UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

SUBMERSIBLE OBSERVATIONS OF THE SEA FLOOR NEAR THE PROPOSED GEORGES BANK LEASE SITES ALONG THE NORTH ATLANTIC OUTER CONTINENTAL SHELF AND UPPER SLOPE

By

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Prepared in cooperation with the
U.S. BUREAU OF LAND MANAGEMENT
under Memorandum of Understanding
AA551-MU8-24

Open-File Report 81-742

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1981

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INTRODUCTION

During the summer of 1978 the U.S. Geological Survey, using the M.V. STATE ARROW and the deep-diving submersible DIAPHUS (fig. 1) gathered geophysical data and made detailed observations and photographed the sea floor along the Outer Continental Shelf and upper Continental Slope of the Georges Bank area, from 40°00.09′N. to 40°50.86′N. and 69°37.24′W. to 67°23.74′W. (fig. 2, tables 1 and 2).

The goals of this fieldwork were to document geological features and processes near future lease sites on Georges Bank and to record in detail by verbal description and photography the sea-floor condition and biota in areas which could be affected by the release and movement of drill cuttings, drilling mud, and even oil from drilling sites. The visual record could prove to be very valuable if there were to be an accident; a comparison with pristine conditions would be needed to show if any damage to the sediment and biota occurred.

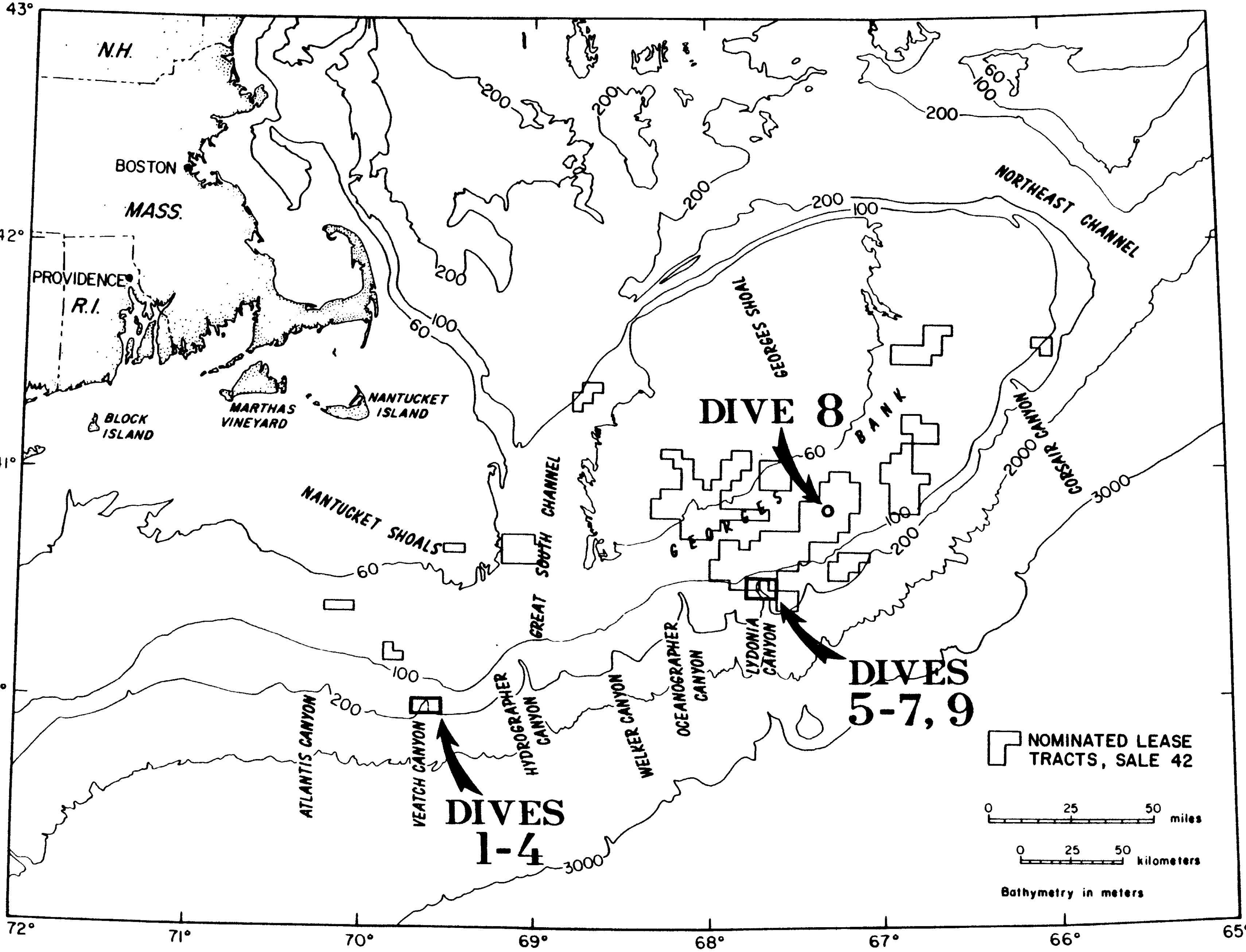
Because submarine canyons which cut into the upper slope and outer shelf of Georges Bank are likely natural conduits into deeper water for any materials from local accident sites, most of the dive sites were chosen in two nearby submarine canyons, Veatch and Lydonia Canyons (fig. 2).

Of special interest also were potential geologic hazards involving large sediment slumps such as those recently outlined along the U.S.

Figure 1. DSRV DIAPHUS-2 man submersible with 365-m diving capability.

DSRV DIAPHUS–2 MAN SUBMERSIBLE WITH 365M DIVING CAPABILITY.

Figure 2. Location map of study areas with dive sites.



N.H.
MASS.
BOSTON
PROVIDENCE
R.I.
BLOCK ISLAND
MARTHAS VINEYARD
NANTUCKET ISLAND
NANTUCKET SHOALS
GREAT SOUTH CHANNEL
GEORGES SHOAL
GEORGES BANK
NORTHEAST CHANNEL
CORSAIR CANYON
LYDONIA CANYON
OCEANOGRAPHER CANYON
WELKER CANYON
HYDROGRAPHER CANYON
VEATCH CANYON
ATLANTIS CANYON
DIVE 8
DIVES 5-7, 9
DIVES 1-4
NOMINATED LEASE TRACTS, SALE 42
0 25 50 miles
0 25 50 kilometers
Bathymetry in meters
60
100
200
2000
3000
43°
42°
41°
40°
72°
71°
70°
69°
68°
67°
66°
65°

Figure 2

Table 1. DIAPHUS dive data

Dive no.	Date	Time down	Time up	Under-water (min)	Submersible's position Start	Submersible's position Finish	Max. Depth (m)	Visi-bility (m)	Pilot/ observer	Film
1	Aug. 4, 1978	0810	1040	150	40°00.68′N.	40°01.33′N.	217	8	Barksdale/	35 mm (0)
					69°37.71′W.	69°37.41′W.			Slater	video (4 min)
2	Aug. 4, 1978	1204	1434	150	40°00.83′N.	40°00.27′N.	207	8	Hickey/	35 mm (120)
					69°37.66′W.	69°37.40′W.			Aaron	video (7 min)
3	Aug. 4, 1978	1821	2026	125	40°00.46′N.	40°00.24′N.	207	8	Barksdale/	35 mm (74)
					69°37.54′W.	69°37.24′W.			Twichell	video (20 min)
4	Aug. 5, 1978	1428	1706	158	40°00.58′N.	40°00.09′N.	134	9	Hickey/	35 mm (129)
					69°37.65′W.	69°37.72′W.			Bryden	video (8 min)
5	Aug. 6, 1978	0850	1040	110	40°25.16′N.	40°25.05′N.	366	8	Barksdale/	35 mm (29)
					67°39.10′W.	67°39.8′W.			Aaron	video (18 min)
6	Aug. 6, 1978	1127	1349	142	40°24.68′N.	40°24.62′N.	230	9	Hickey/	35 mm (33)
					67°42.82′W.	67°41.05′W.			Phipps	video (20 min)
7	Aug. 6, 1978	1505	1625	80	40°26.01′N.	40°25.70′N.	220	8	Barksdale/	35 mm (0)
					67°41.63′W.	67°41.12′W.			Hampson	video (5 min)
8	Aug. 7, 1978	0821	1105	164	40°50.77′N.	40°50.86′N.	85	3	Hickey/	35 mm (91)
					67°23.74′W.	67°24.27′W.			Bryden	video (0)
9	Aug. 7, 1978	1435	1774	219	40°29.46′N.	40°29.32′N.	366	6	Barksdale/	35 mm (66)
					67°41.44′W.	67°41.68′W.			Slater	video (0)

Table 2. M.V. STATE ARROW ship's log

Date	Time	Mission	Weather	Problems
Aug. 4, 1978	0000 - 0730	Transit (Carteret Canyon to Veatch Canyon)	Sunny	Zodiac problems
	0730 - 2100	Diving (Veatch Canyon)	Clear	Minisparker problems
	2100 - 2400	Sparker survey	Calm	
Aug. 5, 1978	2400 - 1400	Sparker survey (too foggy to dive)	Fog	Fog
	1400 - 1730	Diving (Veatch Canyon)	Calm	Steering problems
	1730 - 1800	Transit		3.5 kHz down
	1800 - 2200	Sparker survey		Ship's water contamination
	2200 - 2400	Transit (Veatch Canyon to Lydonia Canyon)		
Aug. 6, 1978	0000 - 0830	Transit (Veatch Canyon to Lydonia Canyon)	Fog	-og
	0830 - 1700	Diving (Lydonia Canyon)	Calm	Steering problems
	1700 - 1800	Transit		Ship's water contamination
	1800 - 2400	Sparker survey		
Aug. 7, 1978	2400 - 0500	Sparker survey	Fog	Fog
	0500 - 0800	Transit (Lydonia Canyon to tripod on shelf)	Calm	Steering problems
	0800 - 1130	Diving (tripod site)	Cleared later	Submersible leaking
	1130 - 1430	Transit (tripod site to Lydonia Canyon)	in morning	
	1430 - 1900	Diving (Lydonia Canyon)		
	1900 - 2000	Transit		
	2000 - 2400	Sparker survey		
Aug. 8, 1978	0000 - 0730	Sparker survey	2-3' swells	Dive aborted on surface
	0730 - 0900	Diving	10-15 knot wind	Bad leak
	0900 - 1030	Sampling		
	1030 - 2400	Transit (Lydonia Canyon to Woods Hole)		
Aug. 9, 1978	0000 - 0730	Transit		

Atlantic Continental Slope (Bennett and others, 1977; Embley and Jacobi, 1977; McGregor and Bennett, 1977; Knebel and Carson, 1979; Slater and others, 1979a). Most of these slumps were interpreted and described from seismic profiles, with few, if any, direct observations. Although seismic profiling is a very effective way of recording the described features, its limitations include an inability to resolve fine structure and to document any features on slopes over 15^{o}-20^{o}. To determine if direct observations of the sea floor could provide data unavailable in seismic profiles and to aid in the assessment of potential geologic hazards, visual comparisons were made between known slump and interslump areas in Veatch and Lydonia Canyons along the upper Continental Slope near the lease sites proposed for sale 42 in the Georges Bank area. The toe of a slump is raised by thrusting or folding, resulting in a hummocky sea floor; the head of a slump is lowered, often by faulting, which exposes part of the slide plane at the sea-floor surface: hummocky sea floor and slide scars are characteristic features which should be identifiable from a submersible.

Other potential hazards to offshore petroleum exploration and production that can be observed from a submersible include gas seeps, sand waves, collapse craters, and evidence of strong currents. Submersible observers were instructed to look for and to describe any of these features.

Dive site selections for this study were made on the basis of reports, previously run seismic-reflection lines, and six (28 km) 3.5-kHz lines obtained during this cruise (table 3, figs. 3 and 4). Many of the tentatively identified slump features recorded were in water too deep (366 m) for the submersible DIAPHUS. Three grab samples were obtained with a Van Veen sampler to help verify submersible observation

Table 3. Summary of seismic data; M.V. STATE ARROW, 1978. See figs. 3 and 4 for seismic line locations on map.

Line no.	Date	Time	Start Finish	Latitude N.	Longitude W.	Course	Length km	Interpretation
1	4 Aug 78	2153		40°02.70′	69°39.22′	180°	16	Dip line paralleling Veatch Canyon axis on the east side. Shows only a slightly eroded surface and seaward dipping underlying Tertiary beds.
	5 Aug 78	0115		39°52.20′	69°33.05′	205°		
2	5 Aug 78	0121		39°51.92′	69°33.50′	275°	7	Poor data. Strike line across Veatch Canyon.
	5 Aug 78	0200		39°51.37′	69°38.45′	295°		
3	5 Aug 78	0206		39°51.92′	69°38.52′	025°	16	Dip line paralleling the canyon axis on the west side showing an erosional surface with the underlying Tertiary beds dipping seaward. This west wall section displays much more erosion than the east wall.
	5 Aug 78	0326		40°00.06′	69°38.88′	010°		
4	5 Aug 78	0342		40°01.18′	69°38.66′	105°	6	Strike line across the upper end of Veatch Canyon. No data in the subsurface.
	5 Aug 78	0415		40°00.78′	69°34.50′	095°		
5	5 Aug 78	0425		39°59.99′	69°34.00′	300°	5	Strike line across Veatch Canyon and the dive area. No data in the subsurface.
	5 Aug 78	0455		40°00.25′	69°37.82′	295°		
6	5 Aug 78	0505		39°59.66′	69°38.35′	105°	5	Strike line across Veatch Canyon showing a steplike topography on the west wall. No subsurface data.
	5 Aug 78	0540		39°59.43′	69°34.45′	105°		
7	5 Aug 78	0555		39°58.09′	69°34.14′	290°	8	Strike line across Veatch Canyon showing a smooth sea-floor surface on both sides of the canyon. No subsurface data.
	5 Aug 78	0640		39°58.01′	69°40.29′	295°		
8	5 Aug 78	0650		39°57.16′	69°40.53′	110°	10	Strike line across Veatch Canyon. Poor data.
	5 Aug 78	0750		39°56.60′	69°33.36′	090°		
9	5 Aug 78	0820		39°55.40′	69°33.31′	295°	9	Strike section across the center of Veatch Canyon showing the nearly flat-lying Tertiary beds in subsurface.
	5 Aug 78	0910		39°55.50′	9°39.90′	290°		
10	5 Aug 78	0924		39°54.36′	69°39.95′	090°	10	Strike line across canyon showing an erosional profile with gently dipping underlying Tertiary beds.
	5 Aug 78	1025		39°54.44′	69°32.86′	100°		
11	5 Aug 78	1030		39°54.31′	69°32.86′	340°	18	Oblique section across Veatch Canyon showing a slightly eroded surface and underlying Tertiary beds.
	5 Aug 78	1211		40°02.44′	69°39.65′	350°		

12	5 Aug 78	1215	40°02.78′	69°39.68′	100°	9	Continental Shelf profile showing an oblique section through an ancient
	5 Aug 78	1310	40°02.55′	69°33.63′	100°		buried canyon.
13	5 Aug 78	1315	40°02.32′	69°33.82′	245°	7	Oblique section across Veatch Canyon head and the outer Continental
	5 Aug 78	1355	39°59.77′	69°38.09′	265°		Shelf. An ancient buried canyon can be seen under the shelf.
14	5 Aug 78	1810	40°00.11′	69°39.63′	090°		3.5-kHz line across Lydonia Canyon.
	5 Aug 78	1850	40°00.08′	69°35.58′			
15	5 Aug 78	1915	40°00.40′	69°34.33′	270°		3.5-kHz line across Lydonia Canyon.
	5 Aug 78	1947	40°00.43′	60°38.68′			
16	5 Aug 78	1955	40°01.02′	69°38.83′	090°		3.5-kHz line across Lydonia Canyon.
	5 Aug 78	2025	40°00.99′	69°35.23′	088°		
17	5 Aug 78	2029	40°00.77′	69°35.10′	270°		3.5-kHz line across Lydonia Canyon.
	5 Aug 78	2050	40°00.05′	69°37.04′			Steering problems.
18	5 Aug 78	2115	40°00.98′	69°37.60′	250°		3.5-kHz line across Lydonia Canyon.
	5 Aug 78	2120	40°00.79′	69°38.10′			Finish of line 17.
19	5 Aug 78	2133	40°01.64′	69°38.79′	090°		3.5-kHz line across Lydonia Canyon.
	5 Aug 78	2155	40°01.33′	69°36.97′	010°		Steering problems. Line rerun.
20	6 Aug 78	1800	40°26.12′	67°41.94′	090°	6	Strike line across Lydonia Canyon. Poor subsurface data.
	6 Aug 78	1830	40°26.10′	67°37.73′			
21	6 Aug 78	1834	40°26.21′	67°37.53′	015°	2	Short line along the Continental Shelf. Poor subsurface data.
	6 Aug 78	1845	40°27.15′	67°37.41′			
22	6 Aug 78	1848	40°27.24′	67°37.63′	275°	6	Strike line across Lydonia Canyon showing an erosional profile with
	6 Aug 78	1937	40°27.07′	67°42.11′	290°		truncated flat-lying Tertiary(?) beds.
23	6 Aug 78	1953	40°28.10′	67°42.16′	105°	6	Strike line across Lydonia Canyon showing the erosional profile
	6 Aug 78	2029	40°28.05′	67°37.76′	100°		with flat underlying Tertiary(?) beds. Steering problems.
24	6 Aug 78	2041	40°29.08′	67°38.24′	285°	8	Strike line across Lydonia Canyon showing the truncated Tertiary(?)
	6 Aug 78	2123	40°28.82′	67°44.05′	295°		beds in the subsurface.
25	6 Aug 78	2145	40°30.02′	67°44.87′	095°	6	Strike line across the head of Lydonia Canyon with truncated underlying
	6 Aug 78	2216	40°30.06′	67°41.16′	110°		Tertiary(?) beds.

26	6 Aug 78	2228	40°31.07′	67°41.33′	290°	4	Strike line across the head of Lydonia Canyon with truncated underlying
	6 Aug 78	2248	40°31.12′	67°44.16′			Tertiary(?) beds.
27	6 Aug 78	2300	40°32.01′	67°44.74′	110°	5	Strike line across the head of Lydonia Canyon showing the bifurcating
	6 Aug 78	2325	40°32.00′	67°41.58′			head.
28	6 Aug 78	2339	40°33.11′	67°41.84′	290°	4	Strike line across the shelf north of Lydonia Canyon showing flat-lying
	6 Aug 78	2400	40°33.04′	67°44.39′	280°		Tertiary(?) beds.
29	7 Aug 78	0014	40°33.47′	67°44.55′	165°	24	Dip line paralleling the Lydonia Canyon axis along the west wall.
	7 Aug 78	0300	40°22.53′	67°38.38′	175°		This wall is extremely eroded with numerous side canyons and gullies
							crossed in this section.
30	7 Aug 78	0310	40°22.30′	67°38.99′	015°	8	Dip line paralleling the Lydonia Canyon axis along the east wall. Shows
	7 Aug 78	0445	40°29.10′	67°38.98′			the dissected and eroded nature of the wall.
31	7 Aug 78	2027	40°24.93′	67°41.90′	105°	6	Strike line across the head of Lydonia Canyon showing some possible
	7 Aug 78	2105	40°24.93′	67°37.83′	095°		slumps.
32	7 Aug 78	2118	40°23.95′	67°37.61′	290°	8	Strike line across Lydonia Canyon, some subsurface data, west wall
	7 Aug 78	2208	40°24.05′	67°43.04′	300°		more eroded than east wall.
33	7 Aug 78	2223	40°23.02′	67°43.16′	100°	10	Strike line across Lydonia Canyon, poor subsurface data.
	7 Aug 78	2335	40°23.07′	67°36.00′			
34	7 Aug 78	2358	40°22.00′	67°35.71′	290°	12	Strike line across Lydonia Canyon, poor data.
	8 Aug 78	0110	40°22.01′	67°44.01′	305°		
35	8 Aug 78	0127	40°21.06′	67°44.20′	100°	13	Farthest south strike line across Lydonia Canyon. Poor data.
	8 Aug 78	0300	40°21.00′	67°35.31′	110°		
36	8 Aug 78	0315	40°21.01′	67°35.31′	350°	23	Dip line paralleling the Lydonia Canyon axis alng the east wall.
	8 Aug 78	0554	40°32.44′	67°41.89′	005°		The erosional character of the wall is evident.
37	8 Aug 78	0555	40°32.49′	67°42.06′	295°	4	Strike line across the northern end of Lydonia Canyon showing
	8 Aug 78	0620	40°32.45′	67°44.66′	300°		only a slight erosional indentation in the shelf.
38	8 Aug 78	0635	40°31.42′	67°44.66′	105°	5	Strike line across Lydonia Canyon showing the canyon cutting through
	8 Aug 78	0710	40°31.41′	67°41.46′			flat-lying Tertiary beds.

Figure 3. Bathymetric map of Veatch Canyon showing seismic line and submersible dive locations.

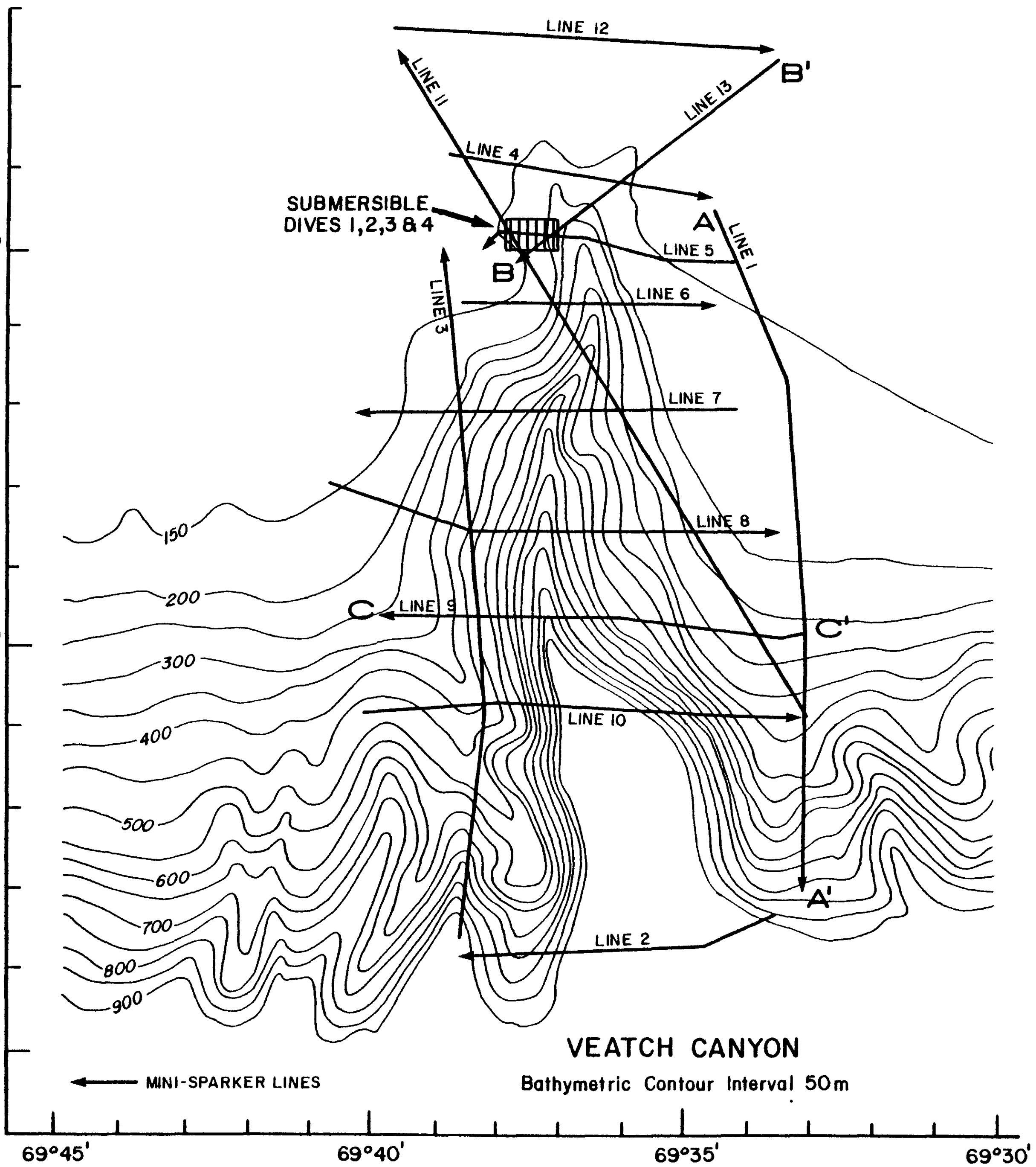
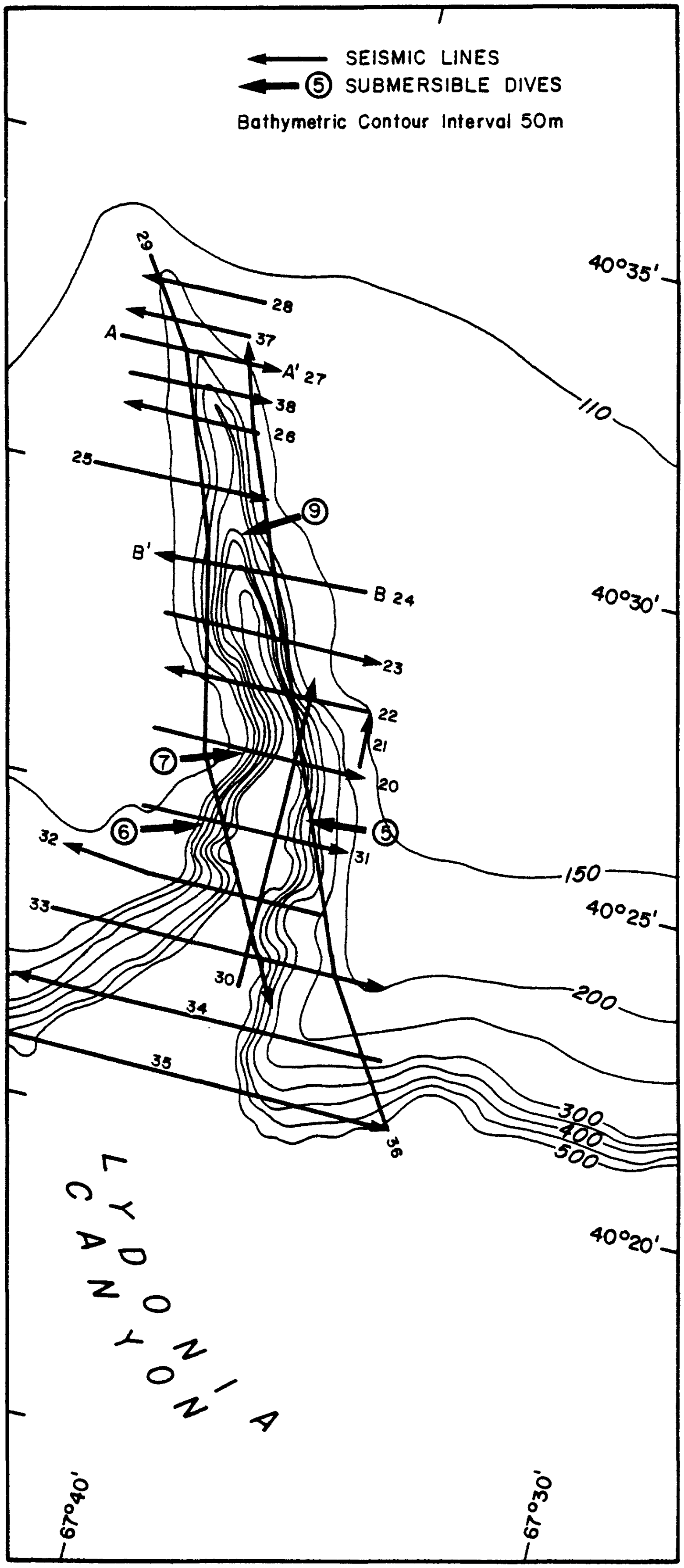

LINE 12
B'
LINE 11
LINE 13
LINE 4
SUBMERSIBLE
DIVES 1,2,3 & 4
A
LINE 1
LINE 5
B
LINE 6
LINE 3
LINE 7
LINE 8
150
200
C
LINE 9
C'
300
LINE 10
400
500
600
A'
700
LINE 2
800
900
40°00'
39°55'
39°50'
69°45'
69°40'
69°35'
69°30'
VEATCH CANYON
Bathymetric Contour Interval 50m
MINI-SPARKER LINES

Figure 3

Figure 4. Bathymetric map of Lydonia Canyon showing seismic line and submersible dive locations.


SEISMIC LINES
5 SUBMERSIBLE DIVES
Bathymetric Contour Interval 50m
40°35'
40°30'
40°25'
40°20'
110
150
200
300
400
500
A
A'
B
B'
29
28
37
27
38
26
25
9
24
23
22
21
7
20
6
5
32
31
33
30
34
35
36
LYDONIA
CANYON
67°40'
67°30'

of the sea-floor sediments and to identify the sediment composition (table 4).

Nine submersible dives (fig. 2, table 2) were made in the study area between August 4 and 7, 1978. More than 540 35-mm photographs and 1-1/2 hours of videotape were taken to document visual observations of the sea floor during the nearly 22 hours underwater. All seismic records, photographs, and videotape gathered in this study are on file at the U.S. Geological Survey Office in Woods Hole, Massachusetts.

SEISMIC INTERPRETATIONS

A total of 32 mini-sparker seismic-reflection lines (table 3) and six 3.5-kHz high-resolution lines were gathered in the Veatch and Lydonia Canyon areas (figs. 3 and 4). These profiles (for example, fig. 5) reveal complexly eroded canyon walls, especially the west walls, the details of which are not revealed on the scale of the bathymetric maps shown in figures 2 and 3. Tertiary beds in the subsurface dip gently seaward (fig. 5) and are truncated by the canyon walls. Sections across the canyons reveal steeper profiles in the middle sections (fig. 6, C´-C and fig. 7, B´-B) than in the heads (fig. 7, A-A´) or farther down the slope. Ancient channels, now buried (fig. 6, B´-B), were revealed on several profiles around the canyon heads.

No large slump features were observed in the profiles, but apparently truncated and deformed reflectors along canyon walls, such as those shown in figure 6 (B´-B), possibly represent slumped or displaced side wall material.

DIVE DESCRIPTIONS

The following descriptions of the sea floor and biota were compiled from the 35-mm photographs, videotapes, and from the audiotapes made by

Table 4. Sample information-Van Veen grab

Station no.	Date	Time	Latitude	Longitude	Water depth (m)	% Gravel	% Sand	% Silt & clay
5003	Aug. 8, 1978	0900	40°31.24´N.	67°44.24´W.	126	0	81.0	19.0
5004	Aug. 8, 1978	0915	40°31.87´N.	67°43.90´W.	165	0	61.2	38.8
5005	Aug. 8, 1978	1000	40°32.64´N.	67°42.00´W.	117	10.0 (shells)	78.2	11.8

Figure 5. Seismic profile, line 1 (A-A') Veatch Canyon.

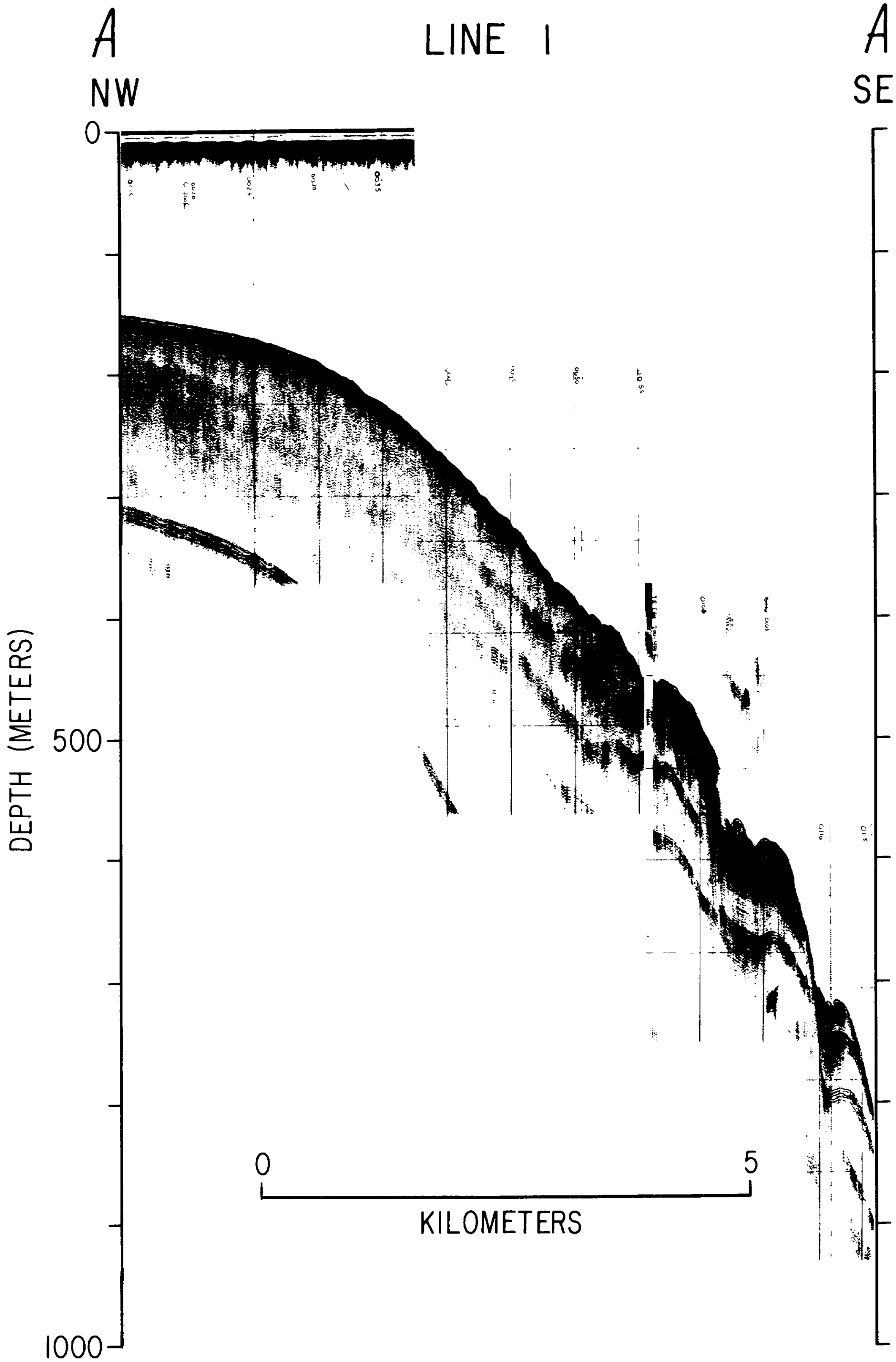
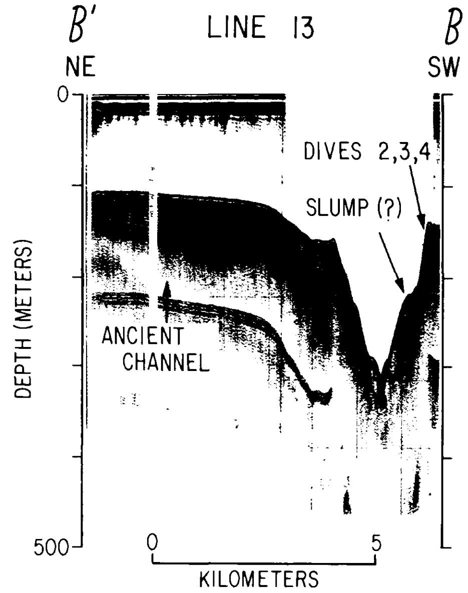

A
LINE 1
A'
NW
SE
0
500
1000
DEPTH (METERS)
0
5
KILOMETERS

Figure 6. Seismic profiles, line 13 (B'-B) and line 9 (C'-C), Veatch Canyon.


B'
LINE 13
B
NE
SW
0
500
DEPTH (METERS)
DIVES 2,3,4
SLUMP (?)
ANCIENT
CHANNEL
0
5
KILOMETERS

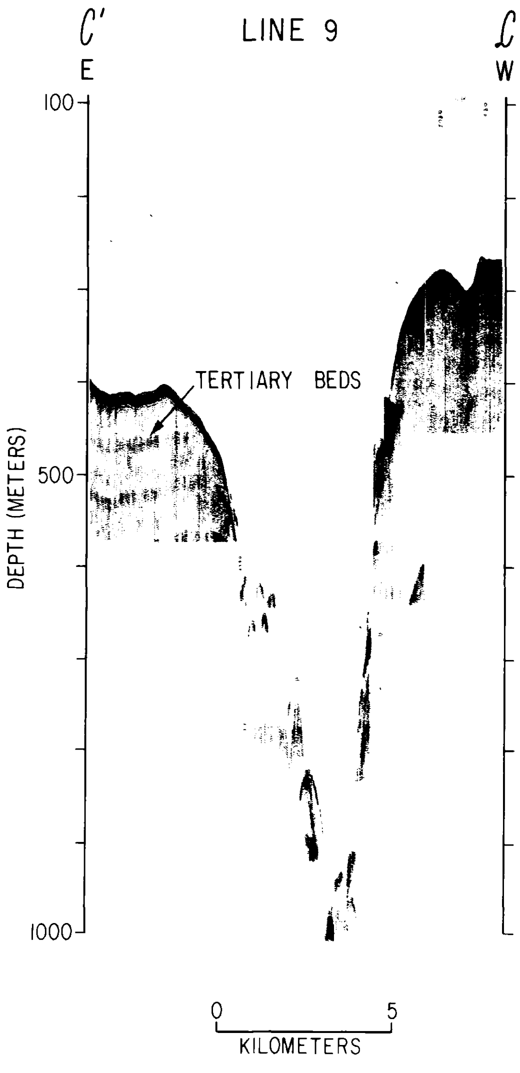
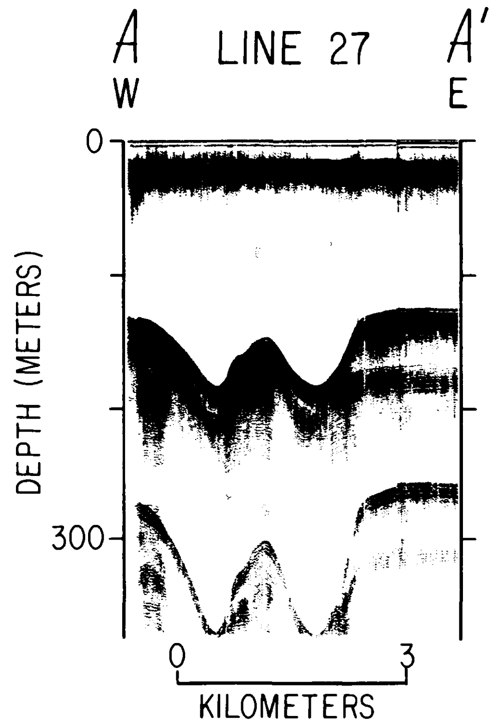
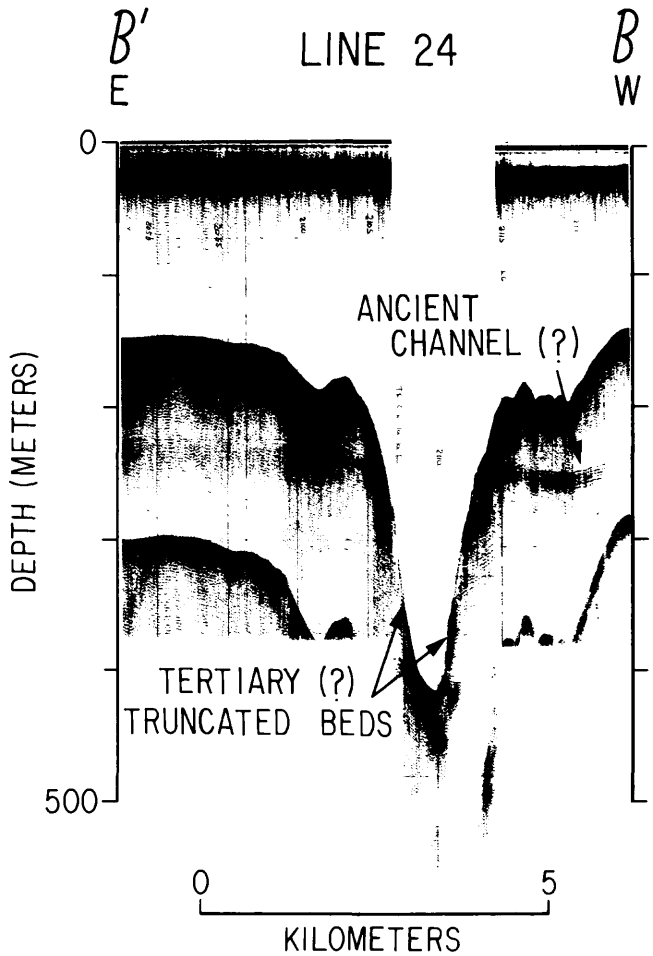

C'
LINE 9
C
E
W
100
500
1000
DEPTH (METERS)
TERTIARY BEDS
0
5
KILOMETERS

Figure 7. Seismic profiles, line 27 (A-A') and line 24 (B'-B), Lydonia Canyon.


A
LINE 27
A'
W
E
0
300
DEPTH (METERS)
0
3
KILOMETERS


B'
LINE 24
B
E
W
0
500
DEPTH (METERS)
ANCIENT
CHANNEL (?)
TERTIARY (?)
TRUNCATED BEDS
0
5
KILOMETERS

the six scientific observers during the nine submersible traverses in the study area. Dives 1-4 were on the west wall near the head of Veatch Canyon (fig. 3) to familiarize the observers with a known slump area discovered during a series of submersible dives there in 1973. Dives 5-7 and 9 were in the head of Lydonia Canyon (fig. 4) which is the most probable conduit into deep water for any material scoured by currents from the potential drilling sites in sale 42 on Georges Bank. Dive 8 was on the Georges Bank shelf (in sale 42) for biological observations of the area around the U.S. Geological Survey tripod at $40^{o}51'$N. and $67^{o}24'$W. (fig. 2). The observations on this dive were to verify the validity of the photographic data being taken by the tripod camera installed there.

Because the dive descriptions in this chapter are concentrated on the sea-floor geology rather than the biology, species identification is only tentative with common or generic names used in most cases. Lamont-Doherty Geological Observatory personnel have analyzed all the 35-mm photographs from these dives and have written a report for the U.S. Bureau of Land Management on the abundance and distribution of the epibenthic fauna in the study area (Hecker and Blechschmidt, 1979). Their study showed that the submarine canyons in this area are unique habitats supporting higher faunal densities than the terrain between canyons.

DIVE 1

The first dive in the Georges Bank study area was made along the western side of the head of Veatch Canyon ($40^{o}00.68'$N., $69^{o}37.71'$W.) in 140-200 m water depth (figs. 3, 8) near a known slump area. First observations at 140 m showed a current moving toward the northeast at

Figure 8. Dive 1 profile (time vs. depth), Veatch Canyon.

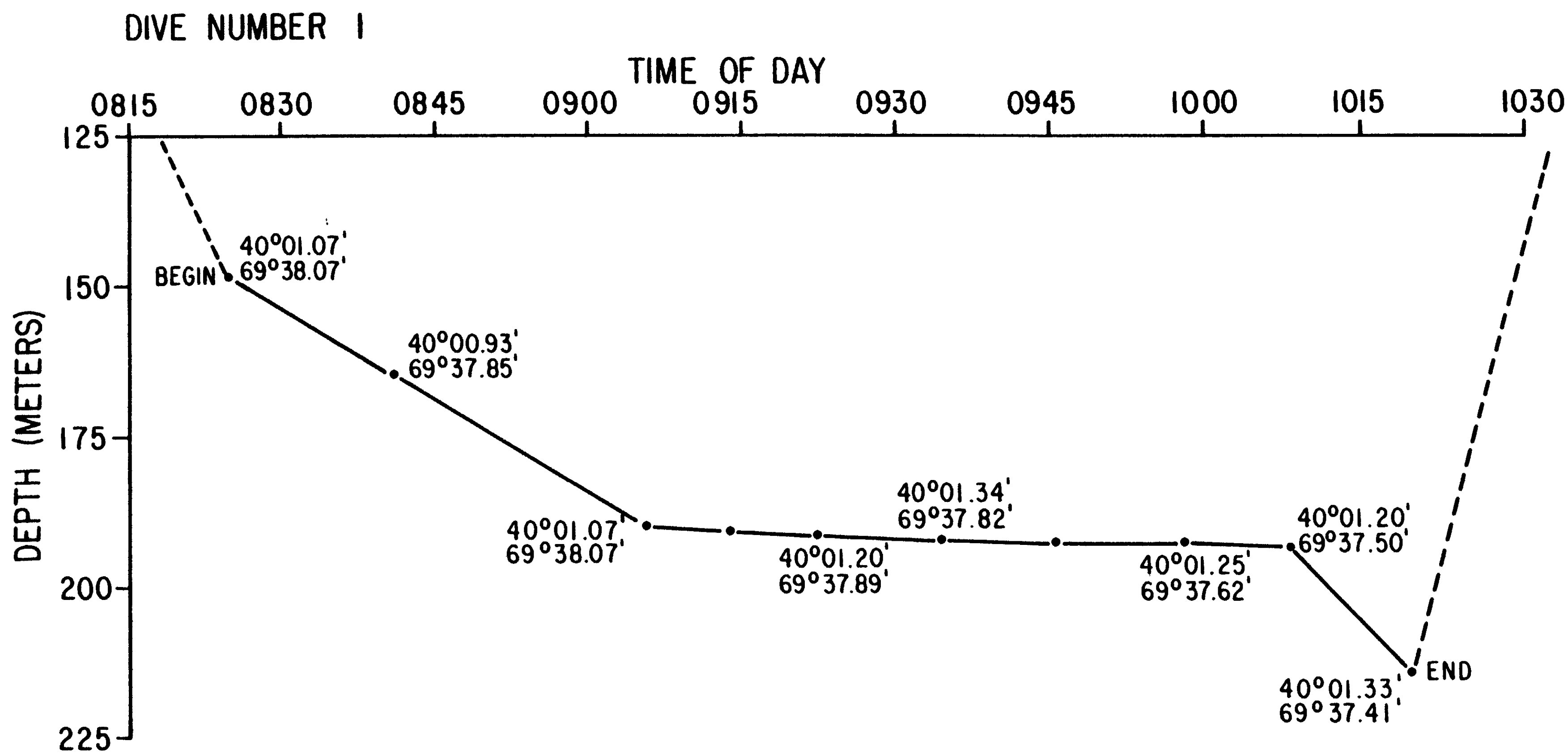

DIVE NUMBER I
TIME OF DAY
0815
0830
0845
0900
0915
0930
0945
1000
1015
1030
DEPTH (METERS)
125
150
175
200
225
BEGIN
40°01.07'
69°38.07'
40°00.93'
69°37.85'
40°01.07'
69°38.07'
40°01.20'
69°37.89'
40°01.34'
69°37.82'
40°01.25'
69°37.62'
40°01.20'
69°37.50'
END
40°01.33'
69°37.41'

Figure 8

15-20 cm/s, and grayish-green, sandy-silt on a slightly undulating sea floor marked by many small mounds and depressions. Numerous tracks and trails were observed, but few biota other than sea pens and empty clam shells. Sparse cobbles and boulders were seen on the sea floor. The submersible's intended heading (090°) was downslope, but because of the current, was actually about 150°. At 183 m, the submersible turned to the northeast to run along the 183-m contour of a 10°-15° slope. The character of the sea floor remained unchanged but occasional fish (hake, four-spot flounder, goosefish, sea robin, whiting, snake eel) and crabs (Cancer, Bathynectes, and Galatheid) were present. Sea pens (Pennatula borealis), brittle stars, and the stalked anemones (Cerianthus borealis) were common.

A series of downslope gullies about 15 m apart, 1 m across, and 25 cm deep with smooth, concave profiles, ran straight down the slope. These features were near the canyon head on the 183-m contour. In deeper (207 m) water these gullies widened out to about 3 m across with 20° slopes on either side. The bottoms remained smooth but the sides of the chutes were hummocky and burrowed. These features are possible conduits for any material moving off the shelf into deeper water and should be mapped in detail. After 2-1/2 hours of observation it was determined that the target slump area was missed and that the dive should be terminated.

DIVE 2

Dive 2 (figs. 3, 9) was started close to the same position (40°00.83'N., 69°37.66'W.) on the sea floor where dive 1 began, but on a southerly rather than northerly heading to find the slump area. There was a slight current from the north at the beginning of the dive as the

Figure 9. Dive 2 profile (time vs. depth), Veatch Canyon.

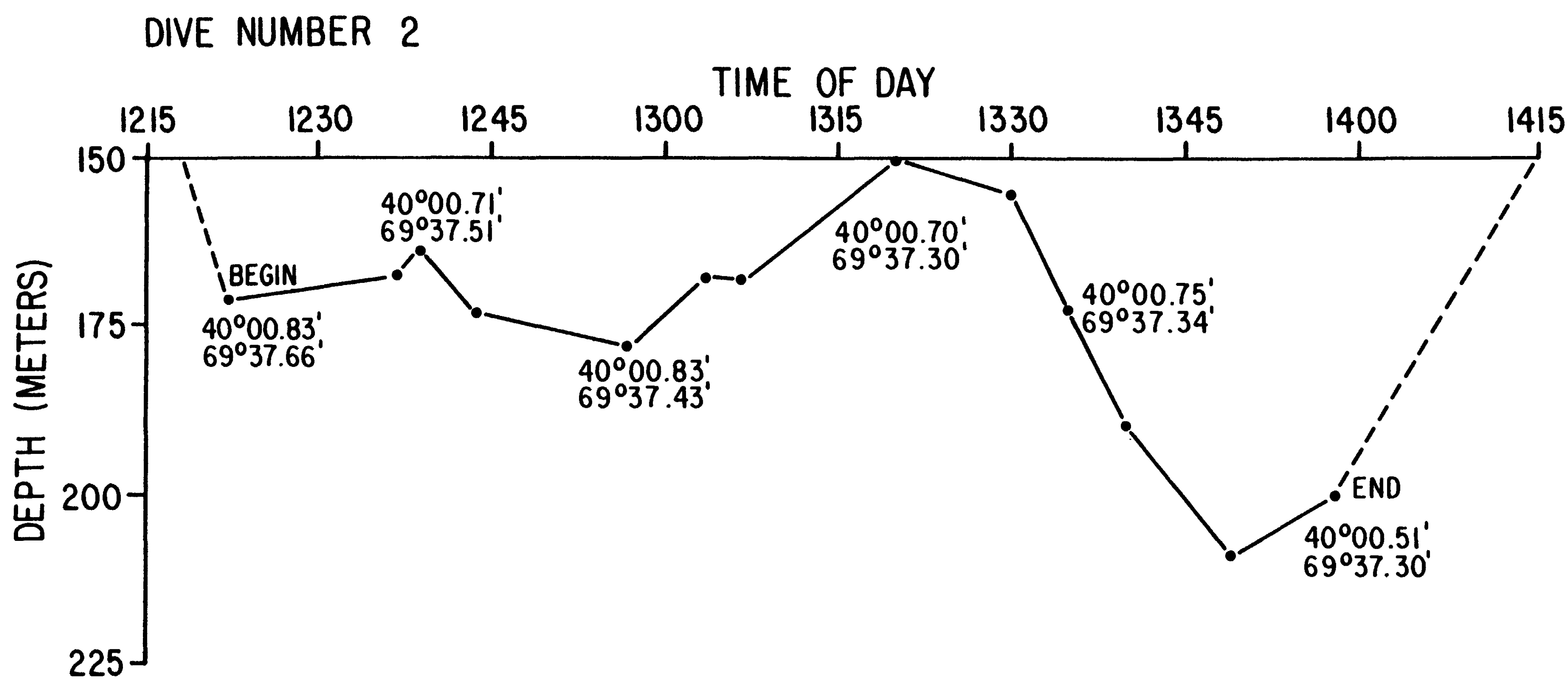

DIVE NUMBER 2
TIME OF DAY
1215
1230
1245
1300
1315
1330
1345
1400
1415
DEPTH (METERS)
150
175
200
225
BEGIN
40°00.83'
69°37.66'
40°00.71'
69°37.51'
40°00.83'
69°37.43'
40°00.70'
69°37.30'
40°00.75'
69°37.34'
END
40°00.51'
69°37.30'

Figure 9

submersible followed the 160-m contour to the south. The bottom at 170-m water depth was floored with sandy silt with some shell hash; the sea floor was smooth except for numerous small (3-6 cm in diameter) polychaete mounds (made of fecal pellets?) and similar-sized conical depressions. Sea pens, fish, and occasional crabs were the only animals seen with fish and crustaceans dominating the fauna in this area. The submersible followed the contour of the canyon wall until the angle of slope became abruptly steeper, about 45°. Shells and shell hash were abundant on the surface of the sea floor here which was heavily burrowed and mottled. Clay balls and chunks of clay gave it a very lumpy look. Sparse large clay blocks had scour marks around them. The submersible then traveled upslope across a series of steps to the 145-m contour where the sea floor leveled off. This slope was actually a series of rubble-covered terraces 2-5 m wide separated by steep (75°), heavily burrowed cliffs 1-3 m high (fig. 10). The scarp and terrace morphology suggested the head of a slump. The burrowed cliffs or scarps seemed to be restricted to areas underlain by semiconsolidated clay beds (figs. 11A-D). The thin (a few centimeters) overlying sandy silt covering most of the sea floor forms poor material for burrowing, so the cliffs support tremendous amounts of life with fish, lobster, and crabs (Galatheid and Jonah) commonly observed in the burrows. Large slabs (1 m across) of burrowed material lay on the terraces below the cliffs. It was difficult to maneuver the submersible in this area because of the strong current.

After recrossing the terraced slope down to 188-m water depth, the submersible traveled on a heading of 110°, pushed from behind by the strong current. Small-scale asymmetric ripples, with their lee sides downcurrent, were common in the silty surface sediment. Their

Figure 10. Typical section of Veatch or Lydonia Canyons walls showing inferred structural control of observed morphology.

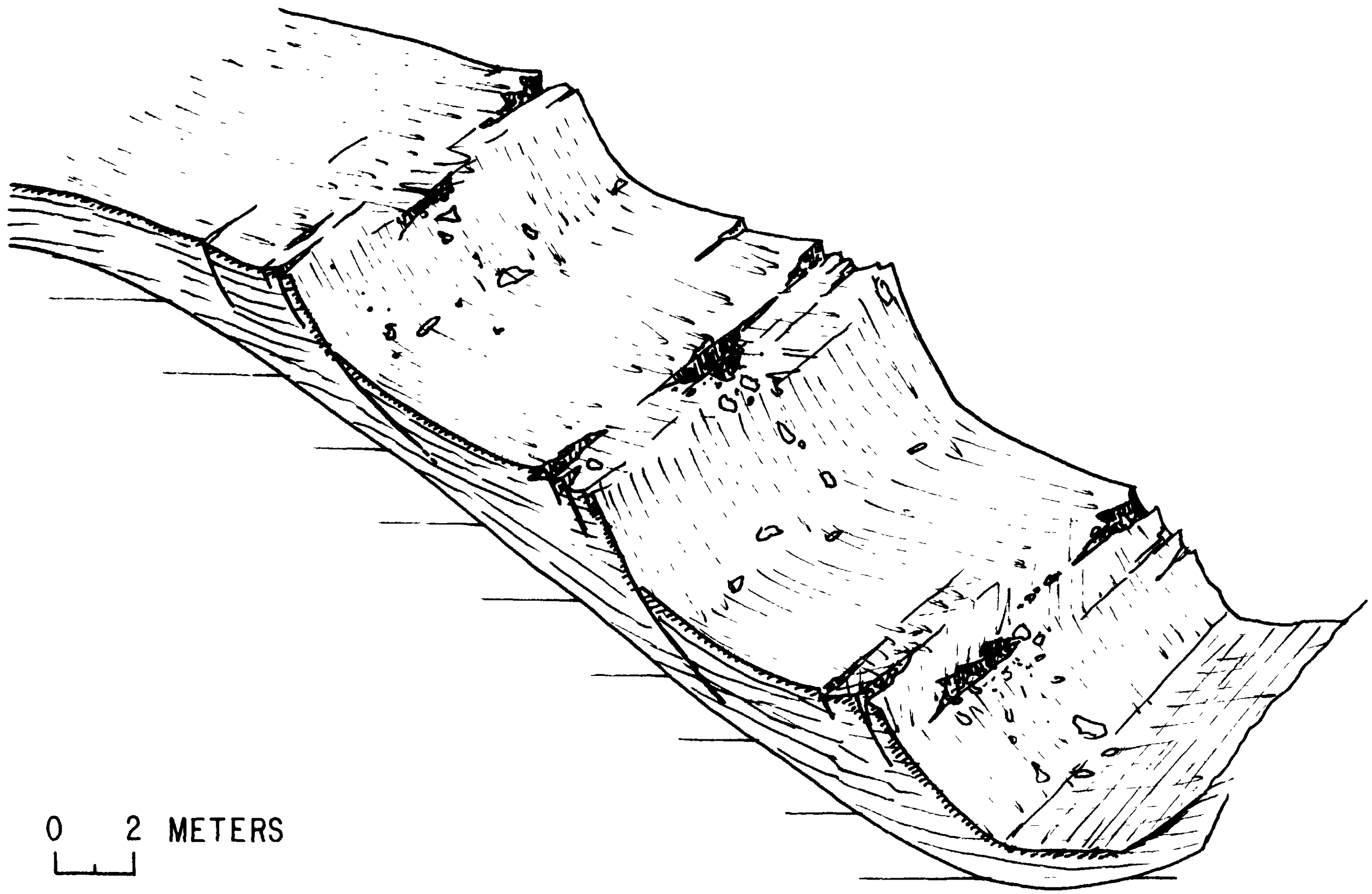


Figure 10

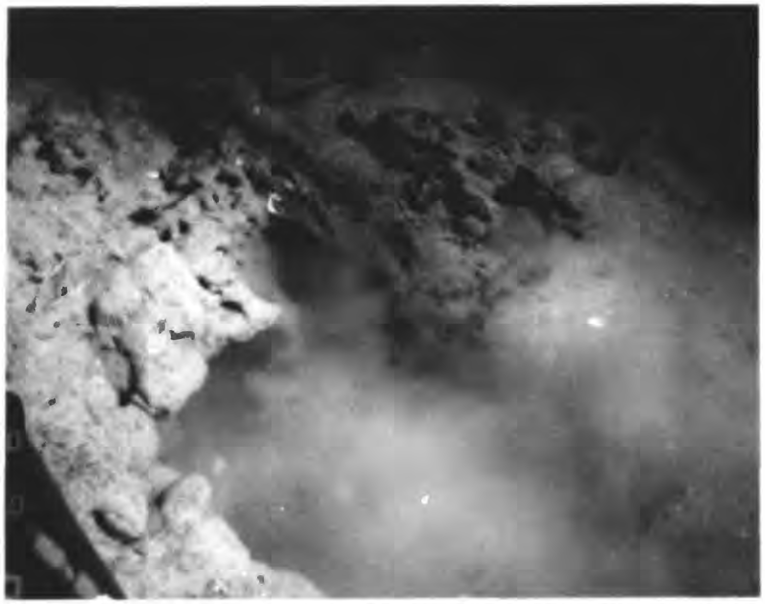
Figure 11. Bottom photographs, Veatch Canyon; bottom approximately 1.75 m across.

A. 171 m close up of bioeroded Pleistocene(?) clay; fine sediment stirred up by 1 m tilefish (*Lopholatilus camaeleonticeps*) which disappeared into hole.

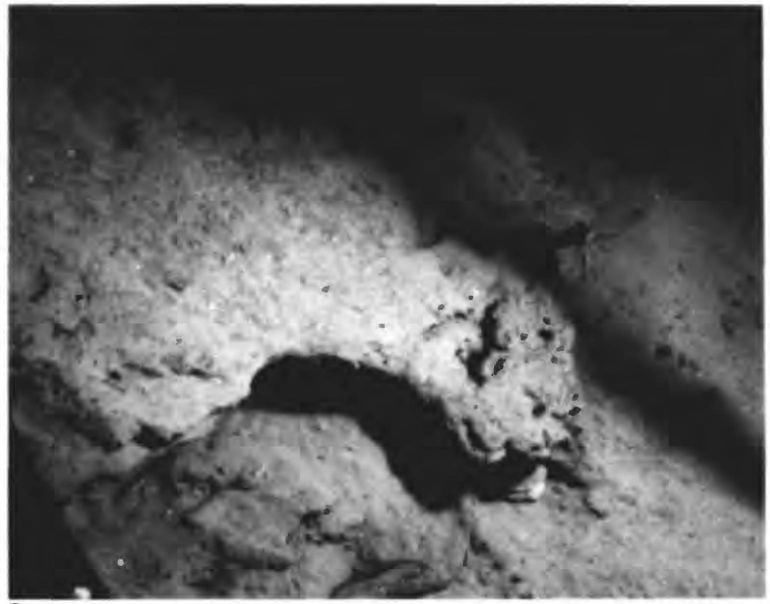
B. 169 m bioerosion into Pleistocene(?) clay beds which dip parallel to the sea floor; scar perhaps due to separation of a slide block.

C. 195 m bioerosion Pleistocene(?) clay outcrop on a 35-40° slope.

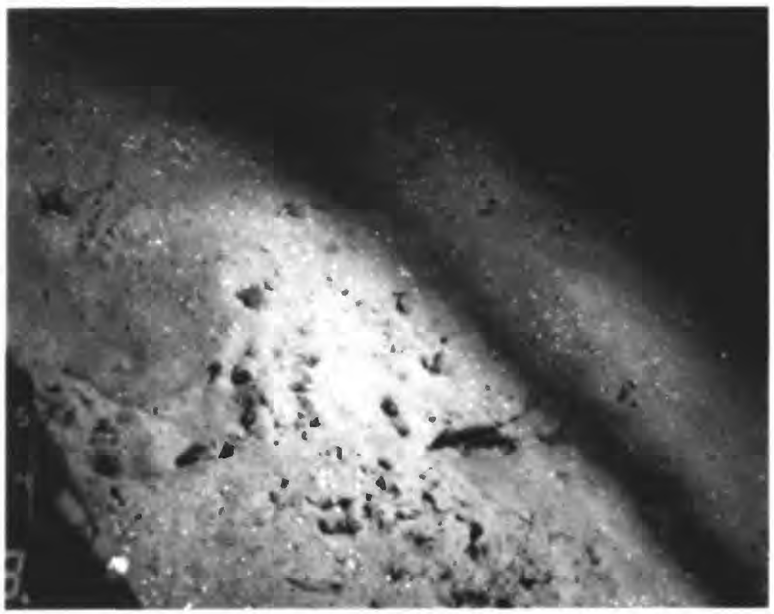
D. 168 m detailed view of bioerosion; cusk (*Brosme brosme*) and shrimp shown for scale.



A 171M—CLOSE UP OF BIOERODED PLEISTOCENE(?) CLAY. FINE SEDIMENT STIRRED UP BY 1M TILE FISH (LOPHOLATILUS CAMAELEONTICEPS) WHICH DISAPPEARED INTO HOLE. BOTTOM OF PHOTGRAPHS APPROXIMATELY 1.75M ACROSS



B 169M—BIOERDSIDN INTO PEISTOCENE(?) CLAY BEDS WHICH DIP PARALLEL TO THE SEA FLODR. SCAR PERHAPS DUE TO SEPARATION OF A SLIDE BLOCK



C 169M—BIOERODED PLEISTOCENE(?) CLAY OUTCROP ON A 35-40 SLOPE

D 168M—DETAILED VIEW OF BIOEROSION. CUSK (BROSME BROSME). THE SHRIMP SHOWN FOR SCALE

Figure 11A-D

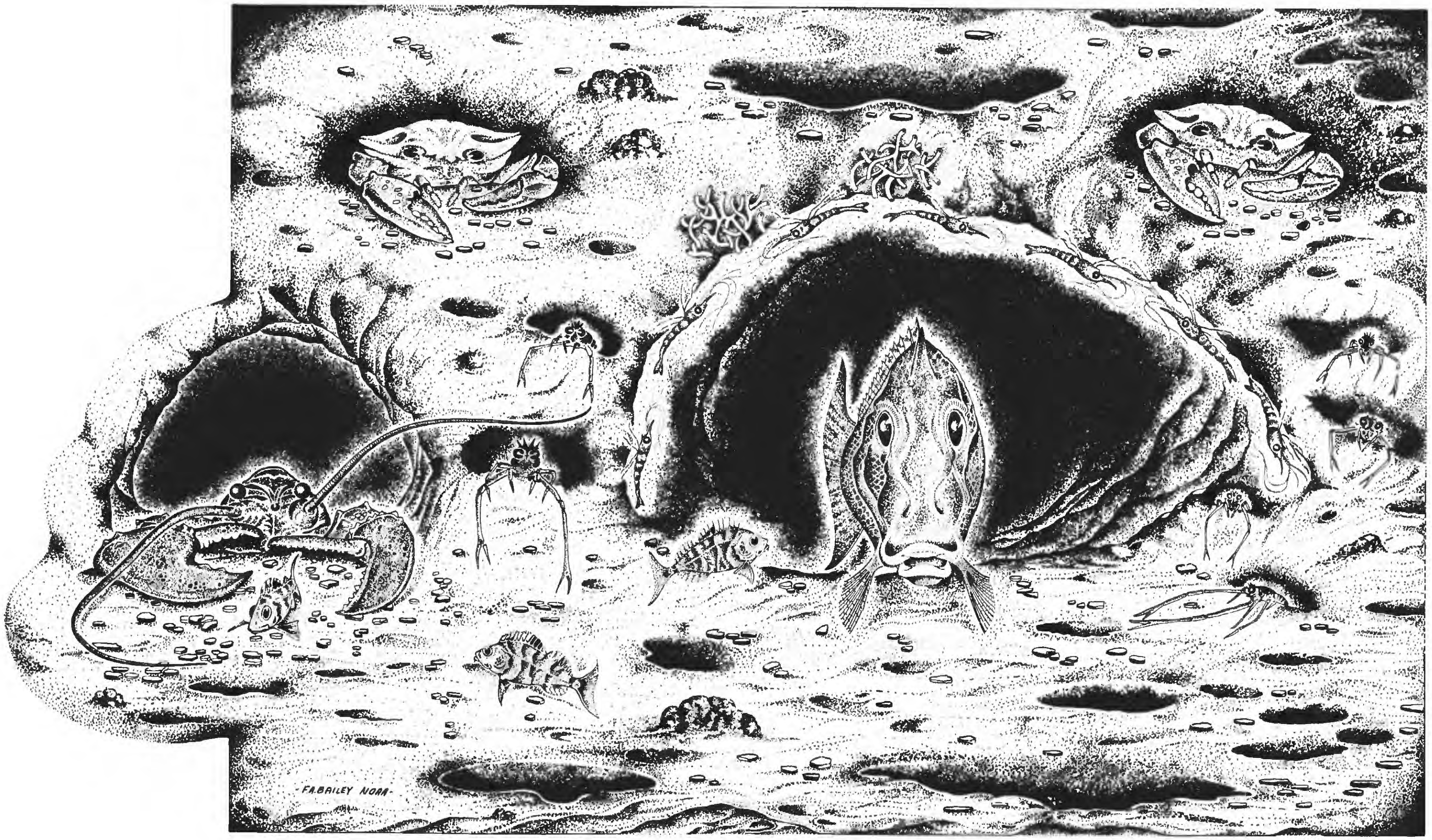
wavelength ranged from 5 cm to 8 cm, and wave height averaged about 3 cm. At 200-m water depth, the slope steepened to nearly 60° and was covered with a fine sediment pitted by the 3-cm wide burrows.

Upon returning up the slope a nearly vertical cliff was observed at a water depth of 147 m. This cliff, apparently a scarp about 4 m high, was burrowed extensively by enormous numbers of crab, hake, lobster, and small fish. At the entrance of most burrows and on the terrace below the cliff, the sediment was covered with shell hash which is assumed to be the result of crustacean feeding. This area was very similar to the "pueblo villages" described by Warme and others (1978) (fig. 12). After 2-1/2 hours of observations, 120 35-mm photographs and 7 minutes of videotape, the dive was terminated in the "pueblo village" area.

DIVE 3

Dive 3 (figs. 3, 13) was made along the west side of Veatch Canyon, around the "pueblo village" slump scar topography, in the same general area of dive 2. Again, there was a fairly strong bottom current but this time it was from the south. Bottom surface sediment at 167-m water depth was very silty with little shell hash. Only rare mounds and burrows were seen on the smooth 10° sloping sea floor. At a depth of 160 m, clay outcrops were observed; several of them contained large tilefish burrows but few tilefish (fig. 11A). The submersible's track went over numerous small scarps and terraces. The terraces had large (up to 50 cm), angular, burrowed, clay chunks lying on them and the many heavily burrowed 60 to 100-cm high clay scarps looked as if they had been formed by the sliding-away of the downslope clay block (fig. 11B). The general angle of slope here was approximately 30°-40°. The best exposed outcrops of clay were found between 152 and 164 m where 30 to

Figure 12. Pueblo village community, Veatch Canyon, 200 m.



PUEBLO VILLAGE COMMUNITY, VEATCH CANYON, 200 M

Figure 12

Figure 13. Dive 3 profile (time vs. depth), Veatch Canyon.

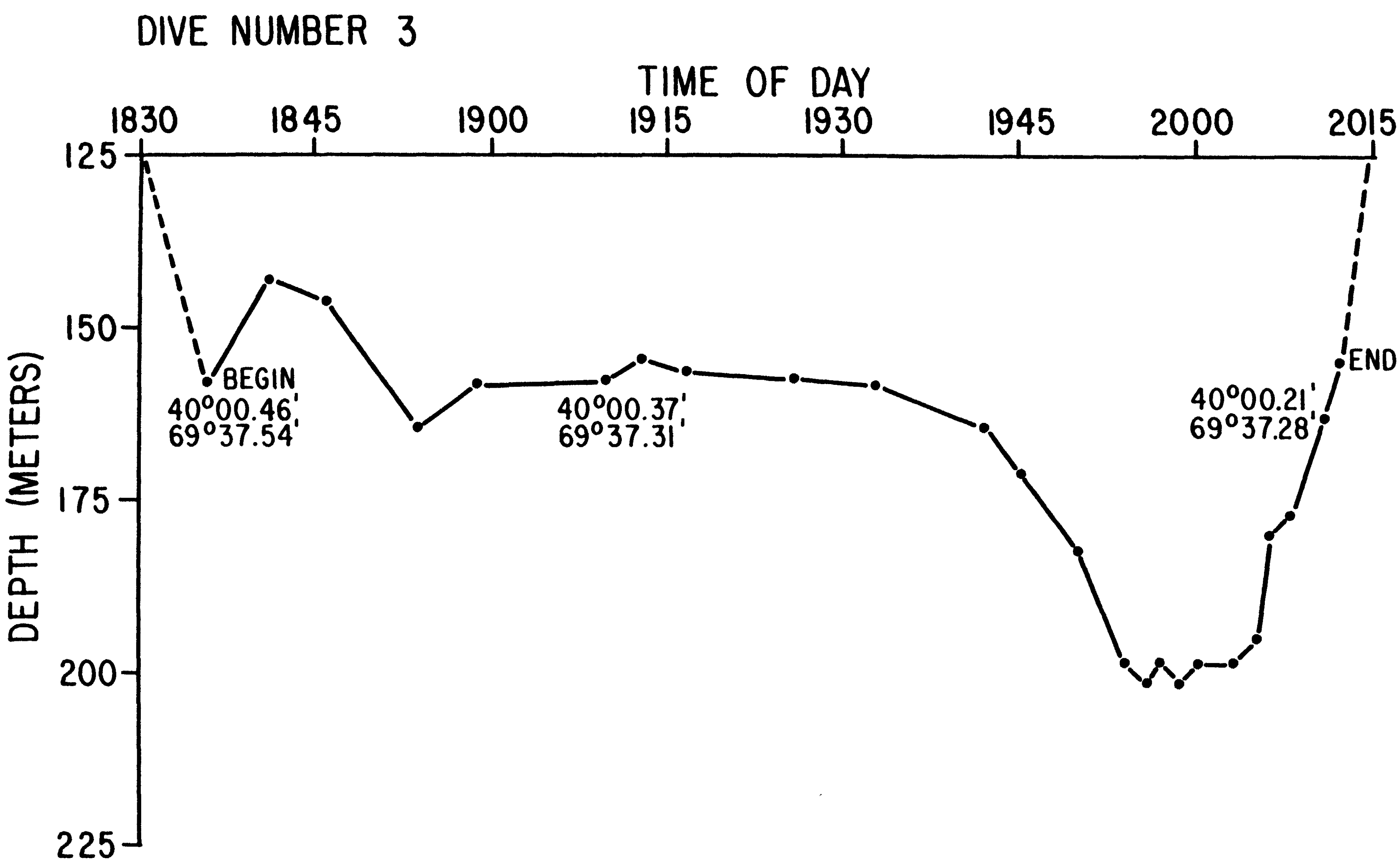

DIVE NUMBER 3
TIME OF DAY
1830
1845
1900
1915
1930
1945
2000
2015
125
150
175
200
225
DEPTH (METERS)
BEGIN
40°00.46'
69°37.54'
40°00.37'
69°37.31'
40°00.21'
69°37.28'
END

Figure 13

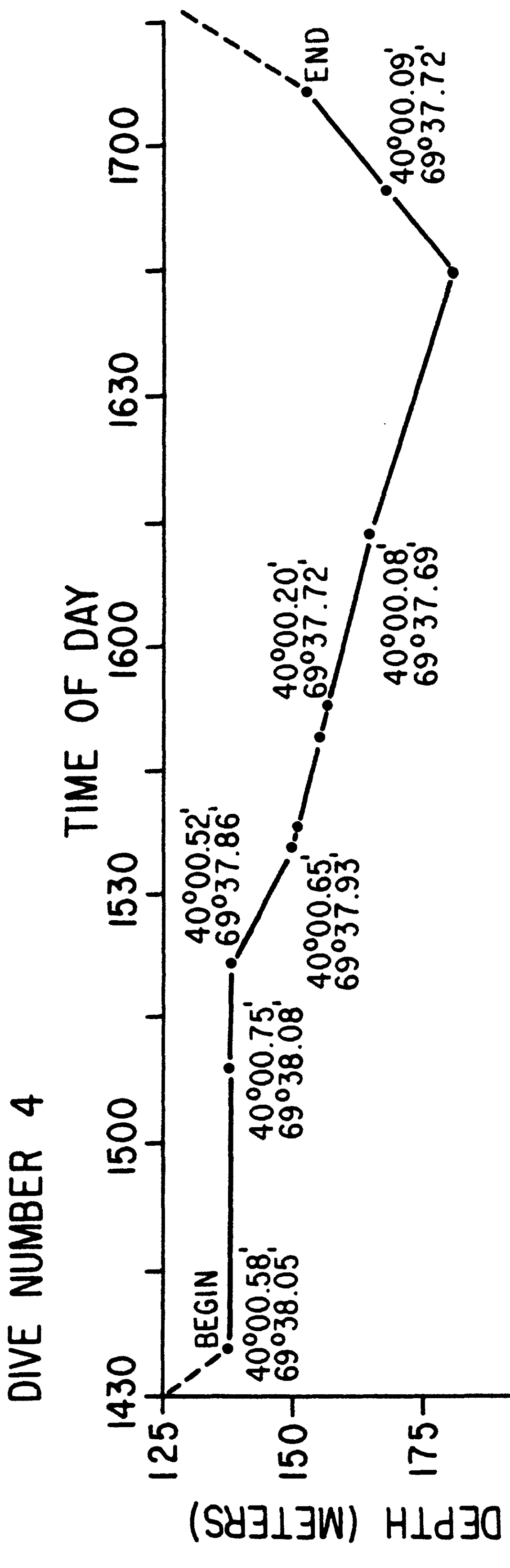
60-cm high scarps, 3 to 7 m wide, were common. The fauna, especially fish and crustaceans, were extremely abundant in this area.

The current direction changed and came from the west during the last half of the dive. The dive was terminated after 2 hours of observations; 74 35-mm photographs, and 20 minutes of videotape were taken.

DIVE 4

Dive 4 took place in the same locality as dives 2 and 3, along the west wall near the head of Veatch Canyon (figs. 3, 14) with a biologist as the observer. The submersible landed on a slight slope in 137 m water depth. The fine surface sediment was formed into numerous mounds or cones, 3 to 7 cm in diameter, with fecal pellets around their tops. These were probably polychaete burrows. The bottom current was flowing at about 25 cm/s from 330° during the dive. As the submersible moved along the sea floor, four-spot flounders, Gulf Stream flounders, Galatheid crabs, small starfish, conical gastropods, Jonah crabs, hake, and quahog shells were seen. A few polychaete worms were observed in their mounds; some of the other tiny holes in the sea floor were assumed to be clam siphon holes. On the flat sea-floor areas, the fauna concentrated around erratics or man-made debris for protection; there was not much epifauna otherwise. As the submersible approached the water depth of 152 m the fine sediment seemed to be covered with sea pens and small orange tentacles belonging to either polychaetes or brittle stars buried below the surface. One erratic 2 m in diameter was covered with small colonial anemones. At 170 m, as the burrowed clay outcrops were encountered, the number of tentacled polychaetes(?) and sea pens decreased. The tilefish in this area indicated a nearly unseen

Figure 14. Dive 4 profile (time vs. depth), Veatch Canyon.



DIVE NUMBER 4
TIME OF DAY
DEPTH (METERS)
1430
1500
1530
1600
1630
1700
125
150
175
200
BEGIN
40°00.58'
69°38.05'
40°00.75'
69°38.08'
40°00.52'
69°37.86'
40°00.65'
69°37.93'
40°00.20'
69°37.72'
40°00.08'
69°37.69'
40°00.09'
69°37.72'
END

Figure 14

"pueblo village" terrain. At approximately 182 m, in the same type of sea floor, some cavernous burrows were observed, one of which contained a very large tilefish.

After 2-1/2 hours underwater with 129 35-mm slides and 8 minutes of videotape taken on this dive, it was decided to end the Veatch Canyon dives and to move on to Lydonia Canyon.

DIVE 5

Dive 5 (40°25.16´N. and 67°39.10´W.) was the first of our dives in Lydonia Canyon (figs. 4, 15). Large schools of fish and squid were sighted as the submersible descended through the water which had a temperature near the surface of 14°C. The submersible landed in 170 m of water (bottom water temperature was 10.6°C), on grayish-brown, silty sand that had many _Onuphis_ sp. worms moving around on its surface. There was a fairly strong bottom current from 140°. As the submersible traversed across the sea floor, a number of conical depressions and polychaete mounds were observed. The epifauna consisted mainly of crabs and starfish amongst abundant clam and scallop shells. There was a scum or fuzz on the sediment surface; this had been seen on numerous other dives in other canyons and appeared to be some type of algal growth. Other than the occasional pebble and cobble, the polychaete mounds (8 to 10 cm high) constituted the major relief on the sea floor. There was a conspicuous lack of fish. At 177 m plentiful gravel (fig. 16A) and larger clasts were all covered with a fuzzy organic coating that could have been hydroids. Scour was common around all large clasts (fig. 16B). The submersible, pushed by a strong current, passed over a boulder field at about 198 m on its path down the canyon wall. At a depth of 204 m, burrowed clay outcrops were observed between boulder

Figure 15. Dive 5 profile (time vs. depth), Lydonia Canyon.

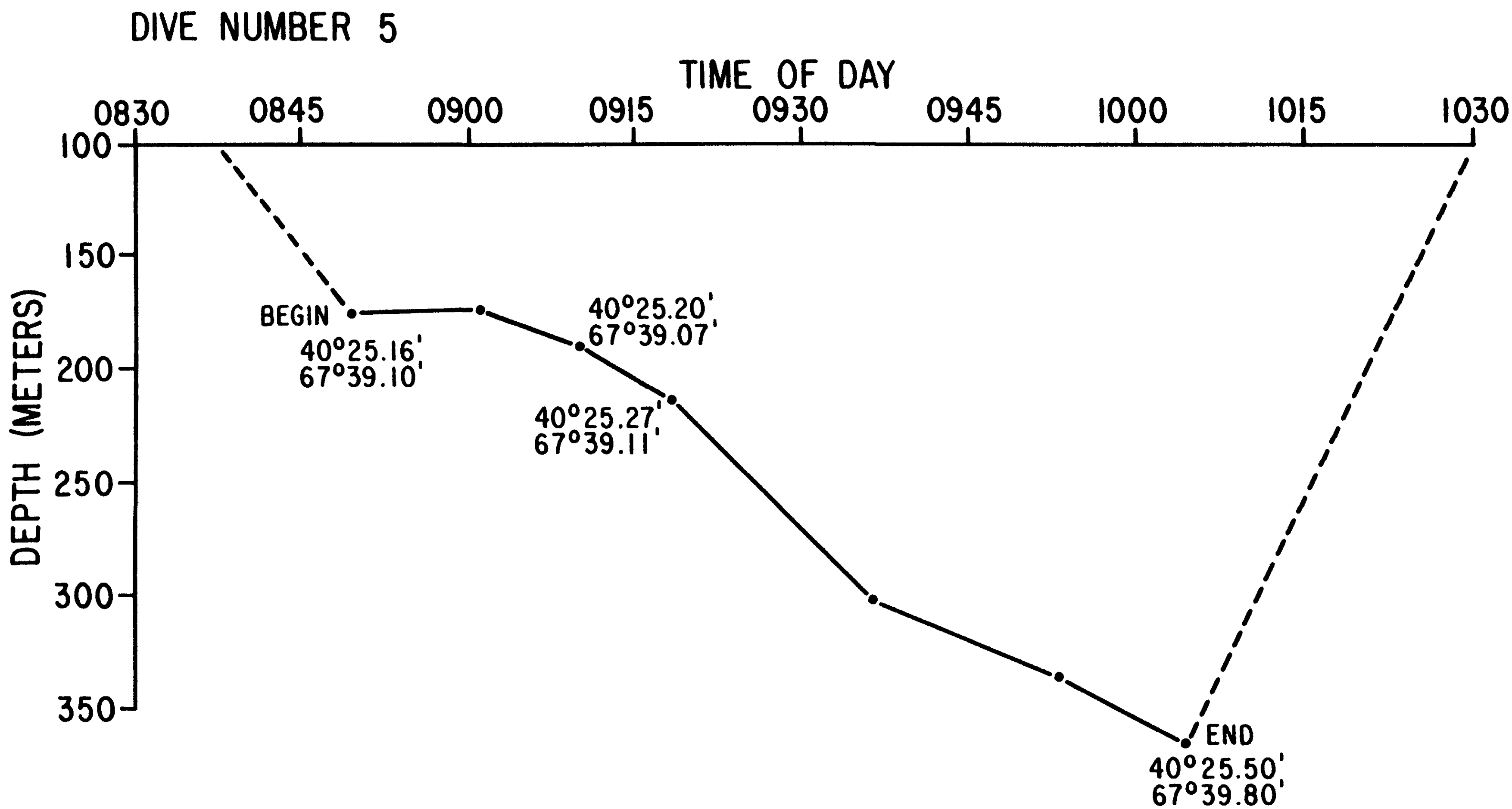

DIVE NUMBER 5
TIME OF DAY
0830
0845
0900
0915
0930
0945
1000
1015
1030
DEPTH (METERS)
100
150
200
250
300
350
BEGIN
40°25.16'
67°39.10'
40°25.20'
67°39.07'
40°25.27'
67°39.11'
END
40°25.50'
67°39.80'

Figure 15

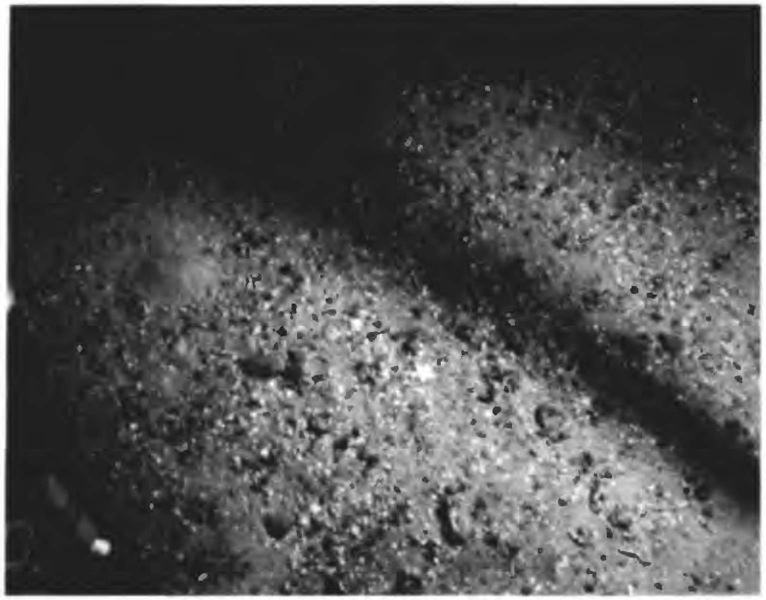
Figure 16. Bottom photographs, Lydonia Canyon; bottom approximately 1.75 m across.

A. 171 m pebbly silty sand on gentle slope.

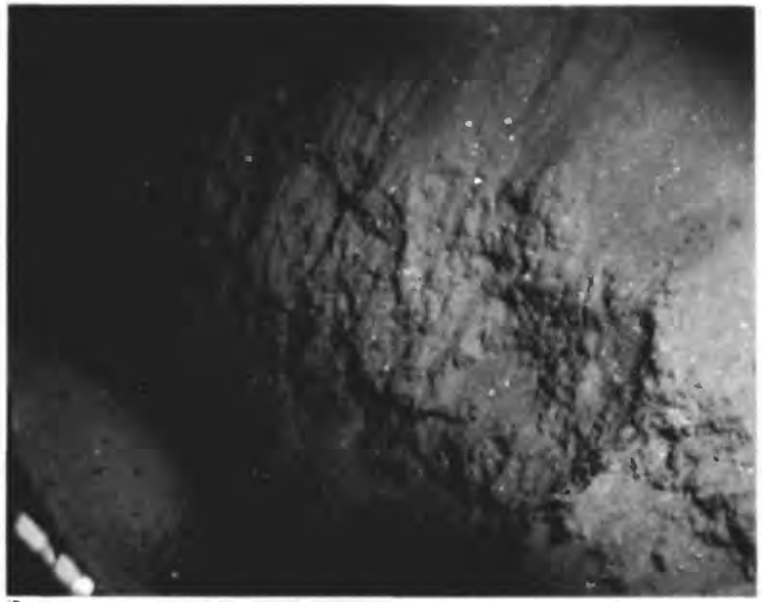
B. 155 m 0.7 m glacial erratic boulder sitting in a hole 1.2 m deep and 2 m across. Current scour and biological activity created the depression, but there is no burrowing in the scar because it is soft silty sand.

C. 205 m step topography showing displacement of pebble covered surface (slump scarp?).

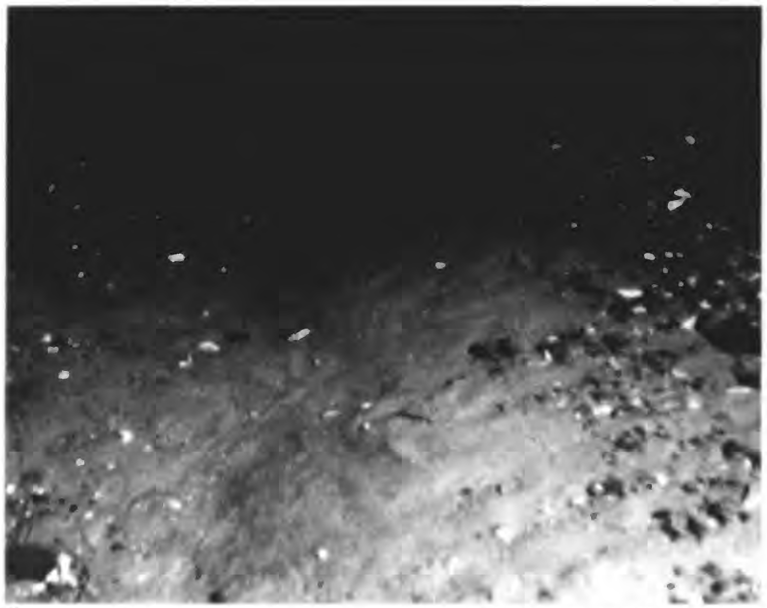
D. 365 m burrowed silty sand sea floor covered with shrimp and brittle stars (Ophiuroid).



A 171M–PEBBLY SILTY SAND ON GENTLE SLOPE. BOTTOM OF PHOTOGRAPHS APPROXIMATELY 1 75M ACROSS



B 155M–0 7M GLACIAL ERRATIC BOULDER SITTING IN A HOLE 1 2M DEEP AND 2M ACROSS. CURRENT SCOUR AND BIOLOGICAL ACTIVITY CREATED THE DEPRESSION, BUT THERE IS NO BURROWING IN THE SCAR BECAUSE IT IS SOFT SILTY SAND



C 206M–STEP TOPOGRAPHY SHOWING DISPLACEMENT OF PEBBLE COVERED SURFACE (SLUMP SCARP?)

D 365M–BURROWED SILTY SAND SEA FLOOR COVERED WITH SHRIMP AND BRITTLE STARS (OPHIUROID)

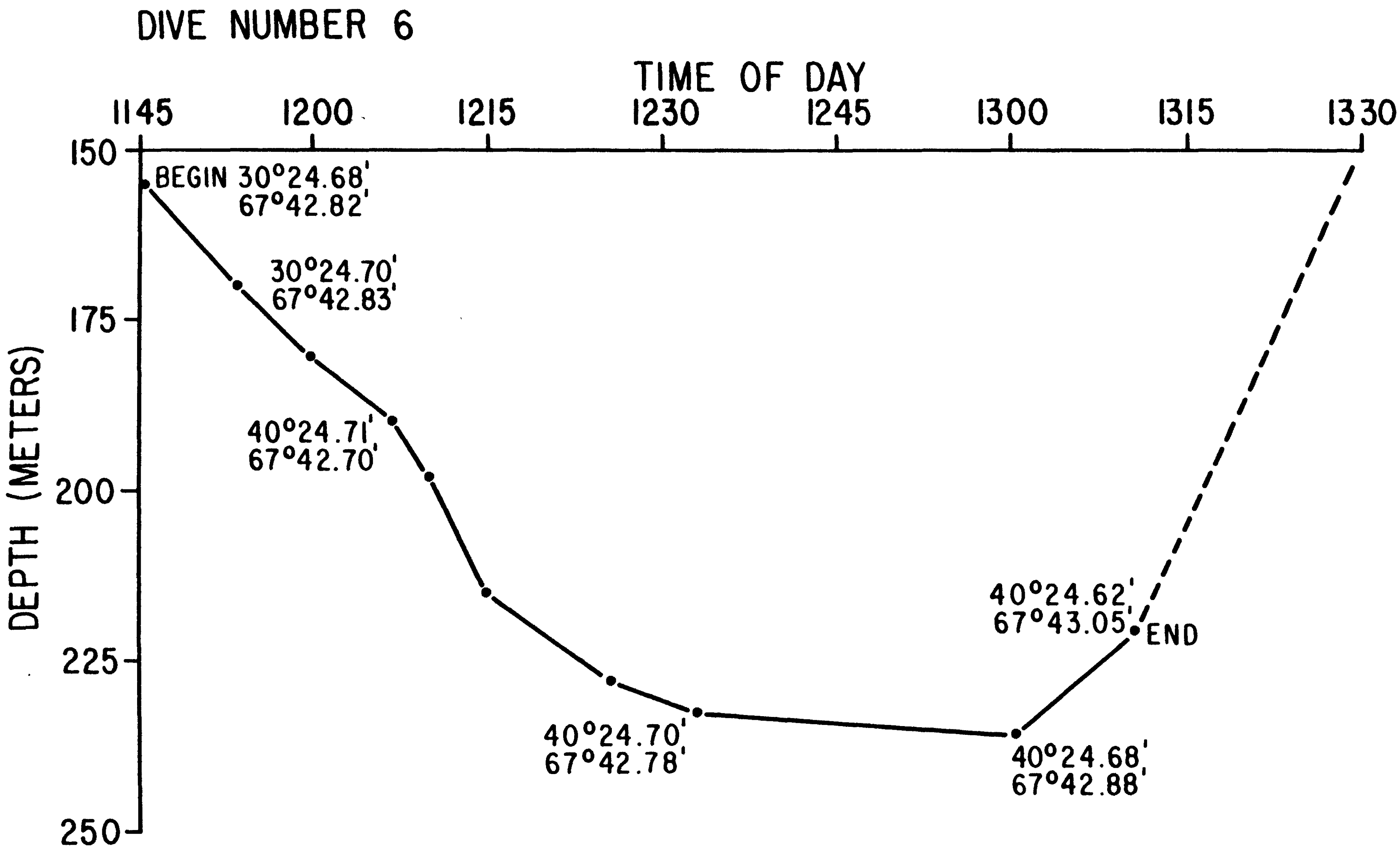
Figure 16A-D

field areas. The gently sloping bottom had no burrows or mounds. The boulder fields had the appearance of glacial moraines. The texture of the sediment around the boulders was sandy gravel, a notable contrast to the silty sand common elsewhere along this dive tract. Sediment ripples appeared on the sea floor at a water depth of 231 m; these trended parallel to the slope and more or less perpendicular to the current. Fish were common in the boulder areas; crabs were common on the sandy sediment environment. At 250 m, the sediment was much finer, again with no boulders, but at 314 m, the sediment was sandier again with shell hash common. Very little life of any kind was observed. The dive was terminated at 366 m in water having a temperature of 6.7°C. In the nearly 2 hour dive the observer took 29 35-mm photographs and 18 minutes of videotape.

DIVE 6

Dive 6 (fig. 17) was also on the east wall of Lydonia Canyon (fig. 4). The submersible landed in 155 m of water on a clean quartz(?), sand sea floor marked by 3-cm high ripples (15 to 20-cm wavelength). Many boulders of granite and metamorphic rock, 30 cm to 1 m in diameter were observed on the bottom. The boulders had some type of organic growth on them, and showed evidence of scour around their bases (fig. 16B). The growth appeared to be a combination of anemones, soft corals, hydrozoans, and bryozoans(?). There was a light brown tinge of some kind on the surface of the sandy sea floor, probably an algal growth. Although there was no noticeable current during this dive, some large (30-cm high, 10-m wide) ripples were seen, indicating that the bottom currents must be quite strong at times. Considerable lag-shell debris in the ripple troughs trended roughly east-west. In

Figure 17. Dive 6 profile (time vs. depth), Lydonia Canyon.



DIVE NUMBER 6
TIME OF DAY
1145
1200
1215
1230
1245
1300
1315
1330
150
175
200
225
250
DEPTH (METERS)
BEGIN 30°24.68'
67°42.82'
30°24.70'
67°42.83'
40°24.71'
67°42.70'
40°24.70'
67°42.78'
40°24.68'
67°42.88'
40°24.62'
67°43.05'
END

Figure 17

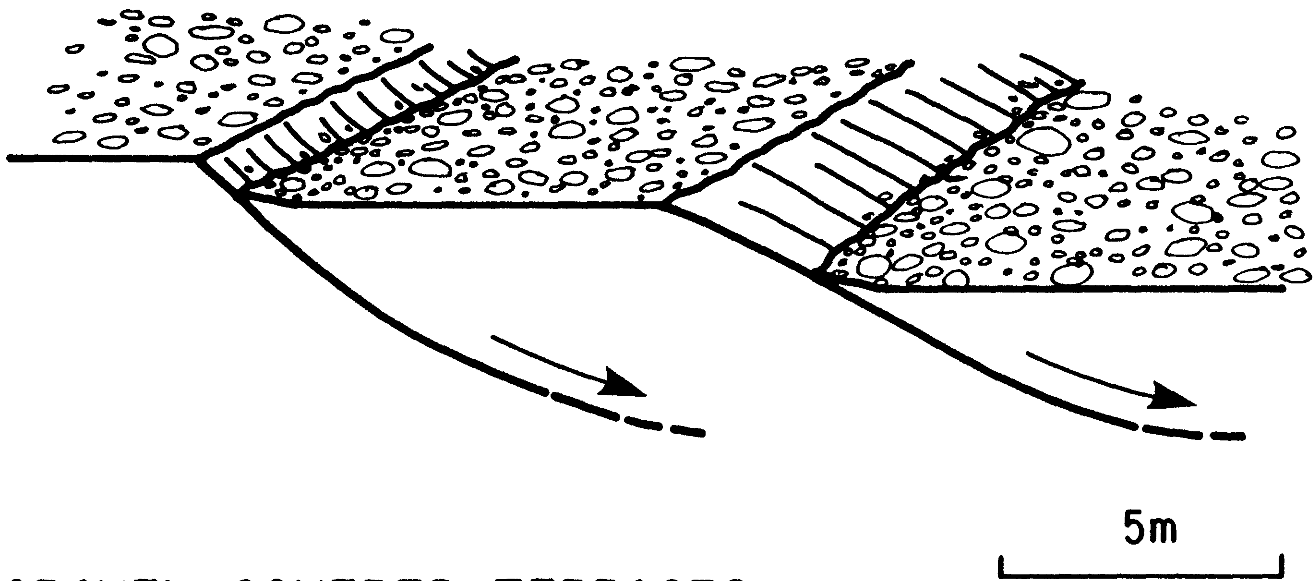
places smaller ripples were superimposed on the larger ripples. There was very little biological activity on the sandy surface, other than the occasional crabs, starfish, and flounder.

The submersible seemed to be going over a series of gravel covered steps as it descended to 180 m (figs. 16C, 18). Ripples were not as well defined at this depth as they were in shallower water. At 183-m depth, rippling diminished abruptly on a surface of fine-grained sediment. The slope at 186 m was approximately 10^{o} and there was a slight bottom current from the south. Some burrowing of the sea floor was evident below 187 m where the slope continued to steepen (20^{o}), but there was still very little evidence of epifauna. A small gully ran downslope with coarse sediment along its bottom. At 232 m, surface sediment became finer still and was pitted with small burrows on a 25^{o} slope steepening with depth. At the 189-m depth level angular clay lumps were common on a very coarse gravelly sea floor. About 10% of the larger boulders on the sea floor at this depth appeared to be clay. Clay observed in exposed scarps seemed to be stratified and to dip about 20^{o} downslope. Thirty-three 35-mm photographs and 20 minutes of videotape documented this 2-1/2 hour dive.

DIVE 7

Dive 7 (fig. 19) took place on the west wall of Lydonia Canyon about halfway between the canyon's head and its mouth (fig. 4). The submersible landed at 146-m water depth on a sandy, shelly sea floor. Gravel and larger clasts were common as the submersible moved along the 5^{o} slope, pushed by a strong northwest current. *Onuphis* sp. worms covered the sea floor in places. There were very few epifauna except for the *Onuphis* sp. worms and occasional starfish, crabs, and fish.

Figure 18. Gravel covered terraces; slump(?) features.



GRAVEL COVERED TERRACES;
SLUMP (?) FEATURES

Figure 18

Figure 19. Dive 7 profile (time vs. depth), Lydonia Canyon.

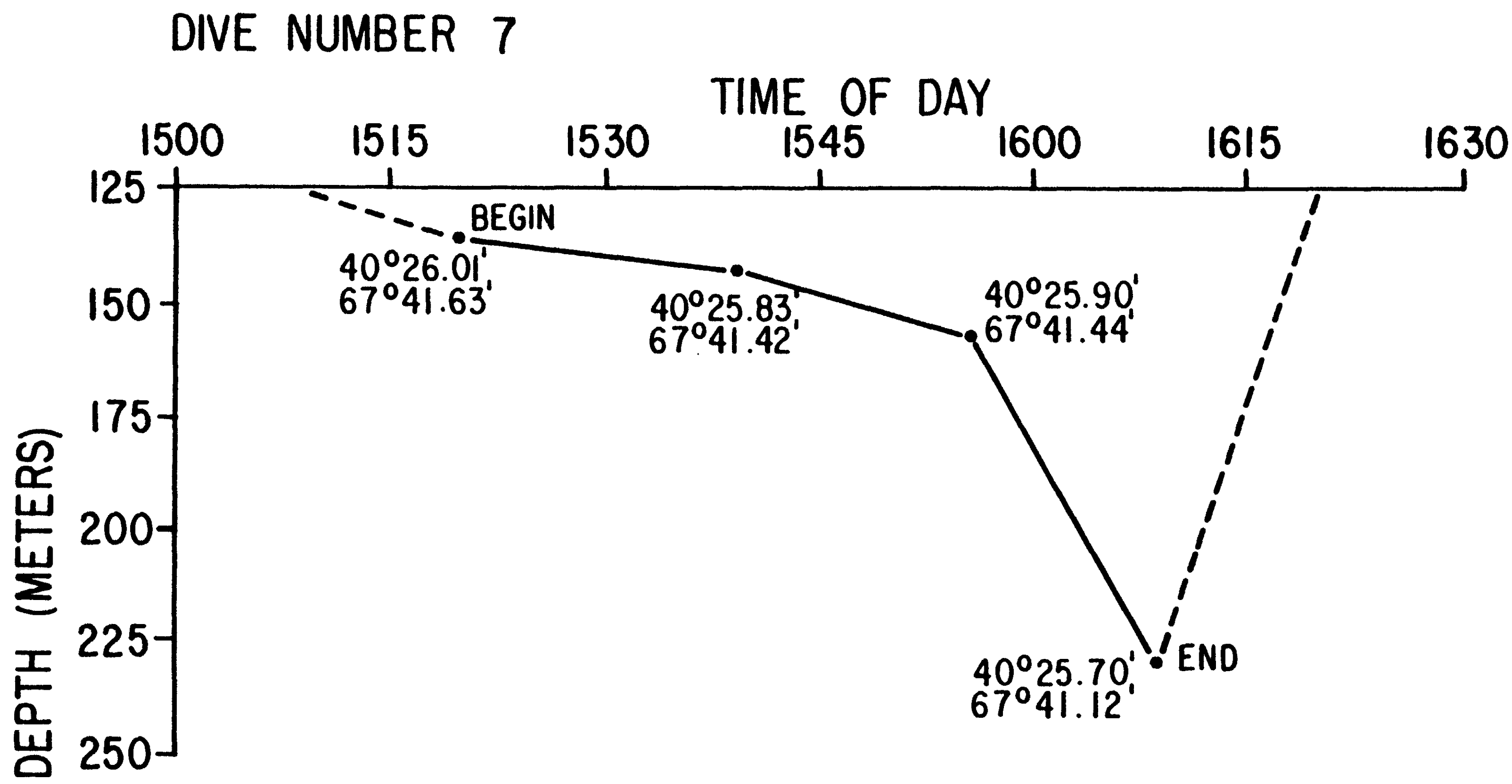

DIVE NUMBER 7
TIME OF DAY
1500
1515
1530
1545
1600
1615
1630
DEPTH (METERS)
125
150
175
200
225
250
BEGIN
40°26.01'
67°41.63'
40°25.83'
67°41.42'
40°25.90'
67°41.44'
END
40°25.70'
67°41.12'

Figure 19

The sand was rippled and seemed to cover a series of steps. Shell and gravel patches were concentrated in gullies or depressions. At a water depth of 183 m, the slope seemed to steepen somewhat and ripple marks were no longer observed. The sediment was finer than that seen at shallower depths with many mounds and burrows on its surface. Below 218 m, the slope steepened to 10° and the current flowed to the north.

The dive had to be aborted at that point because of the low voltage remaining in the submersible's batteries.

DIVE 8

Dive 8 ($40^{\circ}50.77'$N. and $67^{\circ}23.74'$W.) was made on Georges Bank (fig. 2) to observe one of the USGS tripods in 85 m of water. Visibility on the sea floor was poor because of clouds of plankton and the strong current that kicked up and suspended the sea-floor sediment. The sandy sea floor was covered with scallop and clam shells. There were many fish such as hake, dogfish, skate, and sculpin, and lots of floccy (algae) matter on the sediment. Starfish and crabs were common as were living scallops. The submersible was unable to locate the tripod because of the poor visibility. However, the sea floor in the dive area was very similar to that photographed by the tripod camera. A greater diversity of fish was observed from the submersible than from bottom photographs of the area taken by tripod-mounted cameras. Scallops, which were noted in large numbers from the submersible, have not been observed in tripod photographs. Ninety-one 35-mm photographs were taken of the sea floor and biota during this dive.

DIVE 9

Dive 9 was along the northwest wall of Lydonia Canyon (fig. 4). It began at 152 m water depth on a silty sand sea floor on which large boulders with scour marks under them were set about 2 m apart. Downslope, at 186 m, the gravelly sediment gave way to silty sand with a few burrows and mounds on its surface. Only occasional fish and crabs were seen at this depth. At 366 m the surface sediment was very fine. Shrimp and brittle stars were observed around numerous mounds and depressions (fig. 16D).

The dive and all further work had to be aborted because of continuing operating problems with the submarine. Most of nearly 4 hours spent underwater on this dive were taken up with these problems, so very few scientific observations were made.

SUMMARY AND CONCLUSIONS

The eight submersible surveys in Veatch and Lydonia Canyons provide useful oral and photographic documentation of the surficial geology and biota along the upper slope of the continental margin near proposed lease areas.

The outer edge of the Continental Shelf in the surveyed areas is generally covered with moderately well-sorted, slightly gravelly, tan to greenish-tan sand. The sand is composed mainly of well-rounded locally iron-stained quartz; it is probably beach and dune sand deposited during the latest Pleistocene low sea-level stand. Modern mollusc fragments, crab carapaces, and bivalve shells (mainly concave upward) are abundant on this bottom; crabs and starfish are the most common epifauna. Because of numerous conical (5 to 15-cm high) mounds (polychaete?) and small depressions (probably due to crab and fish), 15-30 cm across, the nearly horizontal sea floor has a lumpy appearance. Many tracks and trails are evidence of considerable biological activity in the area.

Sediments in this area are reworked by currents as well as biological activity; most of the silt and clay seem to have been removed by winnowing. But current indicators, such as ripple marks, are apparently quickly destroyed by bioturbation. Rare pavement outcrops of the underlying gray-green Pleistocene(?) clay are seen in large burrows or on low areas of the sea floor. No potential geological hazards were observed in this area during these and previous submersible dives.

The upper part of the Continental Slope in the study area is covered with sediment similar to that on the outer shelf, i.e., greenish-brown silty sand. The sediment is siltier in deeper water and at 300-m depth and deeper, the sediment is silt or clay silt. This sediment ranges in thickness from 3 to 10 cm and in many places is only a thin veneer over a sticky, consolidated Pleistocene(?) clay. The hydraulic arm of the submersible was used to dig down to this clay during several dives. This is the clay seen in burrows and as chunks or balls on the sea floor. The thin silty sand veneer has been reworked by organisms into mounds, burrows, and depressions. Tracks and trails, as well as numerous shell fragments, cover its surface.

Only weak currents were noticed during the dives but in a few areas ripple marks attest to occasional relatively strong currents. These ripple marks probably are quickly destroyed by bioturbation. The silty sand layer is covered in places with a thin (1 cm) flocculated, patchy layer of gray-brown silt that gives the sea floor a mottled appearance. Passing animals (and submersibles) resuspend this silt, which is redistributed by the weak bottom currents as it settles.

The shelf edge around Lydonia Canyon appears to be covered by glacial sand and gravel containing large boulders up to approximately 1 m in diameter. These gravelly-sandy sediments are rippled by bottom currents. Near the shelf edge these ripples increase in amplitude;

their orientation and facing suggest that the surface sediment is slowly being moved toward the canyon. Little of the sand appears on the slope, however.

White sea pens, Cancer and Galatheid crabs, and fish were the most common epifauna to a water depth of 250 m; burrowing anemones, red crabs, and fish predominate below this depth. These faunal assemblages are widely distributed over the sea floor but are relatively sparse compared to biota on the shelf. The infauna are unknown with the exception of the polychaete worms which apparently have built the numerous mounds commonly observed on the sea floor. Tracks and trails are more evident in depths over 265 m, probably because there they are preserved on the less reworked siltier sediment. Most of these tracks seem to have been made by crabs.

The upper Continental Slope in the study area can be divided into two quite different terrains: the submarine canyons and the intercanyon areas. The intercanyon sea floor is characterized by a monotonous surface of relatively low relief. It shows little or no evidence of potential geologic hazards such as slumping. Most of the biological and sedimentological activity observed in the dives occurs in the submarine canyons, especially in their heads.

Currents, which include tidal and internal wave-generated currents and presumable turbidity currents, may periodically scour the canyon floors and undercut the canyon walls (fig. 20). The combination of steep walls (many over 45^{o}), steeply dipping clay beds, and the instability resulting from undercutting probably leads to the features inferred to indicate slumping.

Inferred evidence of canyon wall slumping observed in the dives included series of steps (figs. 10, 16C, 18) that expose scarps of

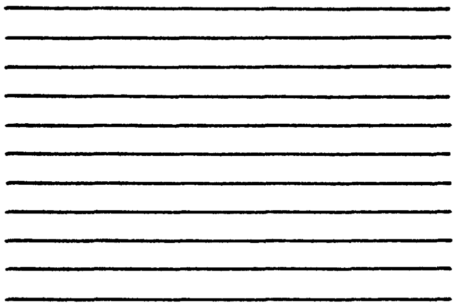
Figure 20. Steps in the origin of submarine canyons off Georges Bank.

A. Cretaceous and Tertiary sediments layed down in nearly horizontal beds.

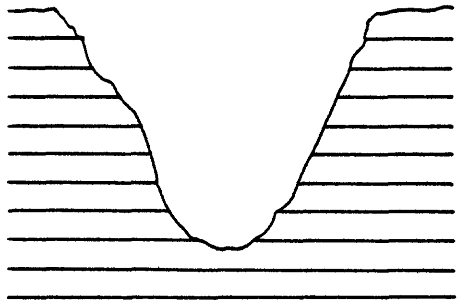
B. Submarine canyons cut through Cretaceous and Tertiary beds during low sea-level stands.

C. Pleistocene and Holocene silts and clays draped over canyons during high sea-level stands.

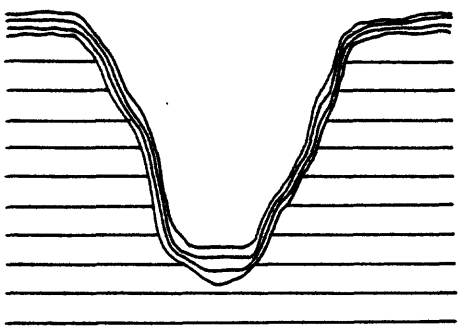
D. Sediment movement by currents (tidal, turbidity, etc.) scour the floor and the base of the canyon walls.



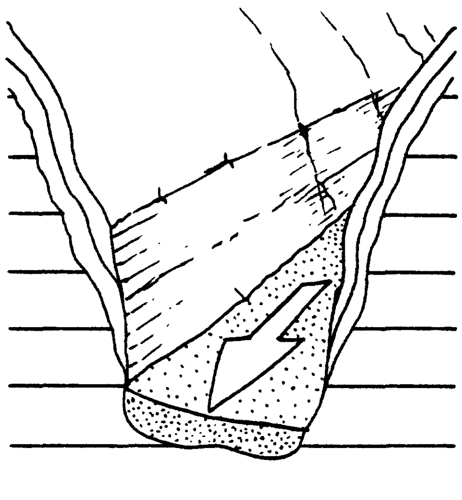
A. Cretaceous and Tertiary sediments layed down in nearly horizontal beds.



B. Submarine canyons cut through Cretaceous and Tertiary beds during low sea-level stands.



C. Pleistocene and Holocene silts and clays draped over canyons during high sea-level stands.



D. Sediment movement by currents (tidal, turbidity, etc.) scour the floor and the base of the canyon walls.

semiconsolidated clay. This exposed clay is heavily burrowed and bored by the local fauna until the small cliffs are honeycombed with cavities (fig. 12).

If drilling continues in this area, the future of drill cutting, drilling mud, formation waters, and oil that escape from the drilling sites could be in these submarine canyons. We have only spot checked these canyon areas in the past few years (always in the summer), and know nothing of the day-to-day activities over the entire year through the different seasons. There is evidence that turbidity currents occur occasionally, tidal currents scour the canyon floors often, slumping is common along the canyon walls, and the canyons harbor the majority of the upper slope fauna. These facts make it important that further detailed work continues.

ACKNOWLEDGMENTS

The submersible was staffed during the dives by Richard Slater, Chief Scientist, and John M. Aaron, Cynthia Bryden, John C. Hampson, and David C. Twichell of the U.S. Geological Survey, and Charles V. G. Phipps of the University of Sydney. Richard E. Sylwester and Gerard McCarthy provided electronics support aboard STATE ARROW and performed the necessary geophysical surveys. Susan J. Purdy served as yeoman for the scientific staff. Don Bolstad, Gordon Barksdale, and Patrick Hickey of Martek, Inc. crewed the submersible. Gerald Ottmer captained the STATE ARROW during the cruise.

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