subaqueous avalanches. Some channels which meander through the dumpsite continue across the lower continental rise and through the lower continental rise hills province to debouch near the northeastern limit of the Hatteras Abyssal Plain.

The continental rise lies beneath the path of the Western Boundary Undercurrent of the North Atlantic (Heezen et al., 1966; Schneider and Heezen, 1966; Schneider, 1970). The boundary current (Figure 8) is part of the North Atlantic Deep Water (Swallow and Worthington, 1961) which flows southward parallel to regional isobaths. Its movement, shown in Figure 9, has been

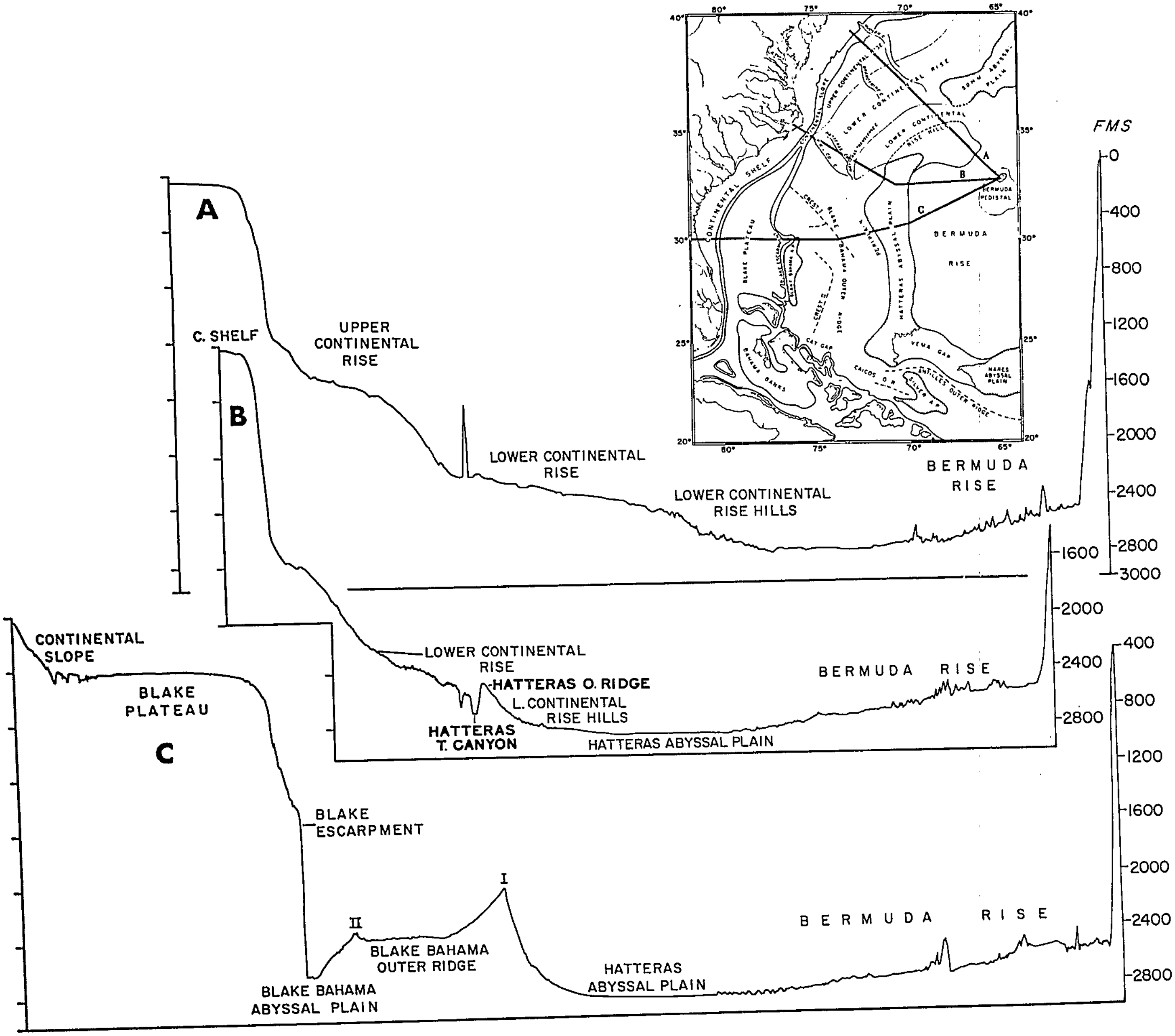
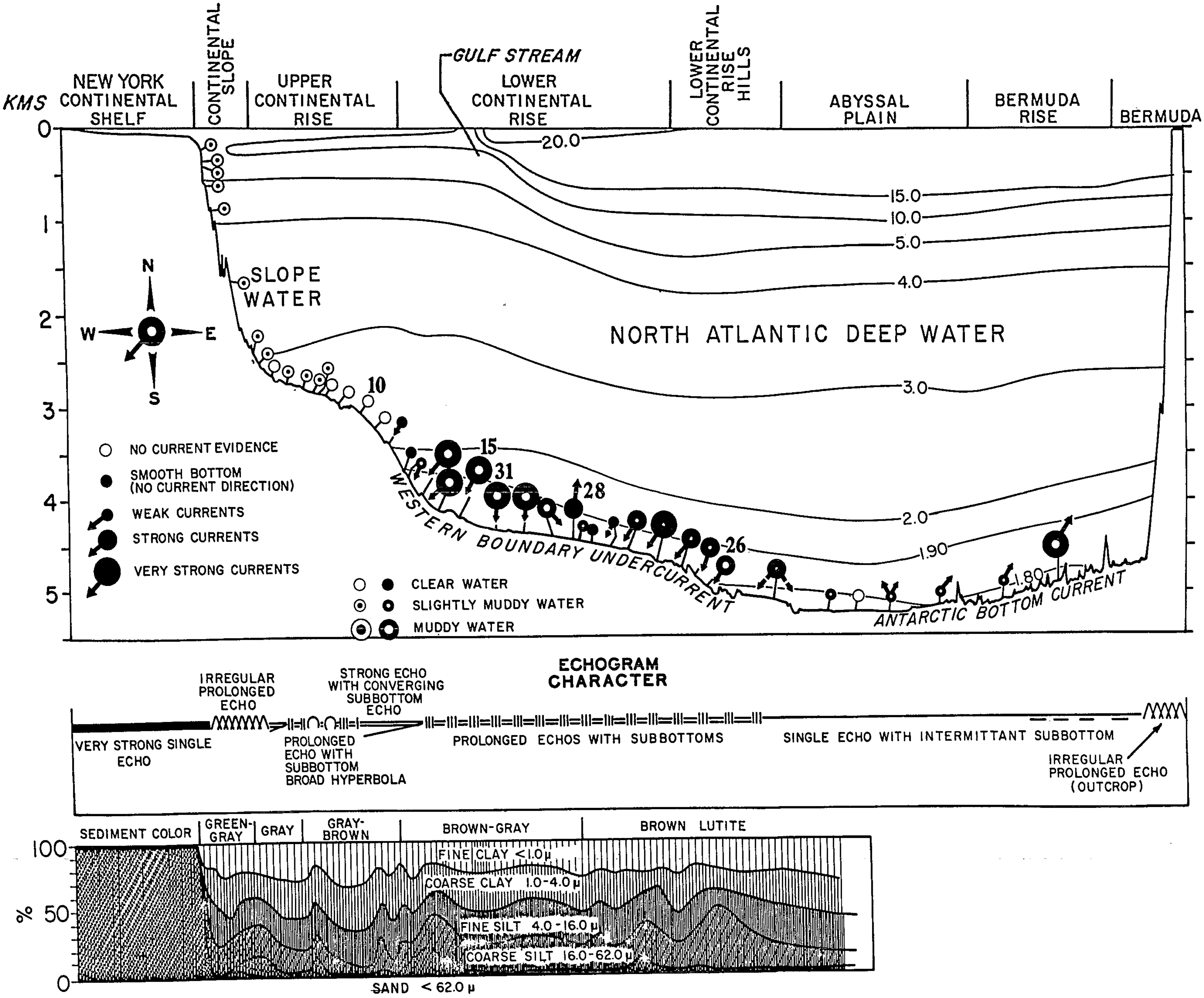


Figure 7. Bathymetric profiles across the continental margin of the eastern coast of the United States. DWD-106 and the radioactive waste dumpsite are situated on Profile A in an area where the continental rise is particularly broad and where it can be differentiated into an "upper rise" with a typical convex surface and a more gently dipping "lower rise." The dumpsite area straddles the limit between the "upper rise" and the continental slope. Vertical exaggeration of the profiles is 1:100 (figure from Schneider, 1970).

Figure 8. Section across the continental margin passing through DWD-106 and the radioactive waste dumpsite. This illustration from Schneider (1970) shows potential temperature of the water column, evidence, magnitude, and direction of near-bottom currents, bathymetric profile, character of the acoustic echo return from the seafloor, and surface sediment characteristics. Strong currents occur below the change in bottom gradient that distinguishes the "upper rise" from the "lower rise." The boundary circulation causes cold-water isotherms (<2°C) to intrude onto the continental rise. Prolonged bottom echo sequences and an increase in the sand- and silt-sized surface sediments are associated with current-swept zones. DWD-106 and the radioactive waste dumpsite are situated landward (to left) and above the Western Boundary Undercurrent in a region where deep-water circulation at present is considerably less vigorous.


KMS
NEW YORK CONTINENTAL SHELF
CONTINENTAL SLOPE
UPPER CONTINENTAL RISE
GULF STREAM
LOWER CONTINENTAL RISE
LOWER CONTINENTAL RISE HILLS
ABYSSAL PLAIN
BERMUDA RISE
BERMUDA
0
1
2
3
4
5
20.0
15.0
10.0
5.0
4.0
3.0
2.0
1.90
1.80
SLOPE WATER
NORTH ATLANTIC DEEP WATER
N
W
E
S
10
15
31
28
26
WESTERN BOUNDARY UNDERCURRENT
ANTARCTIC BOTTOM CURRENT
NO CURRENT EVIDENCE
SMOOTH BOTTOM (NO CURRENT DIRECTION)
WEAK CURRENTS
STRONG CURRENTS
VERY STRONG CURRENTS
CLEAR WATER
SLIGHTLY MUDDY WATER
MUDDY WATER
ECHOGRAM CHARACTER
IRREGULAR PROLONGED ECHO
STRONG ECHO WITH CONVERGING SUBBOTTOM ECHO
VERY STRONG SINGLE ECHO
PROLONGED ECHO WITH SUBBOTTOM BROAD HYPERBOLA
PROLONGED ECHOS WITH SUBBOTTOMS
SINGLE ECHO WITH INTERMITTANT SUBBOTTOM
IRREGULAR PROLONGED ECHO (OUTCROP)
SEDIMENT COLOR
GREEN-GRAY
GRAY
GRAY-BROWN
BROWN-GRAY
BROWN LUTITE
100
% 50
0
FINE CLAY <1.0 μ
COARSE CLAY 1.0-4.0 μ
FINE SILT 4.0-16.0 μ
COARSE SILT 16.0-62.0 μ
SAND < 62.0 μ

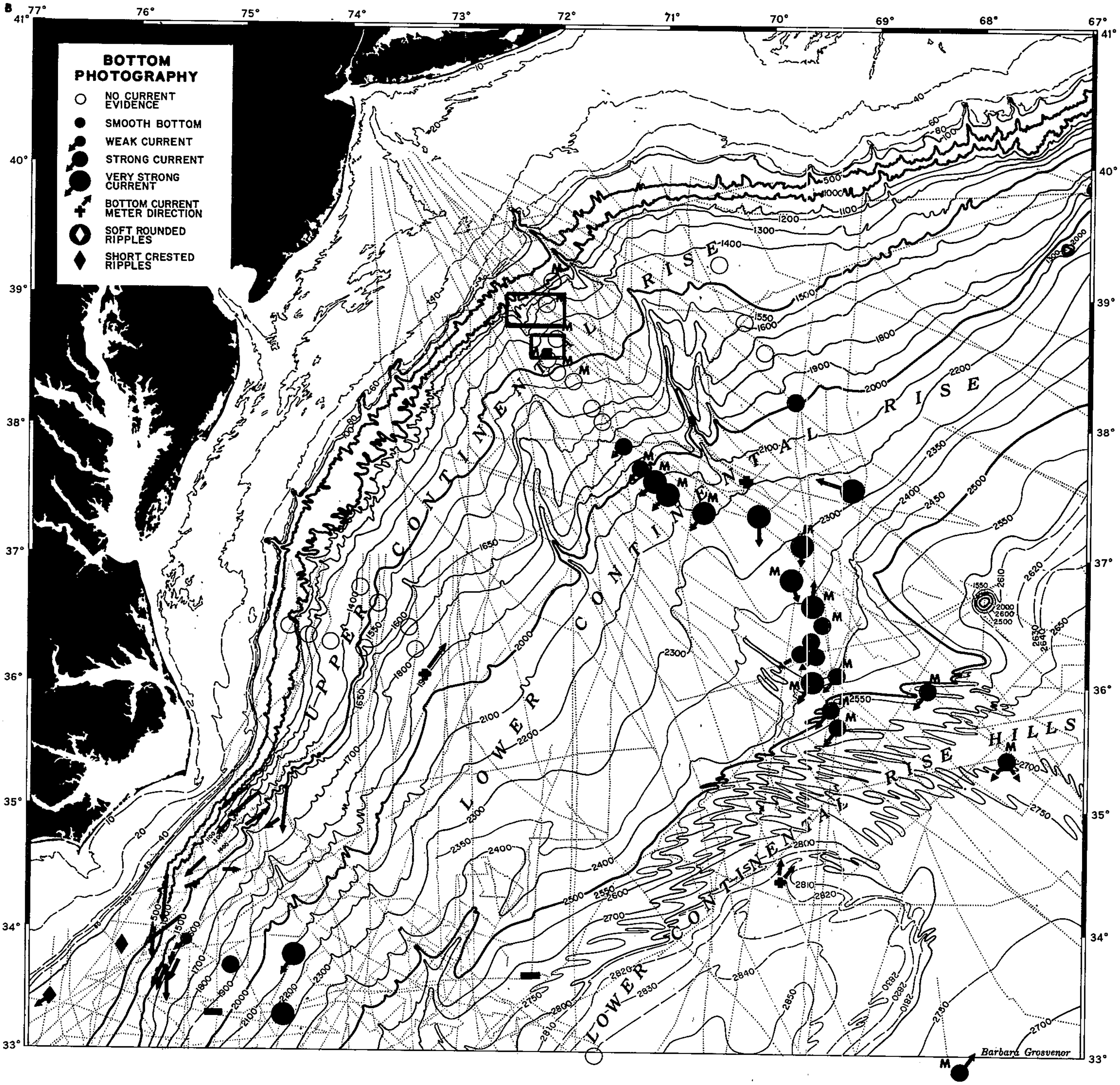


Figure 9. Distribution of bottom photograph stations which show evidence of bottom current direction and relative current speed (map from Schneider, 1970). "M" designates muddy bottom. Arrows without circles show current flow as determined from the tracking of neutrally-buoyant floats. Contours in fathoms. Note the persistent southwesterly direction of the Western Boundary Undercurrent transport on the lower continental rise (below 2200 fm, or 4000 m) and the lack of a detectable current on the upper rise, especially near and within the locality of DWD-106 and the radioactive waste dumpsite.

detected by direct current measurements (Volkmann, 1962) and hundreds of compass-oriented photographic stations (Heezen and Hollister, 1971). These photographs taken in the 1976 ALVIN survey provide distinct evidence of current-swept and current-free zones on the bottom revealed by features such as corrugations, ripples, crag and tail structures, furrows, and inclined stalks of attached epifauna (Figure 10). The most common evidence of bottom currents is reflected in the small-scale relief features on the bottom. Smooth, round, mud ripples (wavelength 2-6 m) are observed in some of the photographs. Linguoid (tongue-shaped) and transverse ripples are bedforms most commonly seen in photographs. Steep lee and gentle stoss slopes indicate the direction of the unidirectional current flow to the southwest.

Nature and Composition of the Sediment Cover

The Lamont-Doherty deep sea core repository contains numerous cores from the region surrounding and within DWD-106 (for example, see station locations plotted in Figure 1). The most thorough published descriptions of a large number of these cores can be found in Ericson et al. (1961).

Two distinct sediment types characterize the continental slope. Cores from the thalwegs of major submarine canyons contain coarse clastics (sometimes including gravel and large fragmented mollusk shells). These clastic beds generally contain micro- and macrofauna reworked and displaced from areas of the shallow shelf. The clastics are in the process of being transported through the canyon systems onto the abyssal plain. Cores between the canyons consist of cohesive dark greenish-gray silty-clays with high organic carbon contents. These sediments are low in calcium carbonate, contain some glauconite, are rich in pyrite, and sometimes are abundant in siliceous microfossils such as diatom frustules. The lack of appreciable stratification in the silty-clay cores suggests deposition under rather steady environmental conditions without significant winnowing by currents. Carbon contents in excess of 1.5% by weight are related to the presence of low oxygen contents in the mid-water column along the continental slope (see Jones, 1983). Outcrops of pre-Recent (i.e., before 11,000 years B.P.) and pre-Pleistocene age claystone and shale indicate erosion of the slope and displacement of part of its uppermost sedimentary cover.

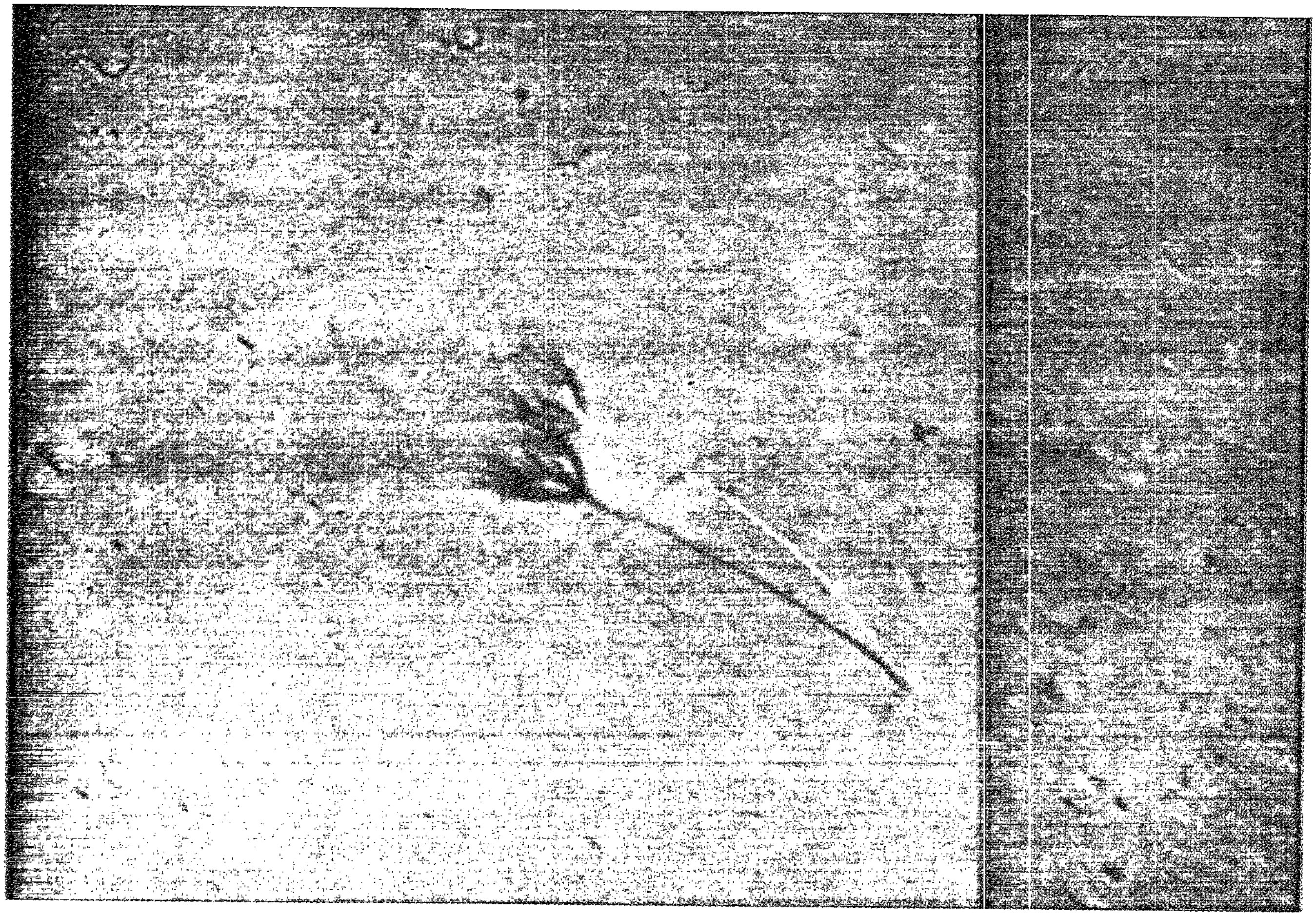
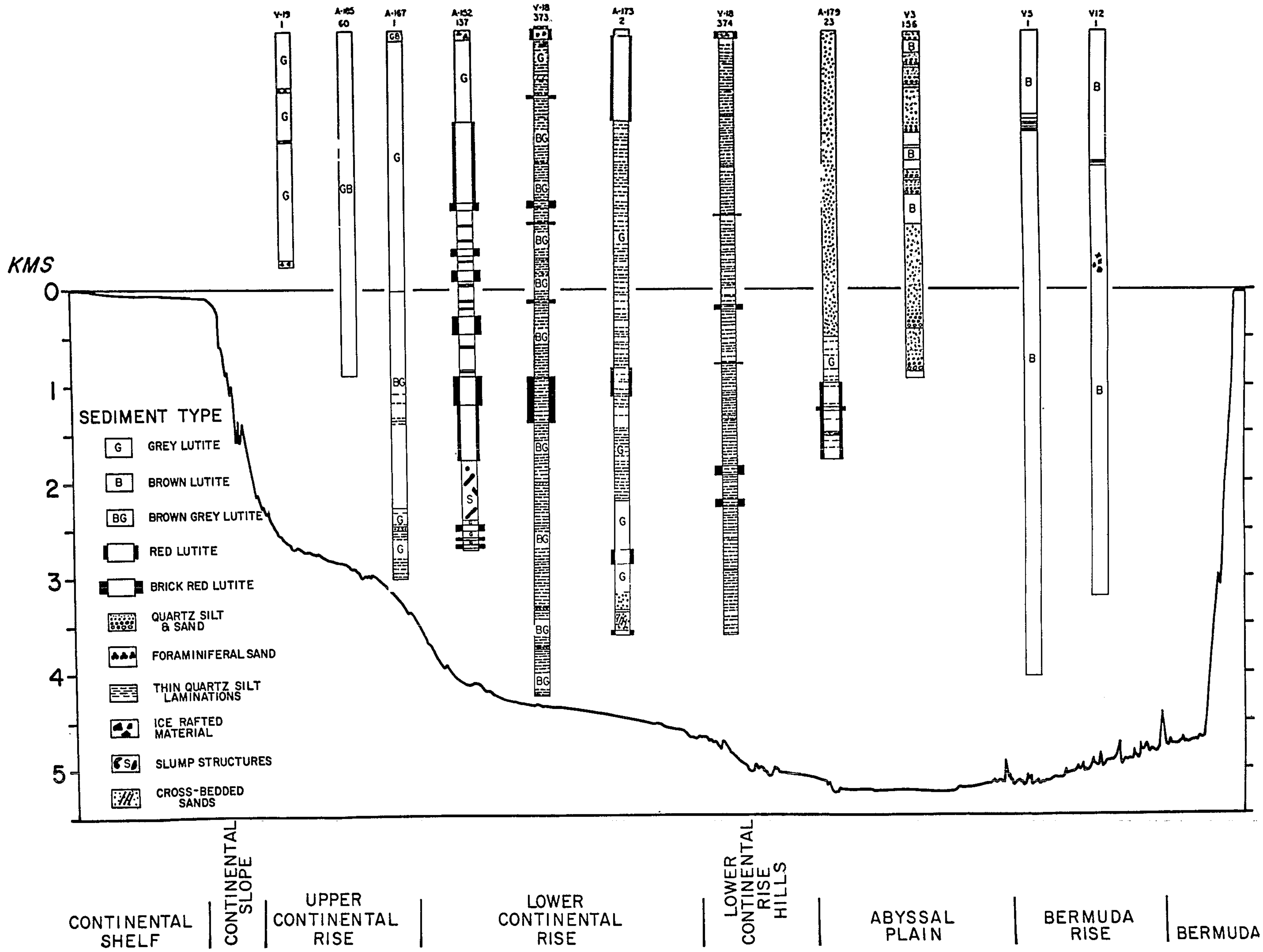


Figure 10. Umbellula, a deepsea octocoral, is shown here deflected in a westerly current within a narrow meandering channel on the upper continental rise at 38°30.51'N, 72°09.28'W, water depth 2788 m. The Umbellula is about 40 cm in height and the current velocity can be estimated to exceed 10 cm/sec. Note smoothing of the regionally flat, gray, silty-clay bottom. This photograph was taken during ALVIN Dive 676 within the low-level radioactive waste disposal site.

The upper continental rise is characterized by homogeneous gray to light-brown colored clays and silty-clays that are significantly more bioturbated than the slope cores. Carbonate contents in the area of DWD-106 and the radioactive waste dumpsite approach 15% to 30% and organic carbon contents are less than 0.4%, indicating effective biological reworking of these sediments. Cores rarely contain pre-Pleistocene age sediment, except as clasts within debris flow deposits. Core A164-1, located just east of DWD-106 and the radioactive waste dumpsite (Figure 1) and southwest of the Hudson Canyon system, has been subjected to biostratigraphic analysis. This core is 8.69 m in length and consists for the most part of homogeneous silty-clay interbedded with a few graded sand and/or silt layers, whose frequency of occurrence increases with increasing depth within the core. On the basis of the abundance of the planktonic foraminifera Globorotalia menardii, Ericson et al. (1961) established biostratigraphic zones which delineate Recent (Holocene) sediments (Z Zone) from those of the last glacial epoch (Y Zone). The boundary between these two Zones has been dated at 11,000 years B.P., and it occurs at a depth of 75 cm in the core. Calculations of sedimentation rates based upon the location of this boundary yield a rate of 6.8 cm per 1,000 years for Holocene deposition. The sedimentation rate of the lower (glacial) section is greater than twice that of the upper 75 cm, reflecting an increase of coarse sediment delivered to the canyon system through subaqueous landslides and debris flows during glacial times (Ericson et al., 1961).

Sediments on the upper continental rise are essentially hemipelagic deposits consisting of skeletal material of marine plankton admixed with clay minerals, fine quartz and feldspar derived from the adjacent coastal plain and shelf. Their distinct homogeneity (Figure 11) points toward a relatively tranquil environment into which coarser silts and sands have not been significantly advected laterally by either traction currents or suspension bedloads. For the most part, the coarse-grained sediments apparently bypass the upper rise by means of canyons and channels where they are confined almost exclusively to the narrow axial thalwegs and the adjacent levees. However, a study of the sediment heavy minerals and size fractions, including percent of sand-size inorganic minerals, at the Atlantic 2800 m radioactive waste dumpsite suggests that some coarse silt and sand is derived from turbidity flows spilling

Figure 11. Lithologies of selected cores from the upper and lower continental rise seaward of New Jersey and Delaware. DWD-106 and the radioactive waste dumpsite would be characterized by the type of surficial sediment found in Cores V19-1, A167-1, and A185-60 (see Figure 1) which is homogeneous with little distinct bedding. Some winnowing is evident by the presence of thin beds of foraminiferal sands such as those occurring in Core V19-1.



V-19 1
A-165 60
A-167 1
A-152 137
V-18 373
A-173 2
V-18 374
A-179 23
V3 156
V5 1
V12 1
KMS
0
1
2
3
4
5
SEDIMENT TYPE
GREY LUTITE
BROWN LUTITE
BROWN GREY LUTITE
RED LUTITE
BRICK RED LUTITE
QUARTZ SILT & SAND
FORAMINIFERAL SAND
THIN QUARTZ SILT LAMINATIONS
ICE RAFTED MATERIAL
SLUMP STRUCTURES
CROSS-BEDDED SANDS
CONTINENTAL SHELF
CONTINENTAL SLOPE
UPPER CONTINENTAL RISE
LOWER CONTINENTAL RISE
LOWER CONTINENTAL RISE HILLS
ABYSSAL PLAIN
BERMUDA RISE
BERMUDA

out of the channels and being transported westward by the contour currents (Neiheisel, 1979).

The lower continental rise is essentially covered by noticeably light-colored brown to tan clays and silty-clays in which there are numerous interbeds of thin well-sorted, ungraded and often ripple-laminated silts and fine sands (Hubert, 1964; Hollister, 1967). A distinct feature of the lower continental rise sediments is the occurrence of bands of bright red clay (Figure 11) derived from Upper Carboniferous red silts of the Gulf of St. Lawrence which have been transported southward by the Western Boundary Undercurrent (Conolly et al., 1967; Needham et al., 1969).

The overwhelmingly stratified nature of the lower continental rise sediments indicates the presence of dynamic and variable sediment processes at these depths (Schneider, 1970). The laminations of well-sorted silt are interpreted as traction deposits laid down by the southwesterly flowing Western Boundary Undercurrent which derives its material from turbidity currents passing across the rise enroute to the abyssal plain. The light color of the sediment provides evidence of a persistent, well-oxidized benthic boundary layer, and higher calcium carbonate contents (see Figure 12) indicate less dilution of biogenic skeletal material in the pelagic layers by clay minerals of terrestrial origin.

THE 1975 SUBMERSIBLE DIVING PROGRAM

During July and August of 1975, nine dives were conducted with DSRV ALVIN on the continental margin east of the Maryland-Delaware coast (Table 1). The purpose of the program was to study DWD-106 and the low-level radioactive waste dumpsite in order to describe the chemical, biological, physical, and geological characteristics of these sites and to initially determine the effects, if any, of dumping on the environment.

The survey was conducted in an area bounded by the coordinates 38°30'N, 39°10'N and 71°55'W and 72°34'W, which encompasses the lower continental slope and the upper continental rise provinces of the continental margin. Dives 586, 587, 589, and 590 were made in the shallower northwest quadrants of the dive area where the slope is incised by small canyons (Figure 13). Dive 587 traversed

Figure 12. Calcium carbonate content in surface sediment samples from the western North Atlantic (map from Schneider, 1970). DWD-106 and the radioactive waste dumpsite contain relatively low carbonate contents (20-30%) characteristic of continental slope and upper continental rise sediments which are heavily diluted by fine-grained, inorganic minerals transported seaward from the adjacent continental coastal plain.

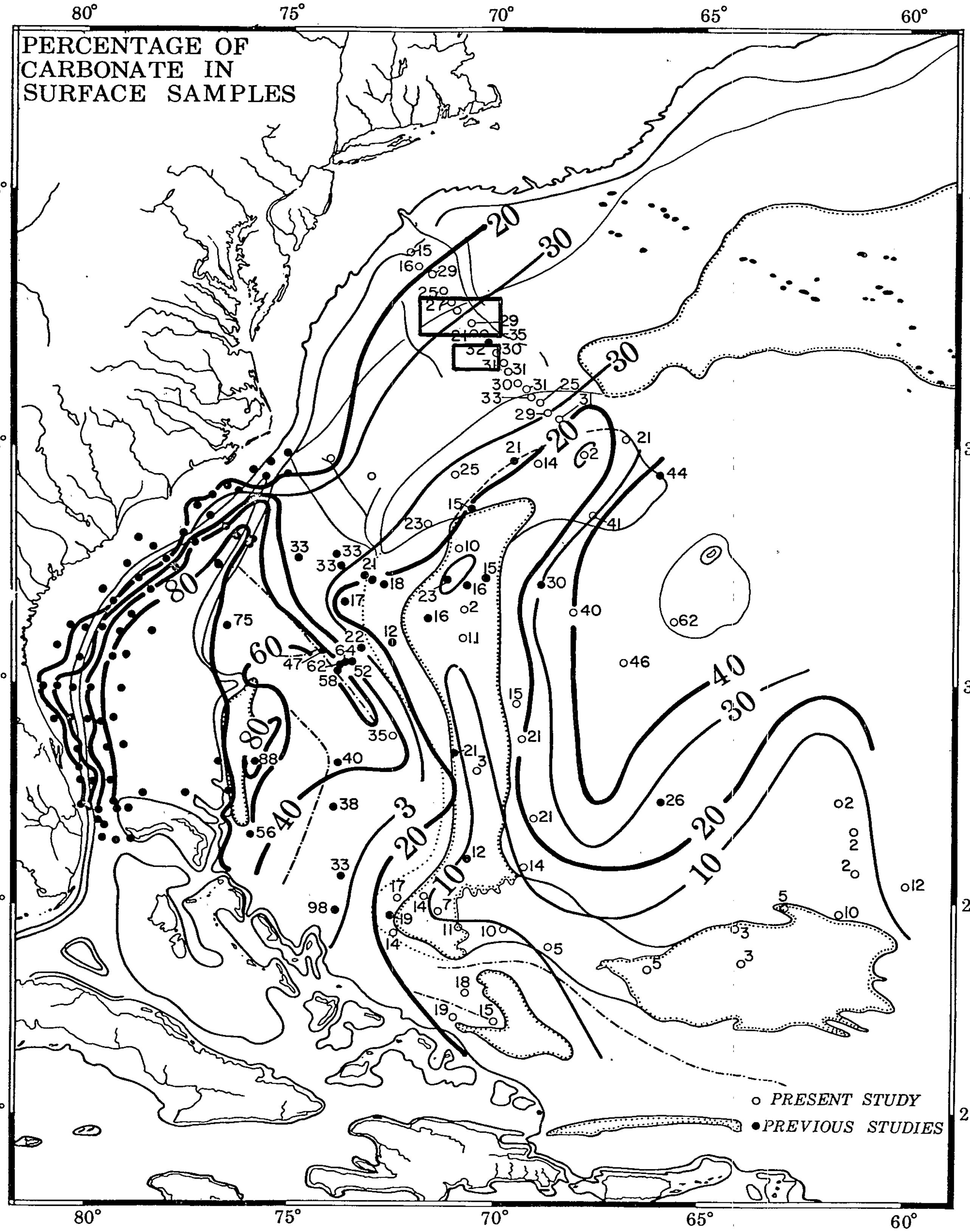
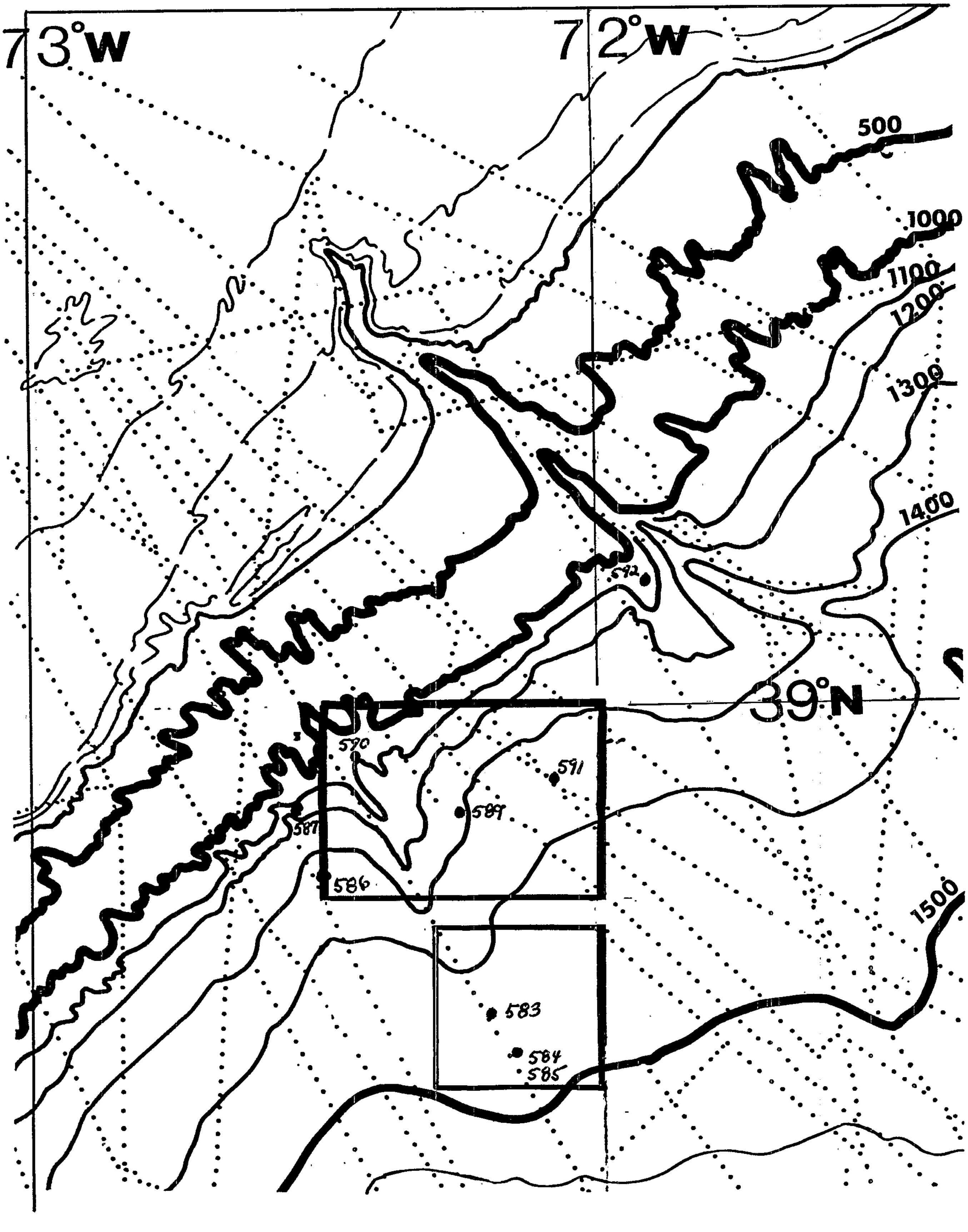

PERCENTAGE OF
CARBONATE IN
SURFACE SAMPLES
o PRESENT STUDY
• PREVIOUS STUDIES

TABLE 1 - LOCATIONS, DEPTHS, AND ENVIRONMENT OF DSRV ALVIN DIVES DURING THE 1975 NOAA-EPA SURVEY AT THE DWD-106 AND 2800 m RADIOACTIVE WASTE DISPOSAL SITES

Dive No.	Date	Latitude	Longitude	Depth	On Bottom	Leave Bottom	Bottom Environment
583	7-25-75	38°33'N	72°12'W	2786m	1153 hours	1753 hours	Many containers, munitions, etc., scattered throughout area. Gentle hills, depressions, and 10 m high erosional escarpments, with abundant encrusting organisms. A few scattered boulders, some of which may be glacial erratics.
584	7-26-75	38°30'N	72°09'W	2806m-2829m	1338 hours	1630 hours	Common boulders on soft gray silty-clay.
585	7-27-75	38°30'N	72°09'W	2818m-2832m	1216 hours	1710 hours	Discovered some damaged low-level radioactive waste drums, and cored sediment in close vicinity.
586	7-28-75	38°45'N	72°31'W	2318m-2340m	1153 hours	1430 hours	Terrain relatively flat with low hummocks, mounds, and depressions of biological origin. An occasional small rock sighted. Slight westerly flowing current.
587	7-29-75	38°50'N	72°34'W	2027m-2148m	1100 hours	1410 hours	Terrain dissected by gullies some 2 to 12 m across and up to 15 m deep or more. Gully floors are flat with abundant animal life resting on thin layer of pale gray sediment covering a more dense, sticky bluish sediment below. Canyon walls display outcrops of whitish marl.
589	7-31-75	38°52'N	72°16'W	2400m-2452m	1339 hours	1808 hours	Flat terrain with few hills and hummocks. Little current. Small rocks and boulders greater than 1 m in diameter on sediment. Abundant "fairy rings."
590	8-1-75	38°56'N	72°26'W	1688m-1833m	1208 hours	1810 hours	Relatively flat at point of descent, a few mounds, hills, and hummocks. Some outcrops and projecting ledge of stiff clay. Outcrops of indurated light marlstone. Some escarpments and high spurs.
591	8-2-75	38°55'N	72°04'W	2440m-2477m	1050 hours	1706 hours	Quite flat bottom. No ripple marks and little evidence of current. Some scattered rocks encrusted with sponges. Clay outcrops.
592	8-3-75	39°10'N	71°55'W	1930m-1982m	0741 hours	1159 hours	Partly flat and partly steep. Some ripple marks. Rounded hillocks and outcrops of "nodular" sediments. Gravel and cobble with occasional sponges and worm tubes. A rounded marlstone was collected (Eocene in age).

Figure 13. Locations of the 1975 DSRV ALVIN dives within the Atlantic 2800 m radioactive waste dumpsite (Dives 583, 584, 585) and the adjacent DWD-106 (Dives 586, 587, 589, 590, 591). This figure is an enlarged segment of Figure 1, with contours in fathoms (1 fm = approximately 1.87 m).


73°W
72°W
39°N
500
1000
1100
1200
1300
1400
1500
592
590
591
589
587
586
583
584
585

a terrain dissected by three gullies 2-12 m in width and up to 15 m deep. The canyon floors were quite flat and supported an abundant epifauna. A thin layer of pale-gray surficial sediment, overlying a bluish sticky sediment, was covered by faint tracks and trails made by echinoderms, holothurians, and crustaceans. The walls of the canyons had slopes varying from 50° to nearly vertical. Erosion of the canyon walls is evidenced by the occurrence of pieces of wall rock, ranging in size from small fragments to slabs 2-3 m long, scattered on the canyon floor. Some were covered with a light dusting of sediment while others were free of any sedimentary material. Brittle stars, branching gorgonians, large sponges, and other fauna were present on the canyon walls which, in some locations, consisted of a whitish marl.

Dive 589 in 2400-2452 m of water took place in a region of relatively flat terrain, with little or no current, and few hills and hummocks. Small rocks, cobbles, and boulders up to 2 m in diameter were seen littering the ocean floor surface. Asteroids, echinoids, sea feathers, and "fairy ring" markings in the sediment were abundant, denoting extensive biological activity on the sediment surface.

Dive 590 encountered a few mounds, hills, and hummocks within a relatively flat terrain. The sediment surface showed pits, mounds, tracks, and trails of biological origin with echinoids, holothurians, ophiuroids, and ceranthid anemones being fairly common. Outcrops of indurated light marlstone, escarpments (up to 20 m in relief), and high spurs were seen.

Dives 583, 584, and 585 took place on the upper continental rise at depths around 2800 m in the low-level radioactive waste dumpsite. On Dive 583, many containers, munitions boxes, and other debris were seen scattered throughout the areas. Surface morphology varied during the bottom traverse ranging from flat terrain to gentle hills and depressions with 12 m high clay cliffs covered by abundant attached fauna. Small to very large granite boulders were observed; some exhibited sparse attached growth while others were devoid of encrusting fauna. These rocks were most likely carried to this region by ice-rafting during glacial epochs. Sediment close to a radioactive waste container was cored on Dive 585. A relatively flat terrain with relief in the form of low hummocks, mounds, and depressions of biological origin was traversed on Dive 586 in a region slightly north and west of the previous three dives (Figure 13). The sediment here was sticky and showed no ripple marks although a slight westerly flowing current was observed. Occasional small rocks littered the surface of the sediment.

Dive 591 in the northeast corner of the dive quadrant transected a featureless area of little relief. No ripple marks were observed and there was little evidence of an active current at the time of the dive. As the ALVIN submersible traversed the bottom, relief increased to 3-4 m giving the visual impression of small hills and depressions. Sponges were present on occasional outcrops; some ophiuroids, holothurians, and sea urchins were observed and photographed.

Dive 592, north and east of the preceding dive area, was in a region of alternating flat relief, dimpled with a few shallow depressions and mounds, and steep relief displaying outcrops. A 0.8 knot (40 cm/sec) current was measured in a region of current ripples where the depressions were shallower and the hillocks were rounded. Outcrops of "nodular" sediment were seen which are interpreted to be highly calcarous by analogy to rocks of similar appearance caused by weathering in terrestrial outcrops. Gravel and cobbles with occasional attached sponges and worm tubes typified the sediment surface. A rounded cobble of marlstone was collected and subsequently determined to be Middle Eocene in age.

THE 1976 SUBMERSIBLE DIVING PROGRAM

During the summer of 1976, another U.S. Environmental Protection Agency radioactive waste dumpsite survey was conducted in the 2800 m low-level radioactive waste dumpsite located southeast of DWD-106. The survey was centered at coordinates 38°30'N, 72°09'W, a position on the upper continental rise approximately 120 miles (190 km) east of the Maryland-Delaware coast.

The survey consisted of five deep submersible dives employing the ALVIN to search for a variety of radioactive waste containers disposed of in the dumpsite area, to record the geological and biological characteristics along each dive traverse, and to collect accurately-positioned sediment samples near low-level radioactive waste packages. One 80-gallon low-level radioactive waste drum was recovered from a depth of 2819 m (Figure 14) on July 31, 1976. Four bottom-moored vector-averaging current meters were deployed, one at each of the corners of the dumpsite area to make a 3-month measurement of the direction and speed of bottom-water transport at a distance of 6 m above the seabed. The mooring in the southwest corner of the dumpsite had an additional current meter at a distance of 96 m off the bottom. The findings of this current meter mooring experiment are detailed in another U.S. Environmental Protection Agency report (Hamilton, 1982). The principle conclusion of that report was that southwesterly mean currents of 3-4 cm/sec were flowing near the bottom, and the low frequency part of the spectrum was dominated by fluctuations around a 16-day period which could be explained as bottom-trapped topographic Rossby waves with horizontal wavelengths of about 200 km.

The southwest corner of the Atlantic 2800 m dumpsite had been previously examined by DSRV ALVIN in 1975. Dives 584 and 585 during July 1975 had located more than half a dozen radioactive waste drums partly buried in the sediment cover near 38°30.0'N and 72°09.3'W. One of these drums, found at 1300 hours, July 27, 1975, during Dive 585 was selected for the 1976 recovery operation. The drums sighted in 1975 were scattered over an area of only about 150 m in diameter. Therefore, the 1976 field investigations required accurate navigation of the submersible, which was accomplished using bottom-moored acoustic transponders.

The 1976 field program comprised five dives (676-680) between July 29 and August 3. The locations of the dives are given in Table 2, and the dive tracks and locations are plotted in Figure 15 (Heezen and Dyer, 1977). The first four dives explored the seabed in the general vicinity of two of the 1975 dives where waste drums had been sighted. The final dive to the west of the previous dives undertook a lengthy reconnaissance track parallel to the regional contours.

A detailed bathymetric survey carried out with precision acoustic navigation revealed the radioactive waste containers to be scattered within a broad amphitheatre-shaped depression characterized by hummocky relief. The dumpsite was crossed by a rather narrow (<100 m wide, 5-20 m deep) channel, which displayed large meanders (Heezen and Dyer, 1977). The broad depression is a slump scar created by the downslope flowage or creep of a 15 to 20 m thick cover of sediment (Embley, 1976). The small hills in the dive area are interpreted to be remnants

Figure 14. Barrel #28 photographed on Dive 676, July 29, 1976, at a depth of 2819 m. A retrieval harness was put on the barrel in preparation for its recovery. The barrel had been partly buried in the seabed for about 15 years. Scour marks show a net current streaking of sediment in the southwest direction. The original disturbance to the seabed made by impact of this waste container has been smoothed and mostly obliterated by the bottom current.

TABLE 2 - LOCATIONS, DEPTHS, OBSERVERS, ENVIRONMENT AND OBJECTIVES OF DSRV ALVIN DIVES OF THE 1976 EPA 2800 m RADIOACTIVE WASTE DISPOSAL SITE SURVEY

Dive No.	Time of Arrival on Bottom	Latitude	Longitude	Depth	Depart Bottom (Time)	Latitude	Longitude	Depth	Scientific Observers	Bottom Environment	Objective
676	1230 hours	38°30.57'N	72°09.32'W	2774m	1900 hours	38°30.33'N	72°09.02'W	2773m	Robert Dyer and Bruce Heezen	Smooth light gray silty sediment, pock-marked by benthic organisms. Previous years ALVIN sled marks still evident. Some outcropping strata along about 5% of traverse. Current about 5 cm/sec to SSW.	Locate and examine radioactive waste containers, collect environmental samples, attach line and pinger to waste container for future recovery.
677	1242 hours	38°30.17'N	72°09.10'W	2778m	1856 hours	38°30.33'N	72°08.92'W	2805m	Bruce Heezen and Kip Durrin	Much debris lying on soft gray partly bioturbated sediment. A few outcrops of light-colored marls, well-rounded. Crossed some hummocky terrain. Light current to SSW.	Attach line to radioactive waste barrel and to retrieval clamp. Search for additional barrels and conduct dye pellet experiment.
678	1235 hours	38°30.35'N	72°09.31'W	2788m	1834 hours	38°30.49'N	72°09.36'W	2788m	Robert Dyer and Bruce Heezen	Numerous barrels and ammunition containers scattered in and between some small ravines cut into a silty-clay substrate. Outcrop sampled is a white chalk covered with sponges.	Collect surface sediment samples with core tube at several distances from a radioactive waste drum. Explore for more containers and obtain a sample of outcrop material.
679	1125 hours	38°30.25'N	72°09.42'W	2787m	1803 hours	38°29.93'N	72°09.20'W	2780m	Robert Dyer and Pamela Polloni	Flat, silty-clay terrain with numerous tracks, "fairy rings," mounds, and depressions of biological origin. One large allochthonous boulder, riddled with holes and encrusted with hydrozoans, anemones, etc. White chalk outcrop sampled.	Conduct biological survey and collect box cores of surface sediment. Sample outcrop.
680	1243 hours	38°30.15'N	72°10.71'W	2767m	1645 hours	38°30.67'N	72°09.80'W	2765m	Robert Dyer and Akihiko Ito	Flat unchanneled area to west of previous dives. Gray silty-clay with single small outcrop. Much evidence of benthic life.	Search for more barrels and collect cores for radiochemical and infaunal analyses.

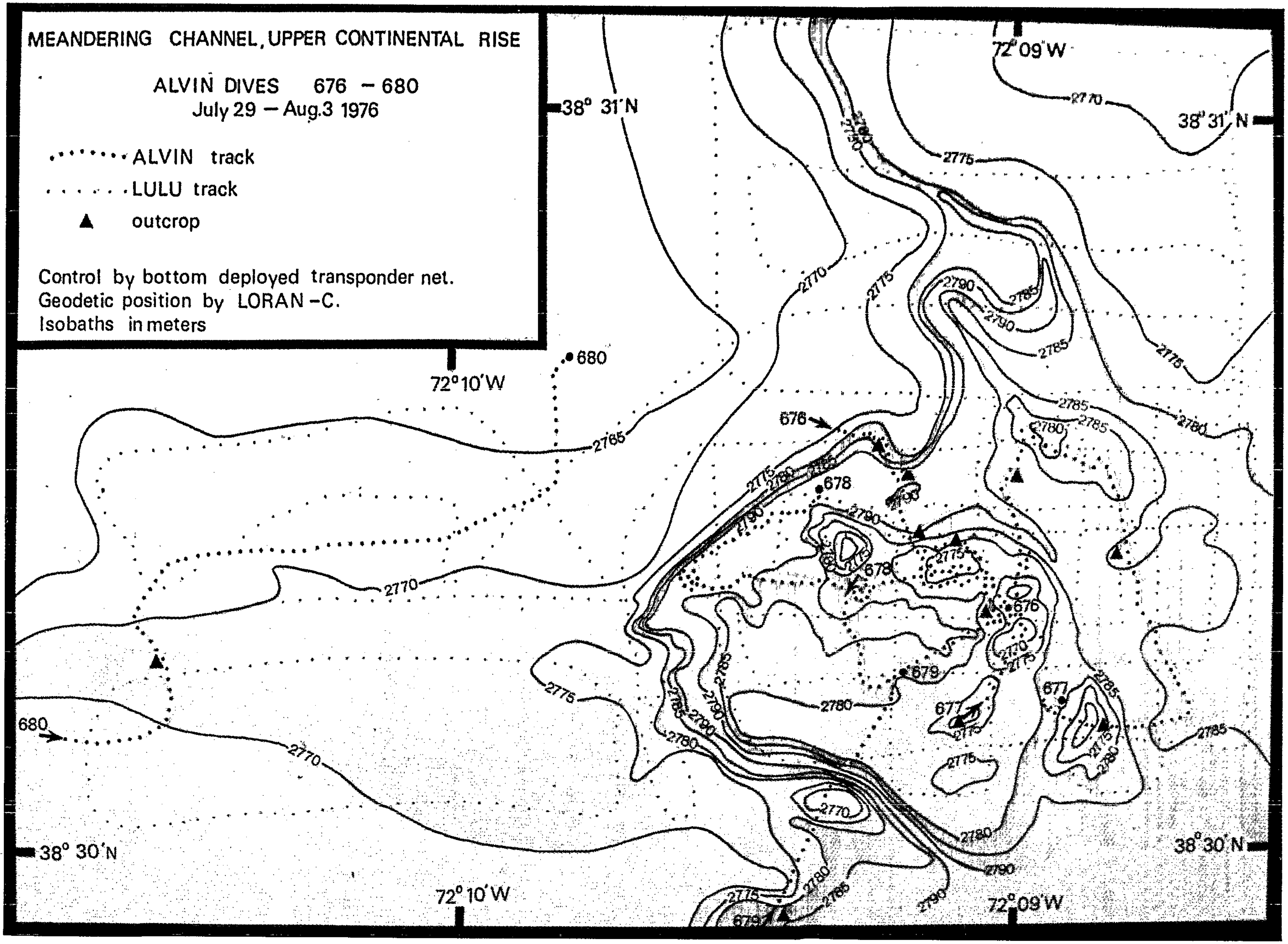


Figure 15. Bathymetric contours (in meters) describing a meandering channel (orange color) on the upper continental rise observed during the 1976 DSRV ALVIN submersible survey in the southwestern corner of the 2800 m low-level radioactive waste dumpsite. ALVIN tracks for Dives 676-680 are also shown (Heezen and Dyer, 1977). Navigation of the survey lines and on-bottom traverses of the submersible were controlled by acoustic ranging to bottom-moored transponders.

of the original cover left behind within the slump scar. The tracks of Dives 676, 677, 678, and 679 cross over these small hills and the flanks frequently expose strata of pre-Recent age. Most of the outcrops were covered with encrusting sponges, worm tubes, hydrozoans, and anemones (Figure 16). Very little modern sediment was observed covering the outcrops, suggesting that recent erosion has occurred in the area despite an average regional sedimentation rate in excess of 5 cm per 1,000 yrs (Ericson et al., 1961). This lack of an appreciable post-Pleistocene sediment cover is somewhat contradictory to the tranquil environment observed from the submersible.

The seabed between outcrops is composed of a smooth-surfaced gray silty-clay and shows no consistent current lineation. Sediment stirred up by the skis of the DSRV ALVIN was seen to move to the southwest with a velocity of approximately 10-15 cm/sec, which is weak compared to currents observed in many submarine canyons on the slope (Ryan et al., 1978b), or compared to the Western Boundary Undercurrent on the lower continental rise. Isolated sedimentary blocks and low-level radioactive waste containers lie both inside and outside the meandering channel and they are surrounded by well-formed scour moats approximately 20 cm in depth.

Sled marks made by ALVIN the previous year (1975) were discernible although the edges of the sled tracks had collapsed and had been partly obliterated by currents and animals (Figure 17). The presence of stalked filter feeders bent in the direction of current flow (Figure 10) indicates that currents were present. Although the currents have been too gentle for the generation of mud ripples, they were sufficiently strong to smooth the sediment. However, the thinness of sediment cover on the outcrops as well as the presence of scour moats seem to indicate that the area is periodically swept by powerful currents. The smooth surface of the sediment is marred by tracks and trails, brittle star impressions, animal "volcanoes," and circles of small holes known as "fairy rings" (some of which cut across the previous ALVIN tracks). Although large holothurians were present and fresh feces were observed, no old feces could be detected suggesting that they are destroyed by bioturbation or currents.

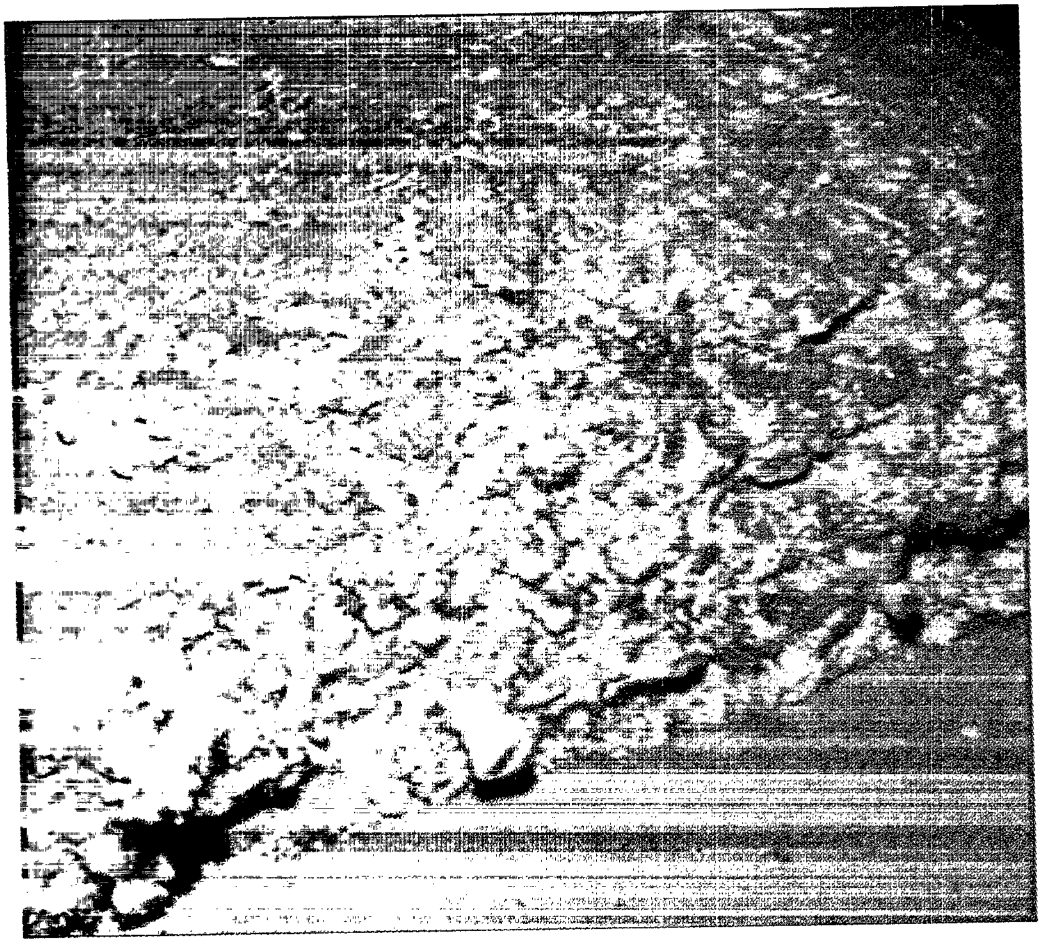


Figure 16. Encrusting sponges, hydrozoans, and anemones on outcrops of lithified marlstone around the flank of an erosion remnant hill at 38°30.33'N, 72°09.04'W. This photograph is from ALVIN Dive 678 in the low-level radioactive waste dumpsite at a depth of 2778 m and shows the very thin dusting of recent sediment on the exposure of much older material. Note the heavily bored nature of the marlstone.

Figure 17. Partly obliterated ALVIN sled marks of previous year (1975) infilled by darker sediment. Note the fractured and friable nature of a semi-compacted disturbed light-colored silty marl. Rattail fish in foreground (Coryphaenoides sp.) is approximately 35 cm in length. Photograph taken at 2778 m depth during ALVIN Dive 677 in the low-level radioactive waste dumpsite near 38°30.28'N, 72°09.01'W.

The abundance of fauna on the bottom demonstrates that the low-level radioactive waste dumpsite is a biologically active area. The most common organisms observed were sponges, worms, gorgonians, ophiuroids, asteroids, decapods, rattail fish (Coryphaenoides sp.), tunicates, sea pens, anemones, and holothurians. Rattail fish were attracted to the sediment stirred up by the ALVIN and were often observed to be feeding on sediment resuspended by the submersible (Figure 18). Occasional similar behavior was also noted in various starfish and shrimp.

Encrusting organisms were scarce on many of the drums although outcrops in the area were covered with such organisms. The scarcity of encrusting fauna may be attributed to either flaking rust on the surface of some containers which does not provide a firm substrate for attachment, or to the inhibition of encrusting organisms by corrosion products. Encrustations were generally observed to be more common on the exposed concrete end of the containers than on the flaking metal sides.

The southeast corner of DWD-106 and the north, central, and western portions of the low-level radioactive waste dumpsite are partly littered with allochthonous blocks of a wide range of sizes composed of indurated sedimentary material carried into the area by subaqueous landslides (i.e., debris flows). Several blocks were encountered during Dives 676 and 678, particularly one massive block several meters in diameter at 38°30.43'N, 72°09.18'W (Dive 676) which is shown from two vantage points in Figure 19. Another somewhat smaller block sampled during Dive 678 consisted of calcareous grainstone of Middle Eocene age (40-43 million years B.P.). Based on the examined faunal content and sediment composition, the grainstone was most likely laid down originally in an outer-shelf, high-energy environment and subsequently carried to the deeper depths of the dumpsite area.

The allochthonous blocks and other substrate outcrops (particularly along the wall of the meandering channel) act as strong acoustic targets for the forward-looking CTFM (Continuous Transmission, Frequency Modulated) sonar aboard the ALVIN. These blocks lie on and within a semi-firm silty-clay and range in size from pebbles to masses larger than the ALVIN submersible itself. Many of them are buried to a depth of about half their diameter which is not greatly different

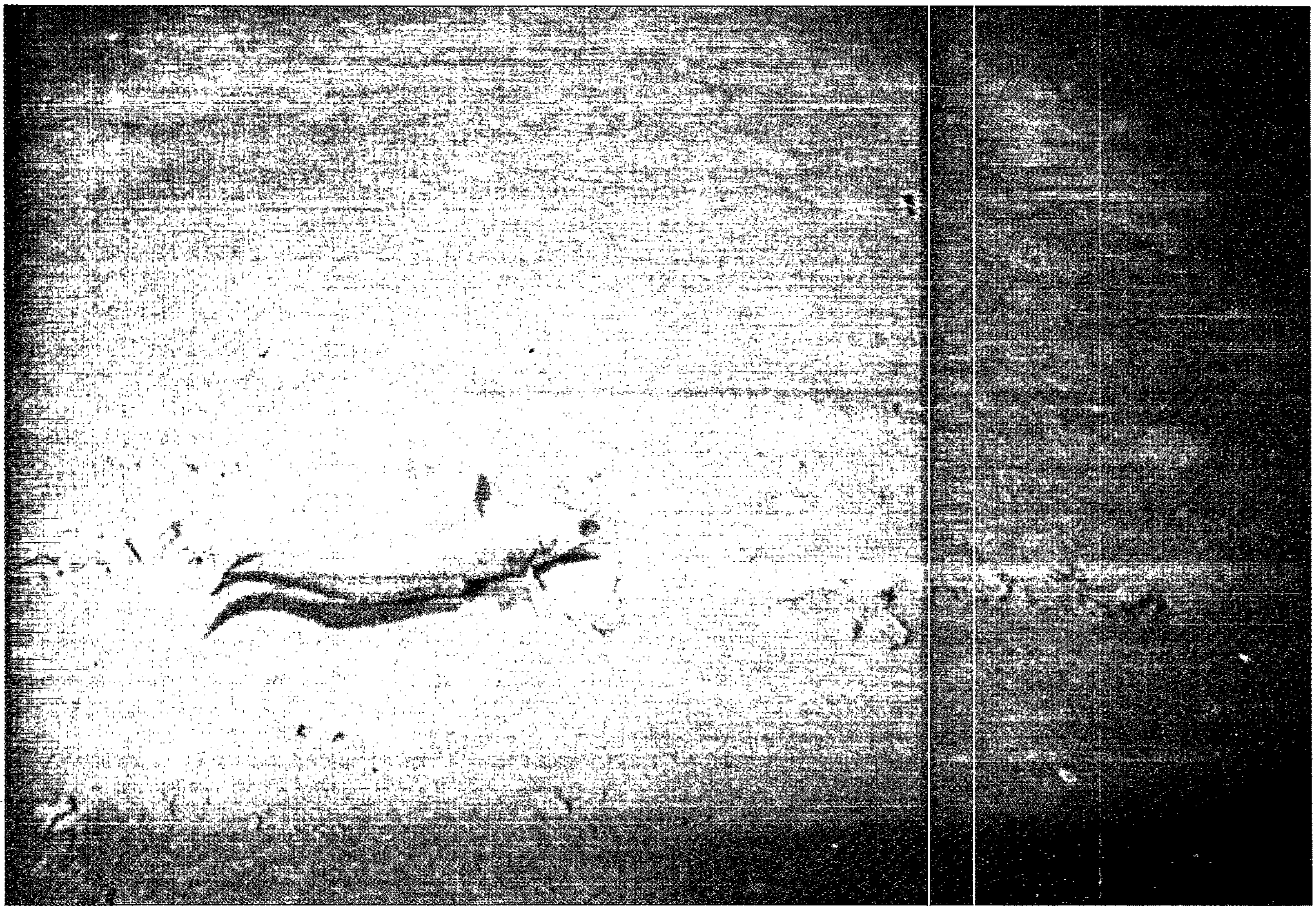


Figure 18. Sled marks on the seabed made by DSRV ALVIN and photographed during Dive 678 at a depth of 2780 m in the low-level radioactive waste dumpsite. Rattail fish (Coryphaenoides sp.) were commonly observed to feed within the sediment which had been freshly disturbed during the ALVIN traverse.

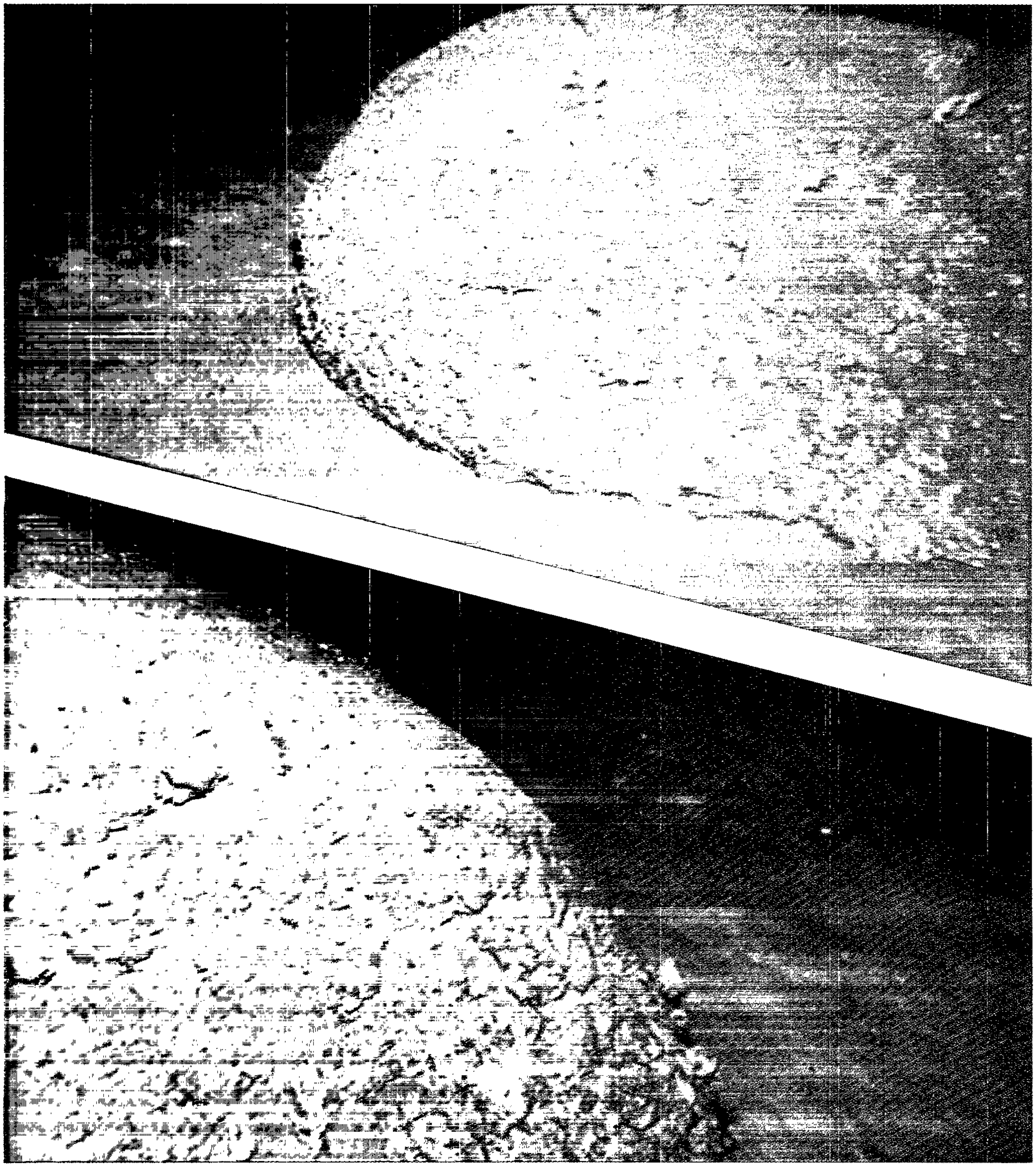


Figure 19. Large sub-rounded olistolith lying partly buried within a slump scar at the 2800 m low-level radioactive waste dumpsite. This allochthonous block of marl, photographed at 2775 m on ALVIN Dive 676, is several meters in diameter and only lightly dusted with sediment. It and numerous other similar blocks were carried into the area in the recent past by a subaqueous landslide originating on the continental slope some 60 to 70 km to the northwest. Note the numerous small attached translucent alcyonaceans, Eunephthya fruticosa, particularly evident on the top surface of the marl block in the upper photograph.

from the radioactive waste drums that were jettisoned into the area from the sea surface.

Tube cores taken near the drum encountered on Dive 678 and selected for recovery could be readily inserted into the silty-clay up to their total length of about 40 cm. The cores were, however, somewhat difficult to extract, suggesting that the clay there has a relatively high cohesive strength.

Most of the drums and some of the allochthonous blocks contained no sediment film or only a very thin dusting. The lack of sedimentation on the tops of the drums is probably caused by the same currents which have scoured broad moats around them. These moats contain coarse-grained lag deposits which give the sediment cover a locally darker texture (Figure 20). In all photographs of drums studied, the metal surfaces were rusted, with flakes of rust peeling away and littering the adjacent sediment surface with an orange film (Figure 20). In the vicinity of the drums the bottom mud seemed browner than usual -- a feature which might be the result of the deposition of rust flakes from the surface of the drums. The rust in the sediment seems to be oriented in a southwesterly direction which correlates with the prevailing current direction. The rust variably caused a discoloration of the sediment to a distance of 30 to 50 cm from the containers.

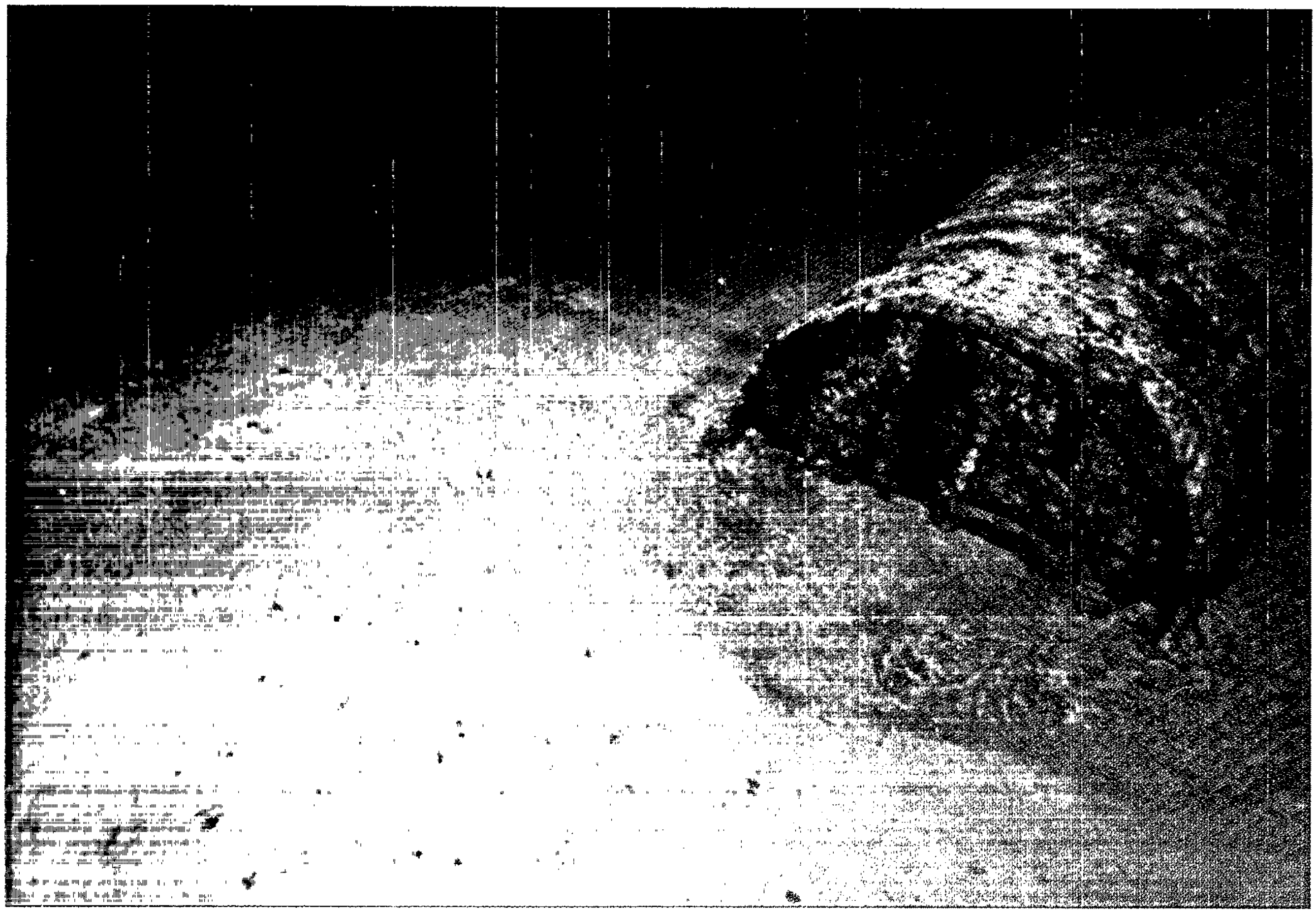


Figure 20. Example of an erosional moat around a corroded and partly buried drum of radioactive waste encountered at 2774 m during ALVIN Dive 676. Flaking of rust has stained the adjacent surface sediment. The moat has collected a distinctly coarser-textured lag deposit of winnowed pteropod tests and fine gravel, swept in streaks in a southwesterly direction along with the iron oxide flakes.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

DWD-106 and the adjacent 2800 m low-level radioactive waste dumpsite occupy a seascape subject to flushing by major natural disturbances such as subaqueous avalanching, debris flows, and turbulent gravity-propelled sediment suspensions. The few available piston cores from the Lamont-Doherty repository which have been recovered from this area indicate an intact Holocene section, partly winnowed, but not removed by slumping. Seismic profiles show extensive gullying which, in the slope area, has cut down into 50 million year old horizons exposing them as outcrops. The extensive denudation of the continental slope and uppermost rise is confirmed by deepsea drilling at DSDP Site 108, immediately to the west of the dumpsite area. Low-level radioactive waste packages, ammunition boxes, and other debris resting on the seafloor could be subject to remobilization seaward by flushing events. Submersible surveys showed the present environment to be both locally eroding (base of escarpments, moats around outcrops, thalwegs of gullies and channels) and locally depositing. The study of piston cores indicates rates of sedimentation exceeding 5 cm per 1,000 years. Hence, many of the waste packages could be buried or nearly buried in some 20,000 years.

Despite the inevitability of shallow burial of objects through sediment deposition, portions of the low-level radioactive waste dumpsite could be exhumed by another debris flow of the magnitude which created the slump-scar characteristic of the 1976 dive area, where 10-20 m of sediment were removed.

Recommendations

The dumpsite area should be more systematically sampled by long cores (5 m or more in length) and/or subsurface drilling. There is a need for comprehensive stratigraphic studies to measure rates of sediment accumulation, the extent of contemporary winnowing of sediment, and, in particular, the frequency of past episodic events which upon reoccurrence will scatter and/or bury debris littering the dumpsite area. The cores need to have a record of at least 100,000 years and preferably 500,000 or more years in order to provide some statistical insight into the repetition and nature of stratigraphic unconformities that are the record of natural flushings. Studies should include biozonation, isotopic and paleomagnetic stratigraphy, radon and thorium geochemistry, and ^{14}C radiochronology.

Much additional accurately-navigated bathymetry and near-bottom, side-scan sonar profiling should be accomplished in order to work out the areal distribution of gullies, meandering channels, slump scars, and remnant hills. A high priority would be to request the cooperation of the Oceanographer of the Navy to provide a multi-beam sonar survey of the dumpsite area.

As a long-range objective we recommend instrumenting the dumpsite area with seismic monitors, tilt-meters, radiation counters, and nephelometers to permit recording of natural disturbances over the period of decades. There is little likelihood of witnessing flushing events during 6-hour submersible dives or even for the few months' recording capability of conventional, self-powered, bottom-moored instruments retrieved by acoustical release mechanisms.

UNRESOLVED PROBLEMS

Many large olistoliths were seen to be resting on the seabed somehwat less deeply submerged in the sediment than low-level radioactive waste drums. However, there is no collaborating evidence that the olistoliths arrived into the site subsequent to the initial dumping of waste packages. The lack of appreciable burial of the olistoliths is puzzling, since they probably originated by downslope avalanching either from submarine canyons or from more proximal slump scars. It is possible, but unproven, that the olistoliths were transported by bottom-hugging fluidized debris flows and therefore not impacted into the seabed. The time of movement and mechanism of emplacement of various allochthonous blocks of assorted size is intimately related to poorly-understood processes capable of flushing the waste out of the dumpsite area to other repositories on either the lower continental rise or abyssal plain.

Corrosion of the metal containers produces a vertical streaking of iron oxides in the sediment at the ends of the barrels. If the containers had been disturbed during residence on the seabed, one should expect to see generations of streaking at different angles to the vertical. None of the audiotape commentaries of Bruce C. Heezen made during the ALVIN dives lend insight into this possibility (Heezen, 1975-76).

Olistoliths and remnant hills were rather commonly observed in the 2800 m low-level radioactive waste dumpsite where a broad amphitheatre-shaped slump scar has been mapped (Figure 15). Are the olistoliths associated with the slump scar and were these blocks torn from place during the slumping event? Large blocks were observed in the northwestern sector of the low-level radioactive waste dumpsite, but neither detailed bathymetry nor side-scan sonar records are available to reveal if slump scars are also present at shallower depths. A correlation of blocks with slump scars is important to establish since the presence of blocks (readily visible from submersibles and bottom photographs) is perhaps easier to detect than the slump scars. Waste containers in areas of existing slump scars cannot be considered to be permanently deposited at those sites.

A meandering, anastomosing channel was mapped where it crosses a slump scar. The presence of the channel raises the question of whether the slope failure of high-porosity and rapidly-deposited sediment of the channel levees was the cause of the meandering and anastomosing nature of the channel in this region, or whether the channel sought out an already existing slump depression as a more optimum route into deeper water environments. Lack of detailed bathymetry prevents estimation of the extent to which the upper continental rise is dissected by channels. Since channels are bypass routes, waste containers along their course are subject to movement and extensive mechanical abrasion during brief but high-energy, turbulent flows.

Numerous submarine canyons incise the continental slope in the northern and western portions of DWD-106. Small-scale gullies, ravines, and spurs were conspicuous, especially during Dives 587 and 590 farthest landward on the slope. Although present bathymetric data are insufficient to resolve details of the morphology of these canyons and gullies, analogies to better-surveyed canyons along the margin of New England suggest that they may display a dendritic pattern. Such a pattern would imply a deep subaqueous process of headward erosion. One likely causal agent for this process is bioerosion resulting from boring and tunneling of crustaceans (mostly crabs) and bivalves feeding on substrates containing organic carbon. Observations made during the 1975 and 1976 ALVIN diving programs do not address sufficiently the occurrence and magnitude of contemporary bioerosion. Perhaps more diving needs to be carried out in the axial parts of the canyon and gullies where the erosion is most extensive due to the outcropping of pre-Pleistocene layers with carbon contents in excess of 2%. Based on the working hypothesis that canyons are most extensively carved at times of lowered sea level when shore lines are in close proximity to canyon heads, the canyons within the dumpsite region should not be expected to be particularly active at present. However, if bioerosion of the type documented by Warme (1975) and Palmer (1976) and of the type which may be pervasive in the Hudson Canyon is a major agent in slope denudation, there is no reason to suspect that the canyons are not subject to contemporary flushings resulting from catastrophic failure of heavily tunneled canyon and gully walls. The very important geological question of just what is the most significant process in sculpturing the submarine canyons off the east coast of the United States is still open. However, the present study provides some insight into the processes which appear to have influenced the DWD-106 and 2800 m low-level radioactive waste disposal areas.

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TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA 520/1-83-018	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Geologic Observations at the 2800-Meter Radioactive Waste Disposal Site and Associated Deepwater Dumpsite 106 (DWD-106) in the Atlantic Ocean		5. REPORT DATE September 1983
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Martine Dreyfus Rawson and William B. F. Ryan		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Geological Sciences Lamont-Doherty Geological Observatory of Columbia University Palisades, New York 10964		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. Contract No. 68-01-3933
12. SPONSORING AGENCY NAME AND ADDRESS Office of Radiation Programs (ANR-461) U.S. Environmental Protection Agency 401 M St., S.W. Washington, D.C. 20460		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE ANR-461

ABSTRACT

During 1975 and 1976 a total of eight manned submersible dives with DSRV ALVIN were carried out in a relatively small region of the Atlantic 2800m radioactive waste dumpsite and were centered at 38°30'N and 72°09'W. Six other dives were distributed through the northern part of Deepwater Dumpsite 106 (DWD-106) near the boundary of the continental rise/continental slope. One of the primary purposes of these dives was to observe the geological conditions in this disposal region slightly south of the Hudson submarine Canyon.

The lower continental slope was found to be incised by submarine canyons debouching into the northern side of DWD-106. The upper continental rise was incised by narrow meandering channels. One of these channels passed through the radioactive waste dumpsite and was surveyed in detail.

On the upper continental rise the local terrain was relatively flat but studded with numerous tracks, trails, holes, and mounds of biological origin. The sediment carpet was composed of a gray silty-clay. Detailed mineralogical analysis was performed.

Boulders and large allochthonous blocks (olistoliths) were encountered on many of the dives. Bottom currents were detected during a majority of the dives. Scour moats were present around rock outcrops and low-level radioactive waste containers. These containers were observed in varying states of integrity.

On the continental rise the local terrain was partly hummocky, with relief of the hills occasionally exceeding 20-30m. Based on this study the dumpsite areas are considered to be in a dynamic deepsea environment.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
ocean disposal low-level radioactive waste disposal marine geology marine foraminifera Hudson Canyon geology packaging for ocean disposal		

18. DISTRIBUTION STATEMENT Unlimited Release	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 61
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE